Deformable Model in Segmentation & Tracking

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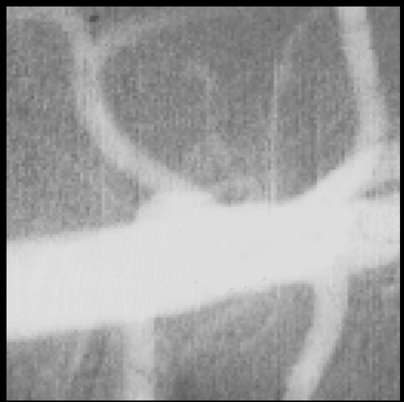
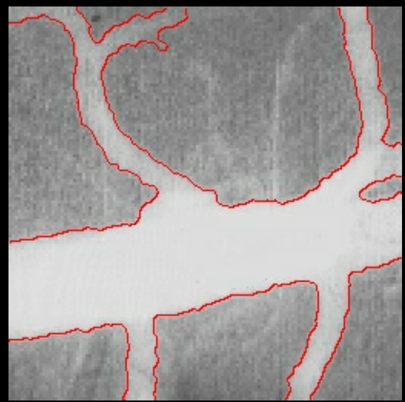
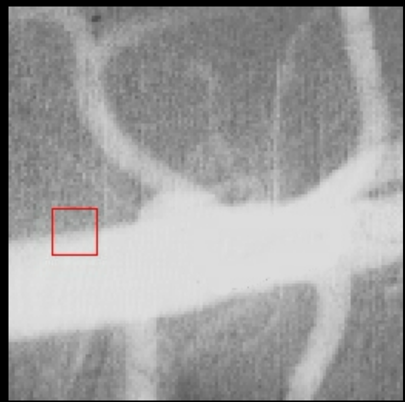
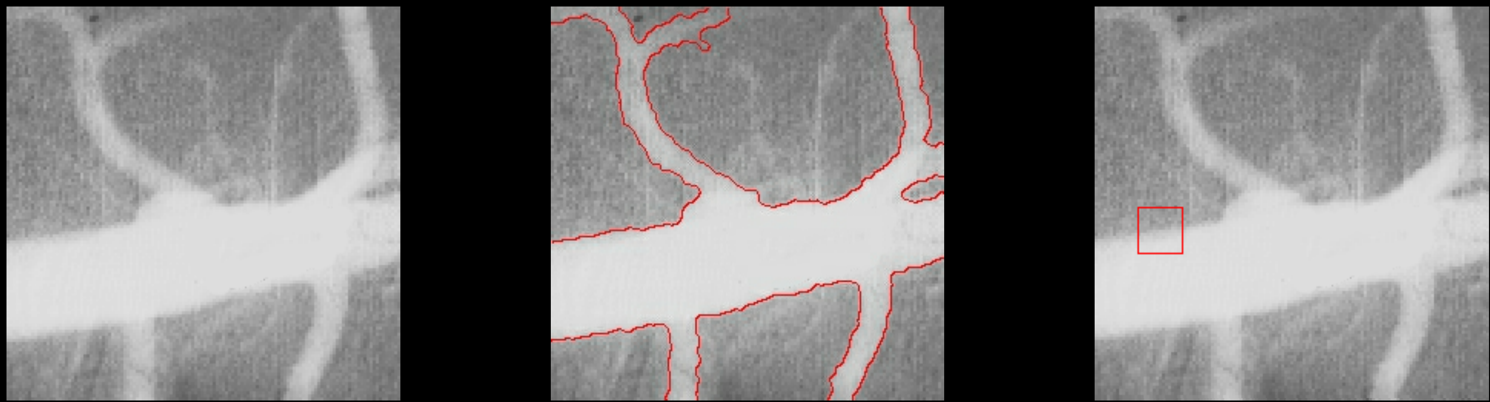
Outline

- Introduction
- Edge based 2D segmentation
- Extension to 3D
  - Direct sequential segmentation of temporal volumetric data
  - Incorporating statistical shape prior
- 3D + T (4D) constrained segmentation
- Tracking using implicit representation
- Implicit representation using RBF (region based)
- Hybrid approach
- Level set intrinsic regularisation (initialisation invariance)
- Conclusions

Introduction

Introduction



Introduction

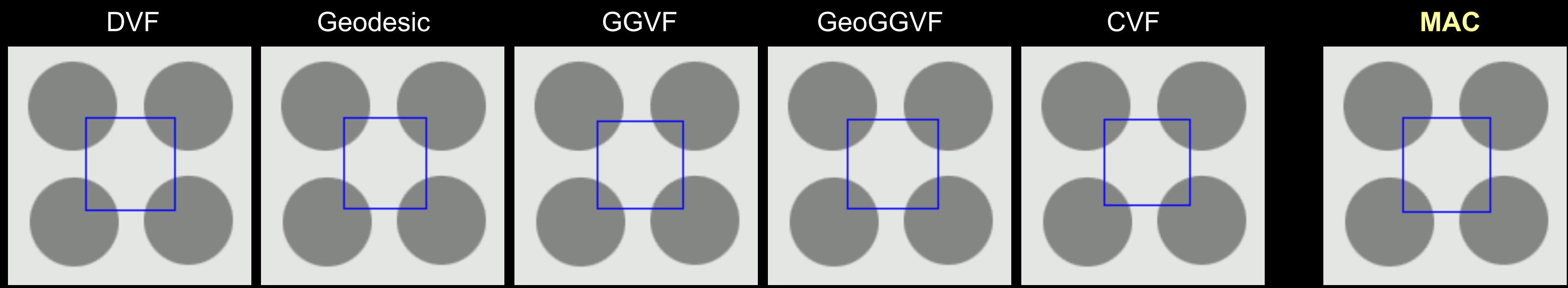
- Design issues
  - Representation & numerical method
    - Explicit Vs Implicit
    - FEM, FDM, Spectral methods
    - RBF-Level Set (Xie & Mirmehdi 07, 11)
  - Boundary description & stopping function
    - Gradient based (Caselles et al. 97, Xie & Mirmehdi 08, Xie 11)
    - Region based (Paragios 02, Chan & Vese 01, Xie 09 & 11)
    - Hybrid approach (Wang & Vemuri 04, Xie & Mirmehdi 04)
  - Initialisation and convergence
    - Initialisation independency (Xie 11)
    - Complex topology & shape (Xie & Mirmehdi 07)
- These issues are often interdependent

- Edge Based 2D Segmentation

Xie & Mirmehdi, MAC, *IEEE Trans. Pattern Analysis & Machine Intelligence* 2008.

Motivation

- Convergence study – 4 disc problem

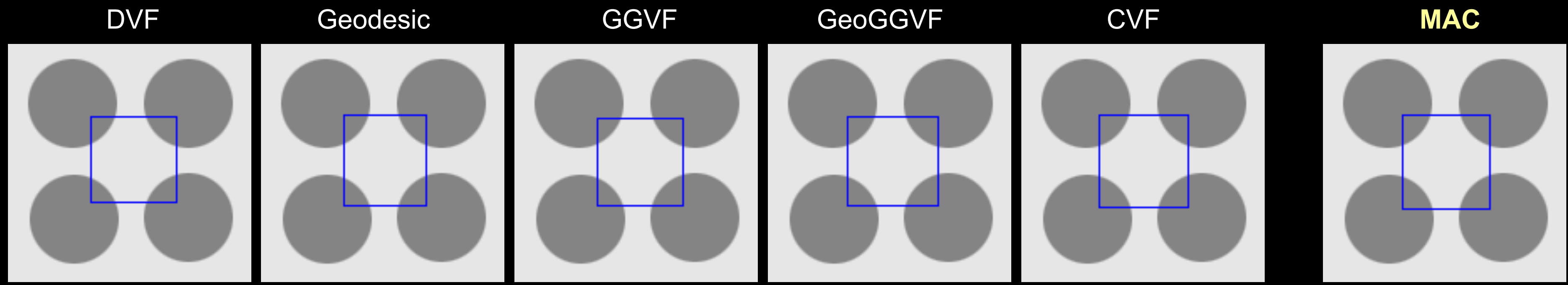


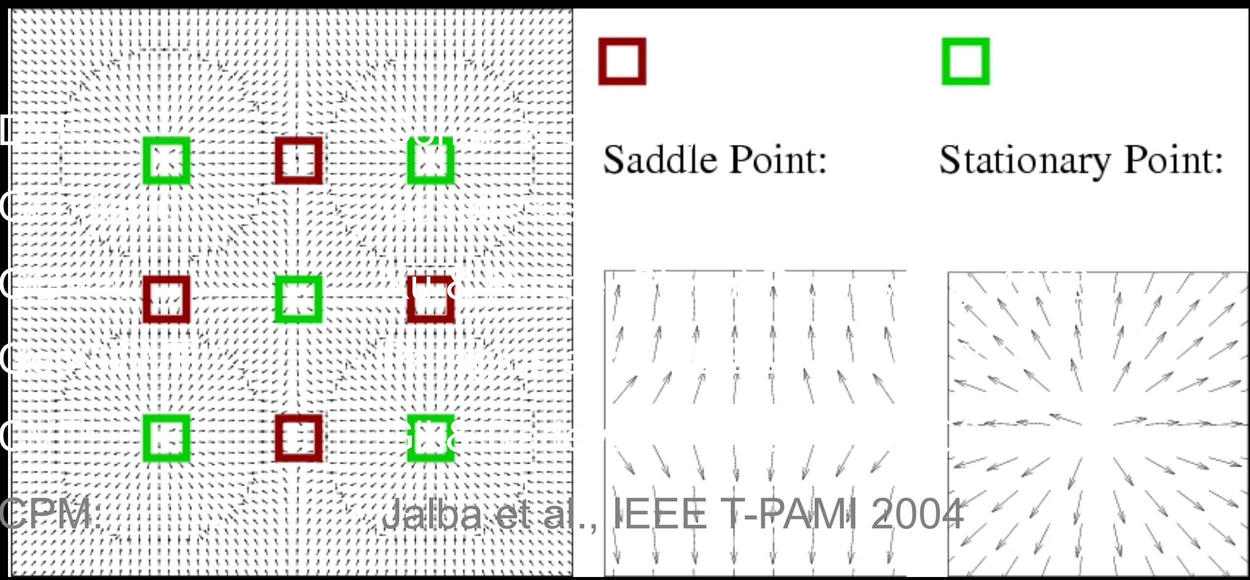
DVF:	Cohen & Cohen, IEEE T-PAMI, 1993
Geodesic:	Caselles et al., IJCV, 1997
GGVF:	Xu & Prince, Signal Processing, 1998
GeoGGVF:	Paragios et al., IEEE T-PAMI, 2004
CVF:	Gil & Radeva, EMMCVPR 2003
CPM:	Jalba et al., IEEE T-PAMI 2004

Xie & Mirmehdi, MAC, *IEEE Trans. Pattern Analysis & Machine Intelligence* 2008.

Motivation

- Convergence study – 4 disc problem





CPM: Jalba et al., IEEE T-PAMI 2004

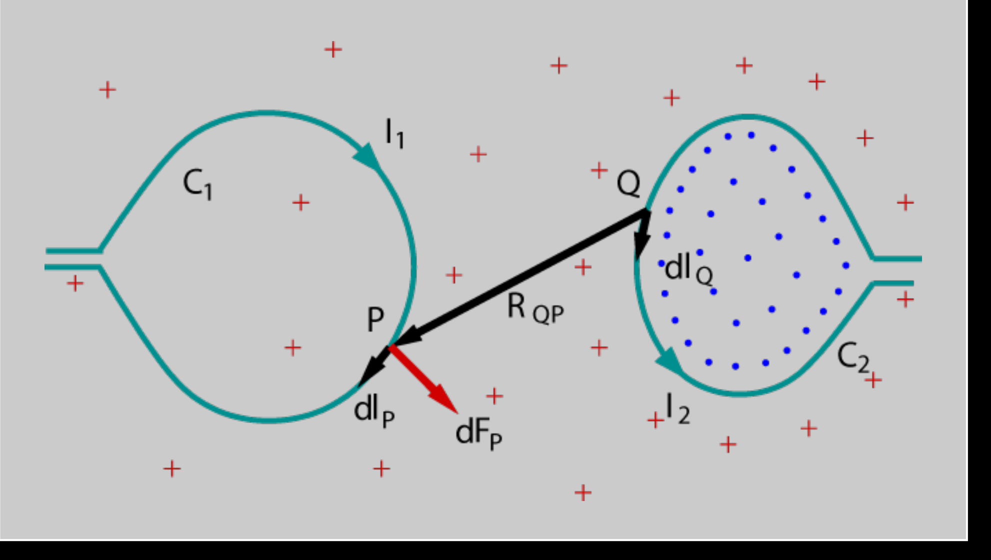
Xie & Mirmehdi, MAC, *IEEE Trans. Pattern Analysis & Machine Intelligence* 2008.

Motivation

- Objectives
  - Long range force interaction
  - Dynamic force field, instead of static
  - Bidirectional – allow cross boundary initialisation
  - Efficiency
- Region based or Edge based
  - Prior knowledge
  - Boundary assumptions
    - Discontinuity in regional statistics
    - Discontinuity in image intensity
  - Application dependent
- Goal: improving edge based performance
  - Comparable to region based approaches
  - Benefit from less prior knowledge, simpler assumption, and efficiency
  - There are scenarios boundary description does not need region support

MAC model

- Proposed method
  - Novel external force field
  - Based on hypothesised magnetic interactions between object boundary and snake
  - Significant improvements upon initialisation invariancy & convergence ability
  - Yet, a very simple model
- Magnetostatics



MAC model

- Edge orientation
  - Analogy to current orientation
  - Rotating image gradient vectors

$$\mathbf{O}(\mathbf{x}) = (-1)^{\lambda}(-\hat{I}_y(\mathbf{x}), \hat{I}_x(\mathbf{x}))$$

λ = 1: anti-clockwise rotation; λ = 2: clockwise rotation.
$(\hat{I}_x(\mathbf{x}), \hat{I}_y(\mathbf{x}))$: normalised image gradient vectors.

  - (actually, these are 3D vectors)

- Current orientation on snake
  - Similar to edge current orientation estimation
  - Rotating level set gradient vectors $\nabla\Phi$

MAC model

- Magnetic force on snake
  - Derive the force on snake exerted from image gradients

$$\mathbf{F}(\mathbf{c}) = I_C \boldsymbol{\Upsilon}(\mathbf{c}) \times \mathbf{B}(\mathbf{c})$$

$$\mathbf{B}(\mathbf{x}) = \frac{\mu_0}{4\pi} \sum_{\mathbf{s} \in f(\mathbf{s})} I_{f(\mathbf{s})} \boldsymbol{\Gamma}(\mathbf{s}) \times \frac{\hat{\mathbf{R}}_{\mathbf{xs}}}{R^2_{\mathbf{xs}}}$$

$\boldsymbol{\Upsilon}$: electric current unit vector on snake

I_C: current magnitude on snake, constant

$\boldsymbol{\Gamma}$: electric current vector on edges

$I_{f(\mathbf{s})}$: current magnitude on edges

$\hat{\mathbf{R}}_{\mathbf{xs}}$: unit vector between two point, x and s

μ_0: permeability constant

- Uniqueness
  - The force on snake is dynamic
  - Relies on both spatial position and evolving contour
  - Always perpendicular to the snake
  - Global force interaction

MAC model

- Snake formulation

$$C_t = \alpha g(\mathbf{x})\kappa\hat{\mathbf{N}} + (1-\alpha)(\mathbf{F}(\mathbf{x})\cdot\hat{\mathbf{N}})\hat{\mathbf{N}}$$

κ : curvature

$\hat{\mathbf{N}}$: snake inward normal

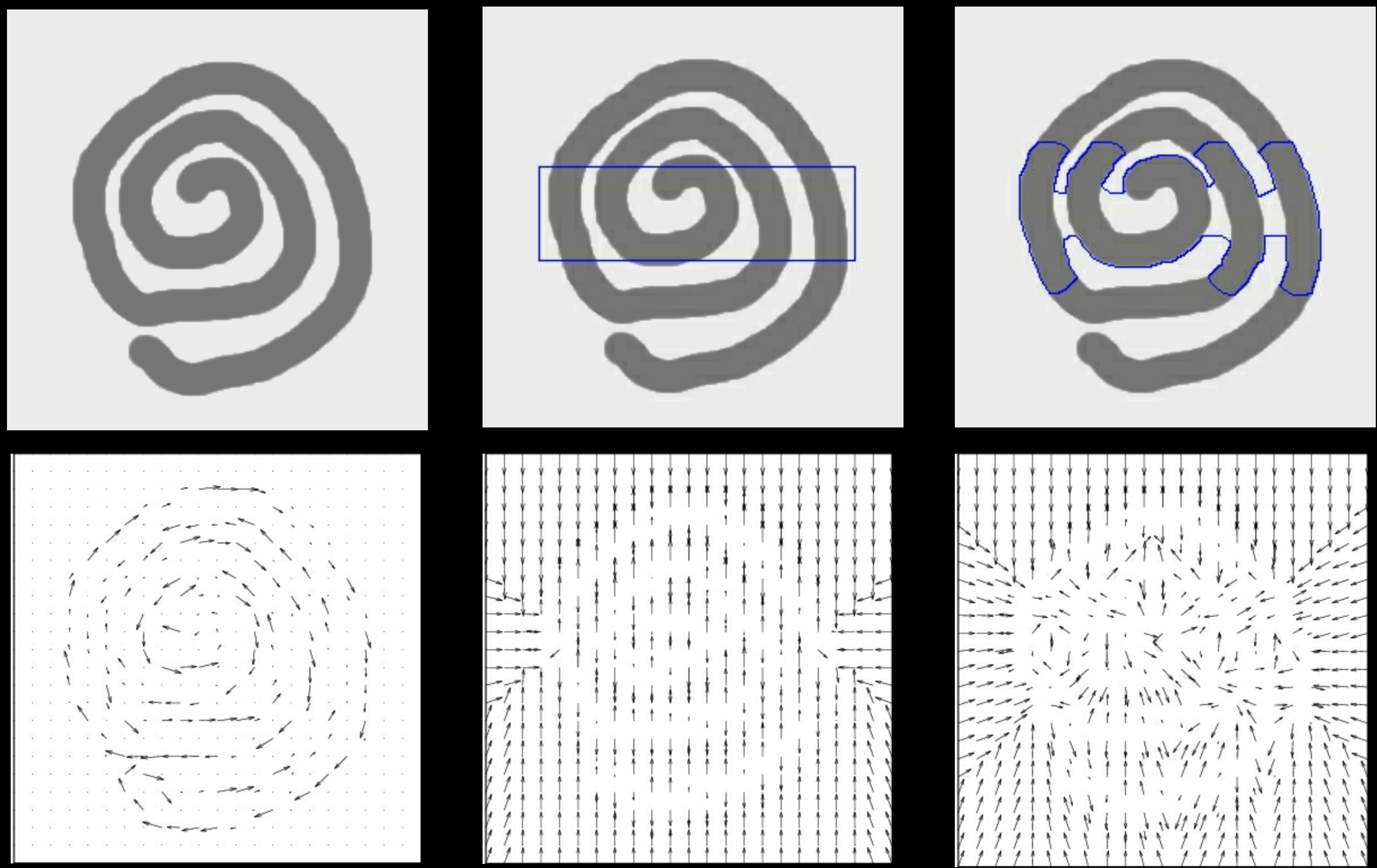
- Level set representation

$$\Phi_t = \alpha g(\mathbf{x})\nabla\cdot\left(\frac{\nabla\Phi}{|\nabla\Phi|}\right)|\nabla\Phi| - (1-\alpha)\mathbf{F}(\mathbf{x})\cdot\nabla\Phi$$

- Force field extension
  - Snake is extended in a 2D scalar function
  - Accordingly its forces upon it
  - Fast marching
  - In this case, simply compute forces for each level set

MAC model

- An example of dynamic force field



MAC model

- Edge preserving force diffusion
  - Minimise noise interference
  - Nonlinear diffusion of magnetic flux density
  - Similar to GGVF, but…
  - Add edge weighting term in diffusion control

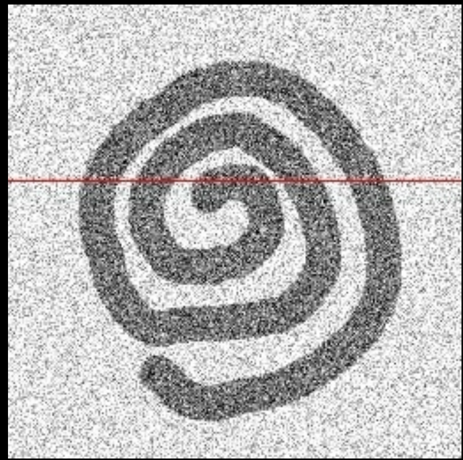
$$\mathcal{B}_t(\mathbf{x}) = p(B(\mathbf{x}))\Delta\mathcal{B}(\mathbf{x}) - q(B(\mathbf{x}))(\mathcal{B}(\mathbf{x}) - B(\mathbf{x}))$$

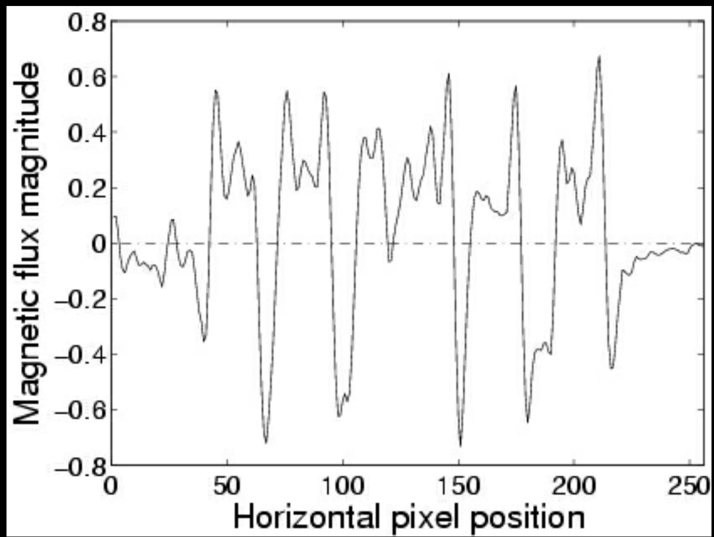
$$p(B(\mathbf{x})) = e^{-\frac{|B(\mathbf{x})|f(\mathbf{x})}{K}}, \qquad q(B(\mathbf{x})) = 1 - p(B(\mathbf{x}))$$

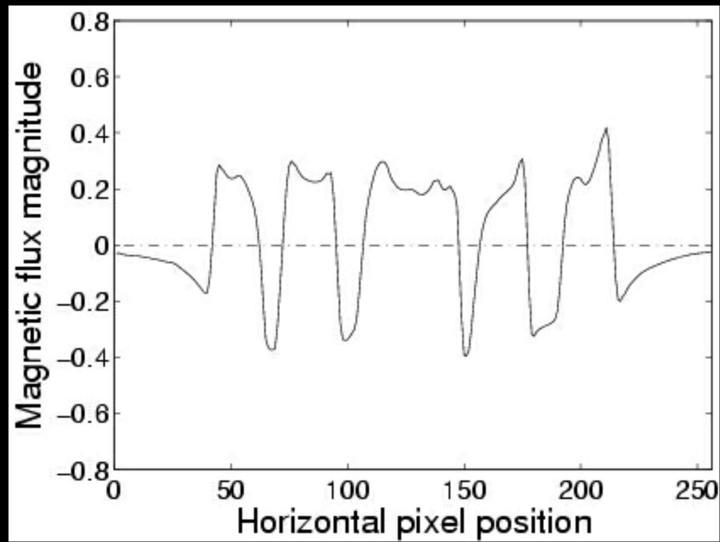
- As little diffusion as possible at strong edges
- Homogeneous and noisy area which lack consistent support from edges will have larger diffusion

MAC model

- Edge preserving force diffusion



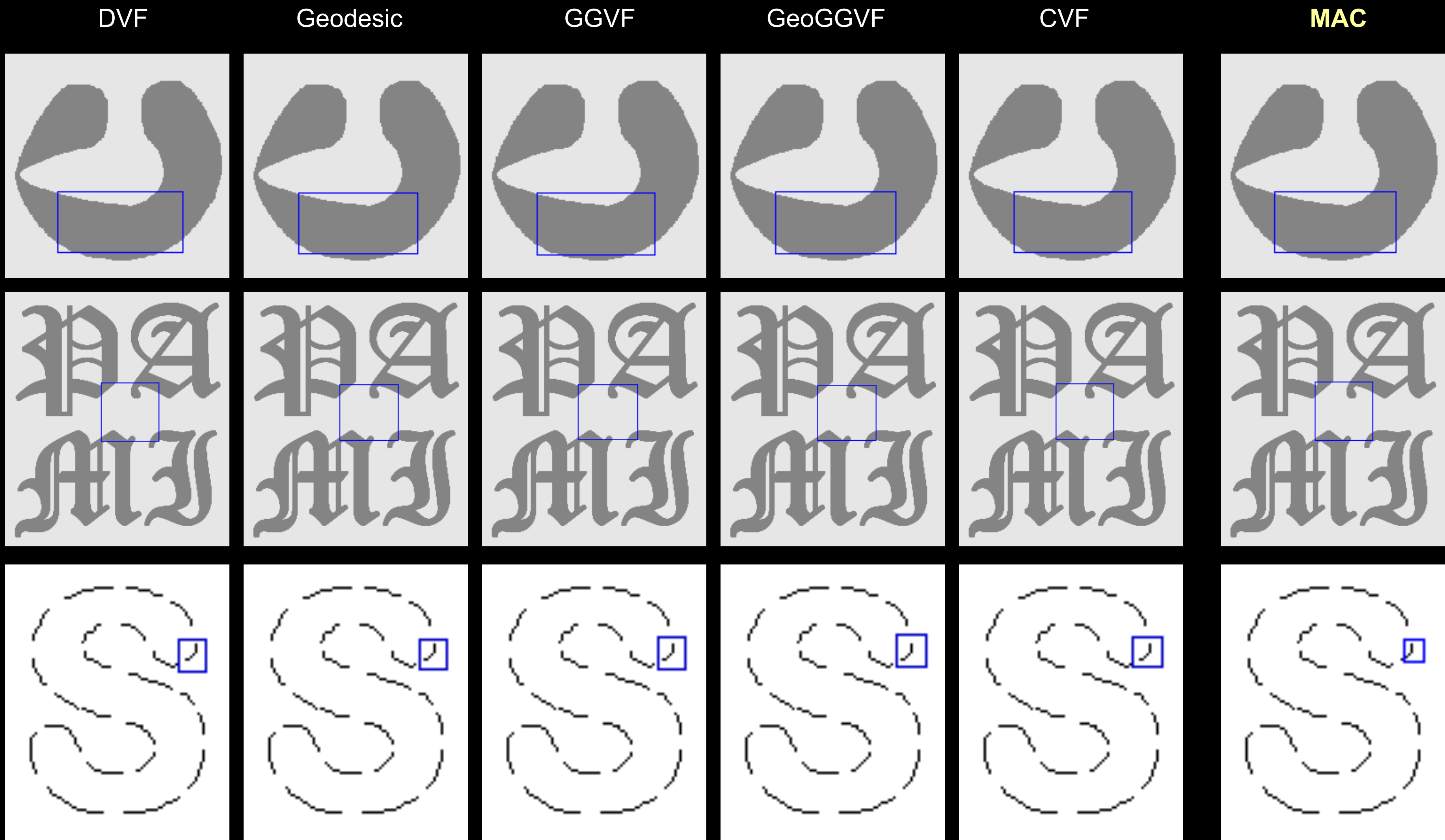




- Fast implementation
  - Decompose the magnetic flux term
  - Fast computation in the Fourier domain

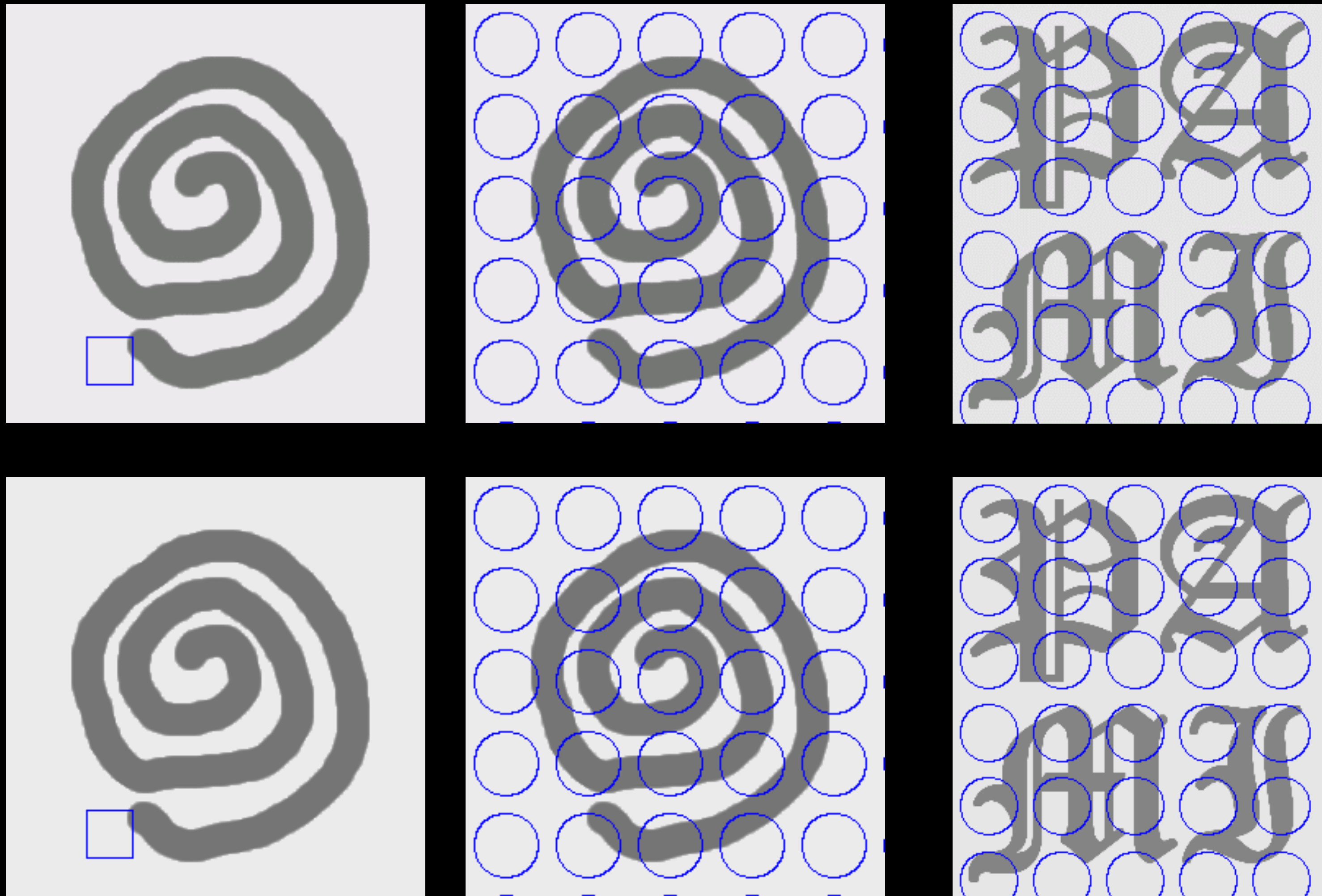
Experimental results

- Comparative analysis on synthetic images



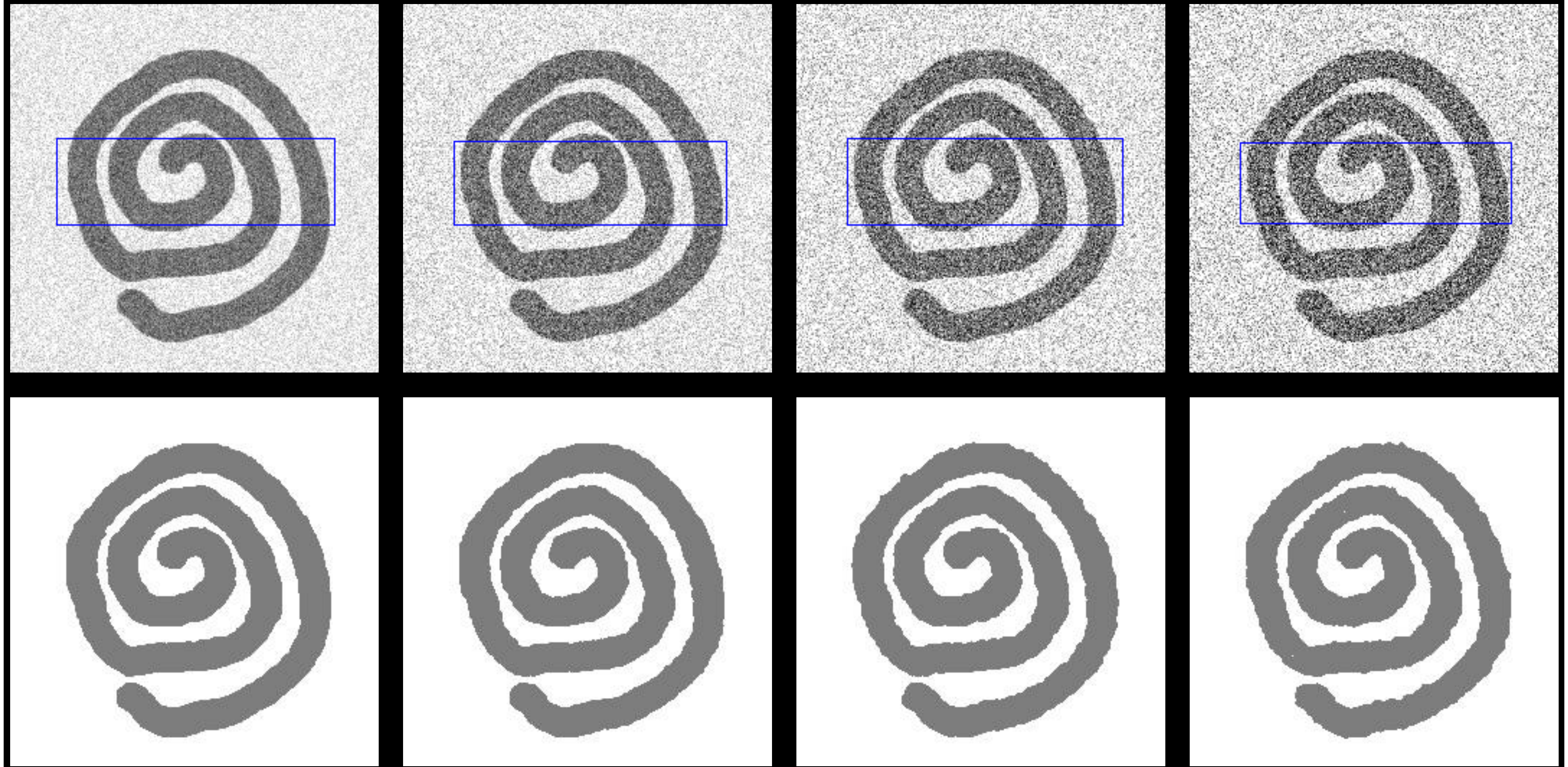
Experimental results

- Arbitrary initialisation



Experimental results

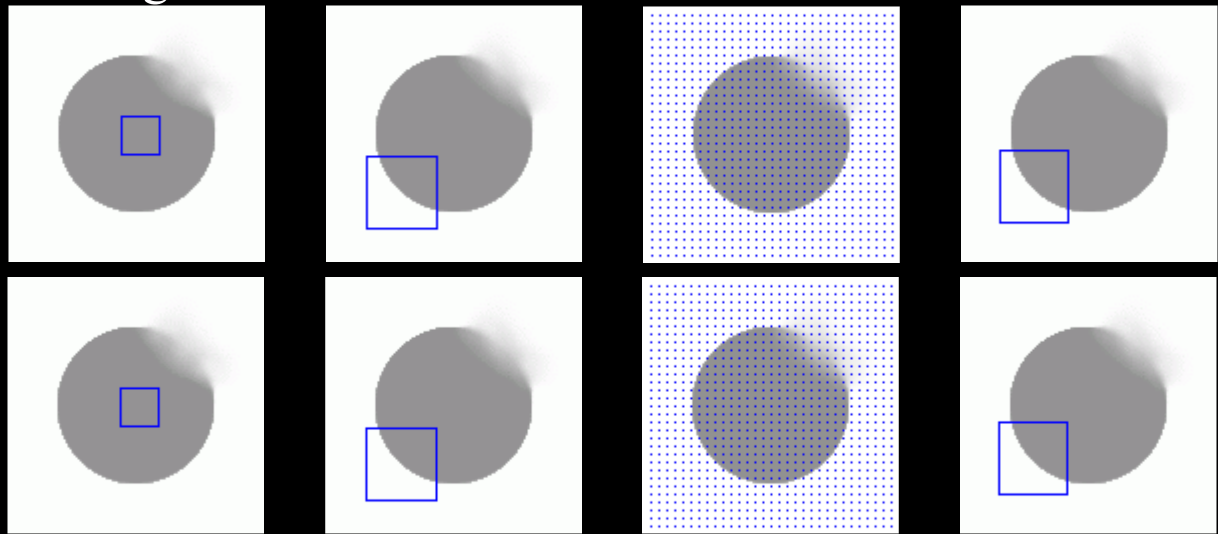
- Noise sensitivity



20% noise | 30% noise | 40% noise | 50% noise

Experimental results

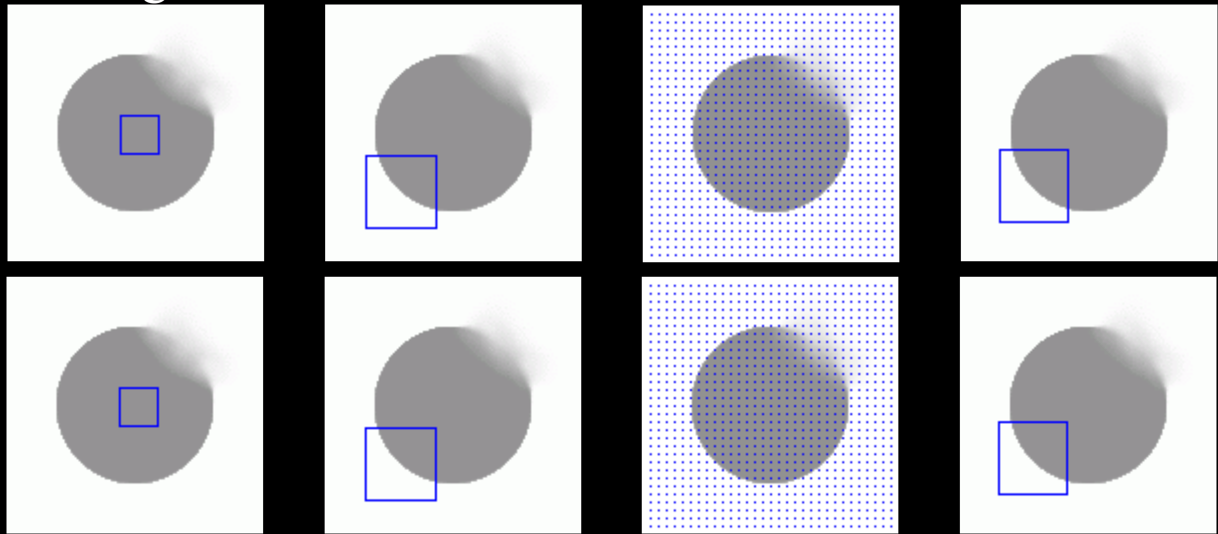
- Weak edges



Geodesic GGVF CPM **MAC**

Experimental results

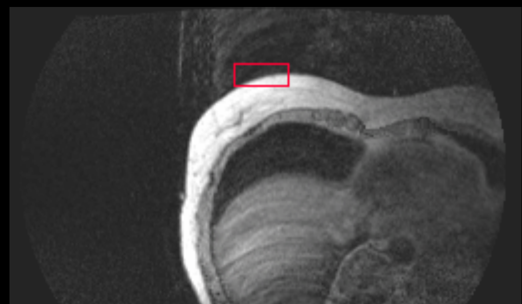
- Weak edges



Geodesic | GGVF | CPM | **MAC**

- Brief comparison to Region Based

Region based (MoG)

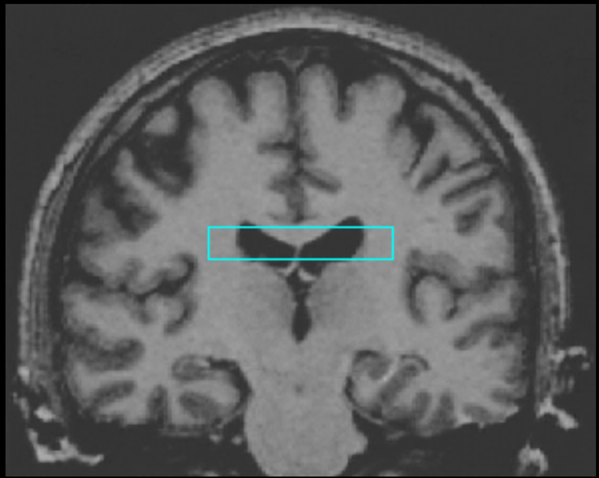


MAC

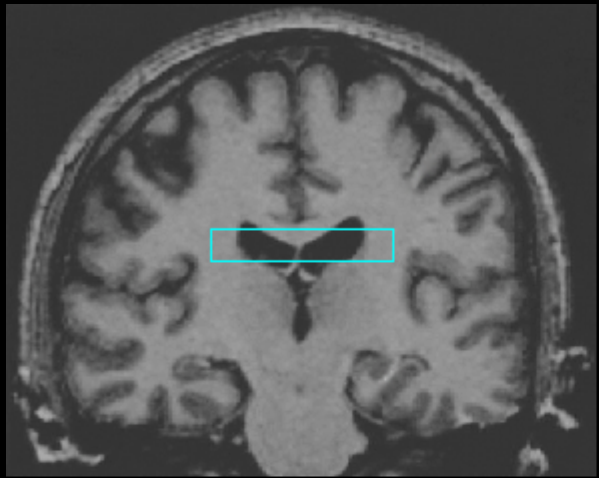
Experimental results

- On real images

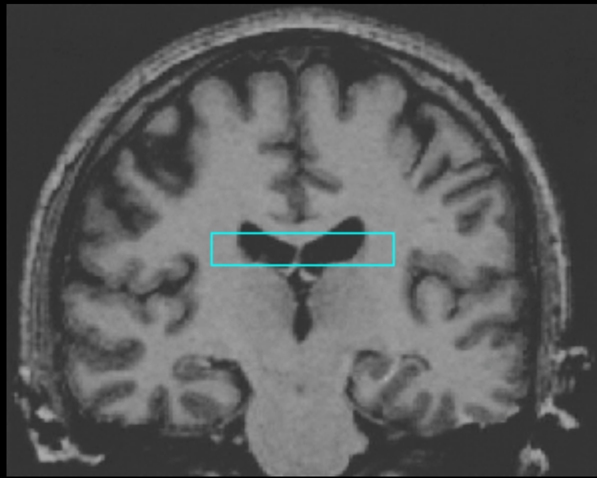
DVF



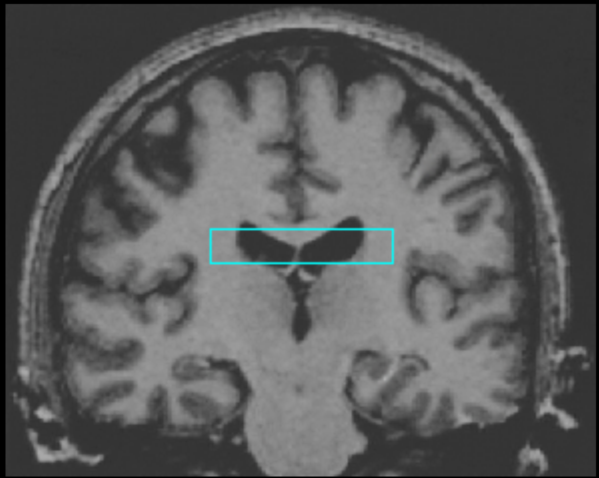
Geodesic



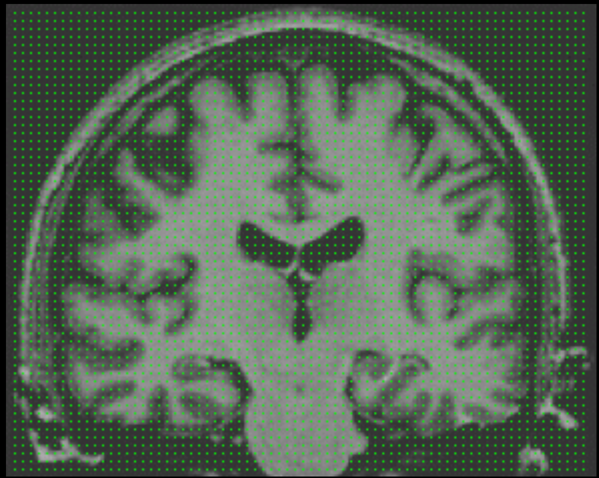
GGVF



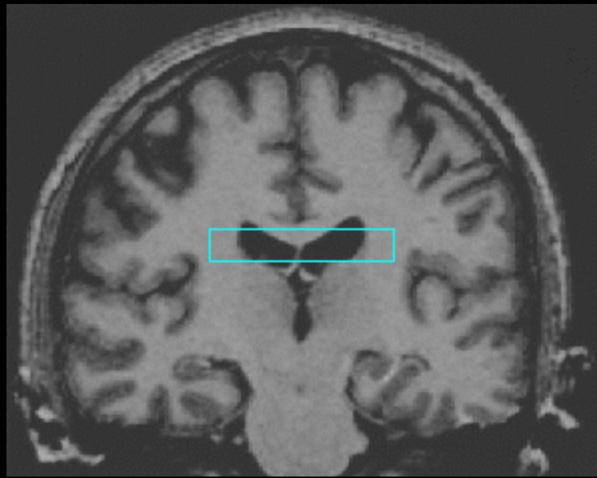
GeoGGVF



CPM



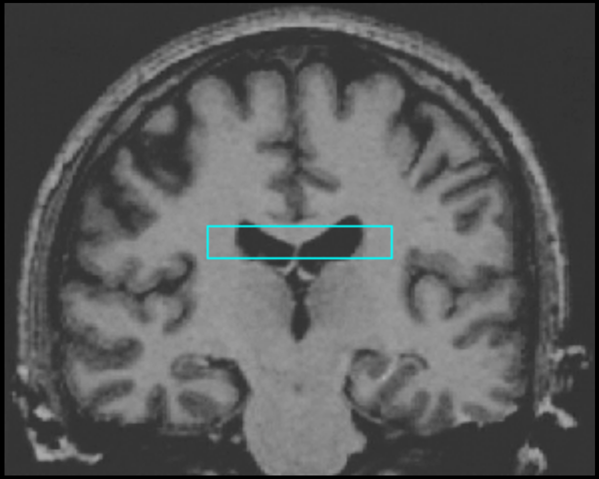
MAC



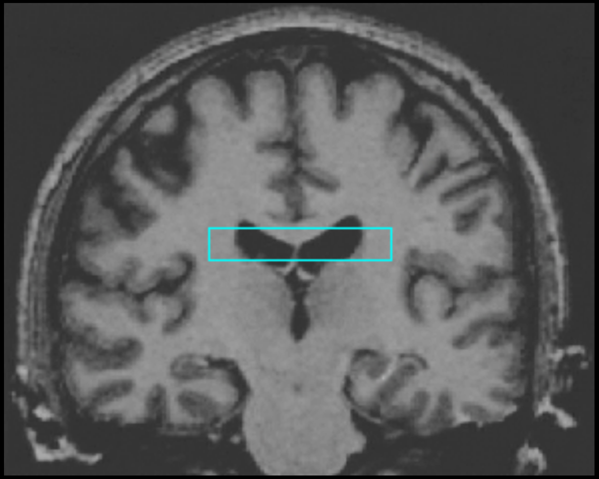
Experimental results

- On real images

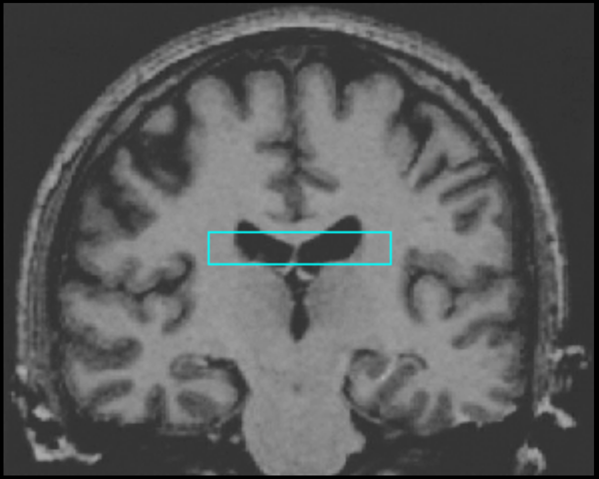
DVF



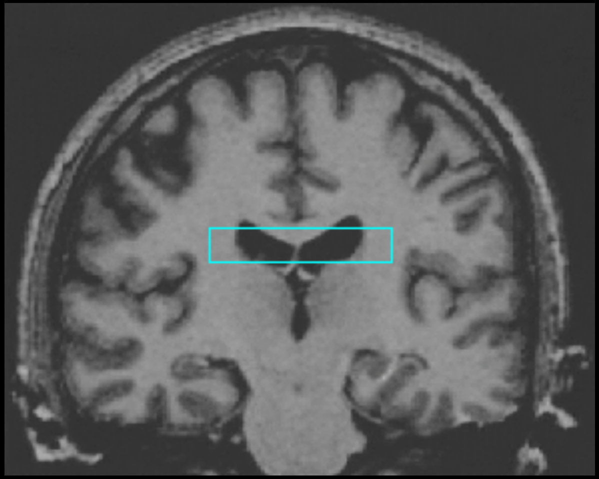
Geodesic



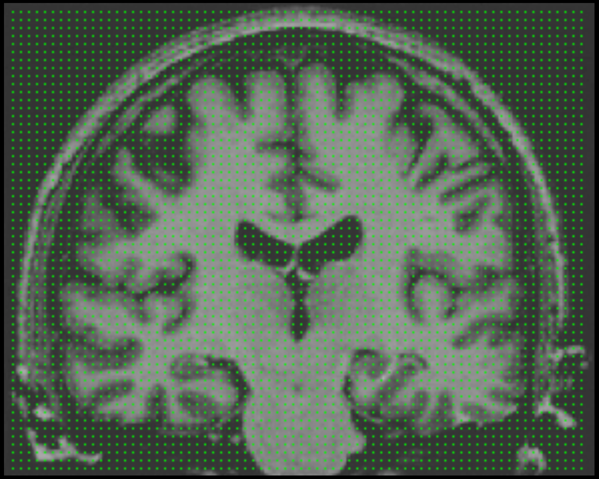
GGVF



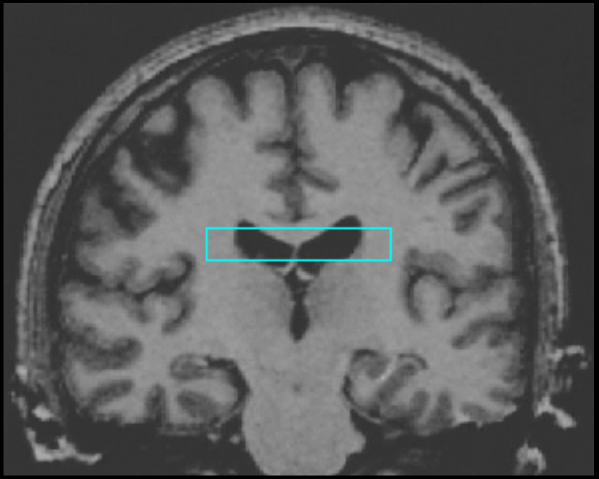
GeoGGVF



CPM



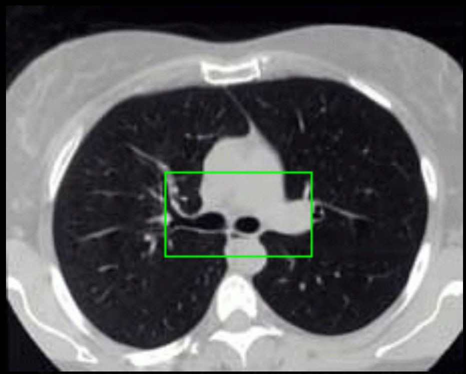
MAC



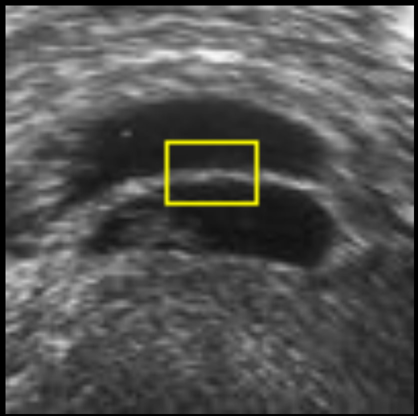
Experimental results

- On different types of images

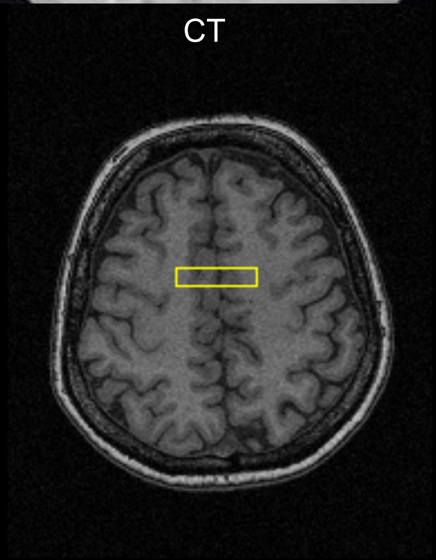
Planar X-ray



CT



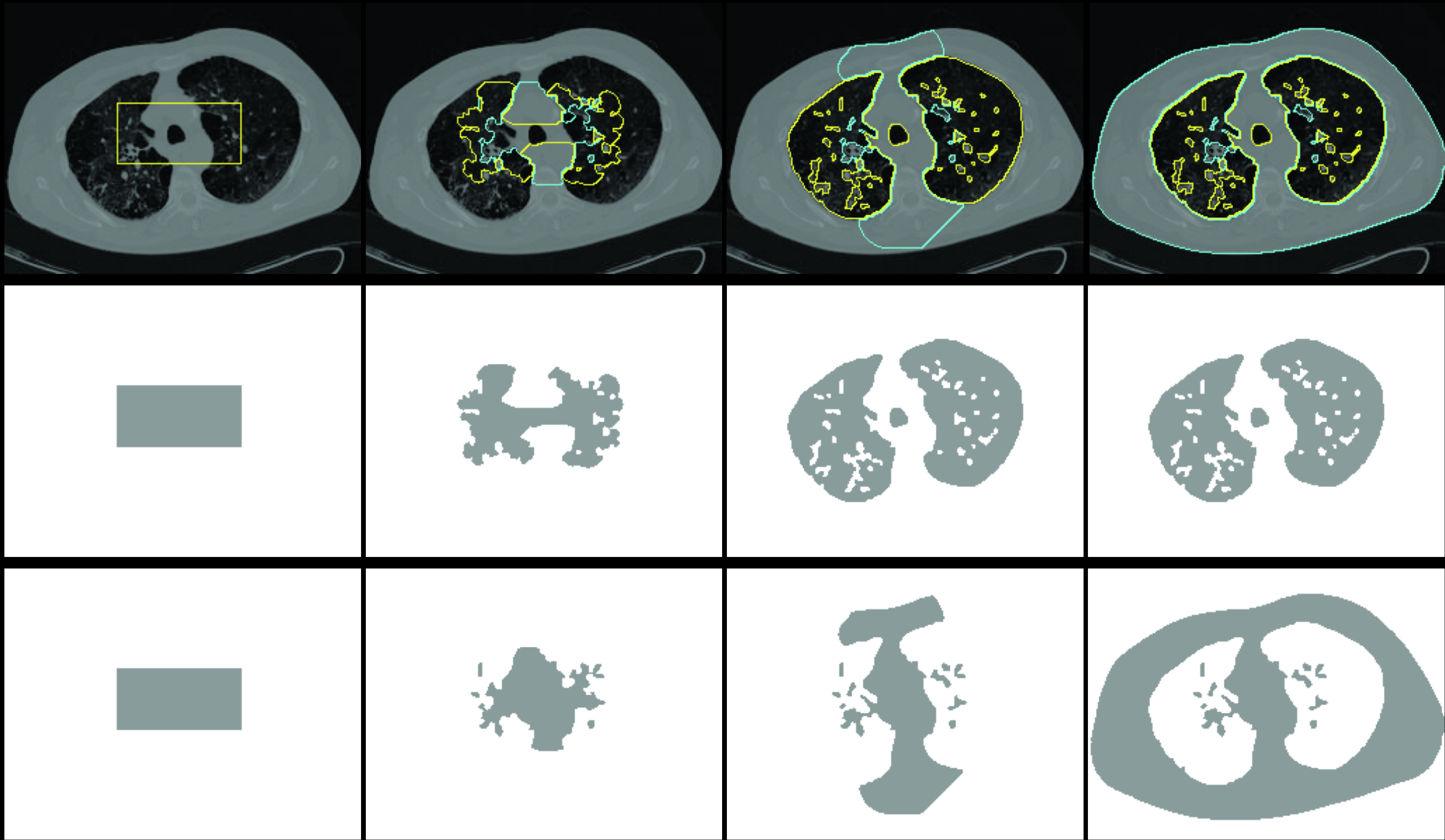
Ultrasound



MRI

Experimental results

- Dual level set



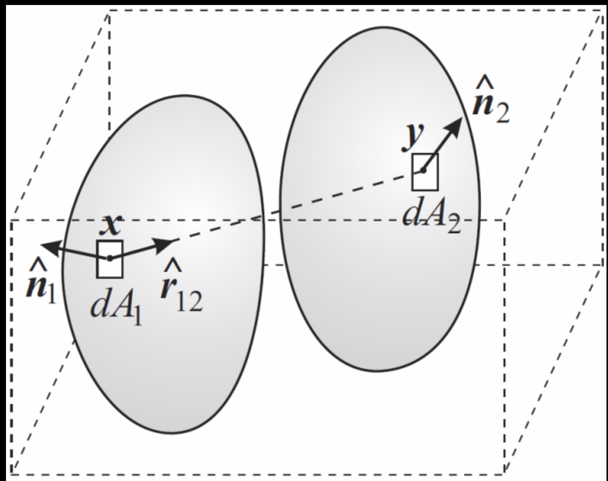
Xie & Mirmehdi, MAC, *IEEE Trans. Pattern Analysis & Machine Intelligence* 2008.

- Extension to 3D

Yeo, Xie, Sazonov, Nithiarasu, GPF, *IEEE Trans. Image Processing* 2011.

GPF model

- Geometrical Potential Force
  - Suitable for 3D data
  - Based on hypothesised geometrically induced force field between deformable model and object boundary
  - Generalisation of the MAC model



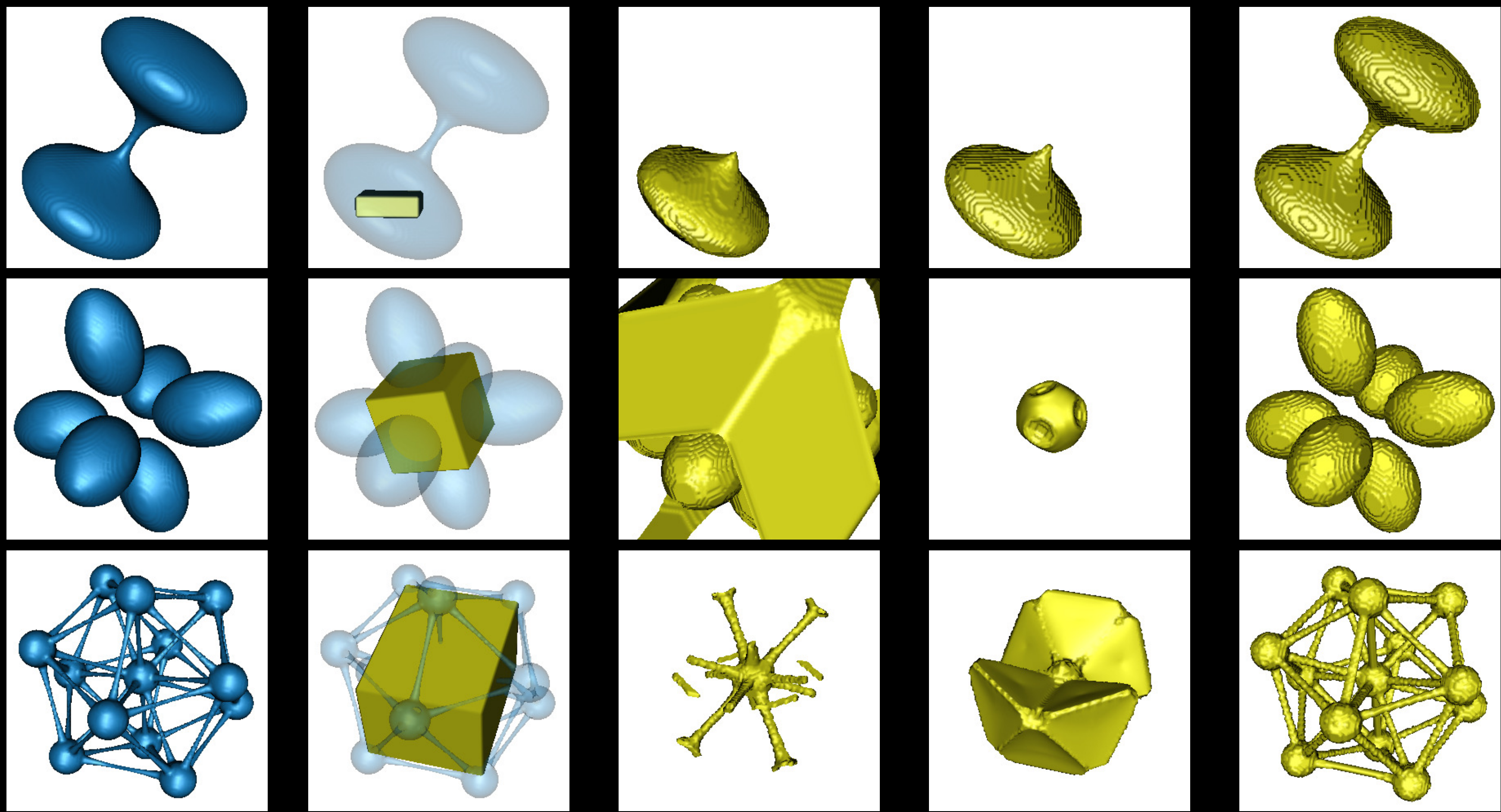
- Unique bi-directionality
- Dynamic force interaction
- Global view of object boundary representation

Yeo, Xie, Sazonov, Nithiarasu, GPF, *IEEE Trans. Image Processing* 2011.

GPF model

- Comparative Results

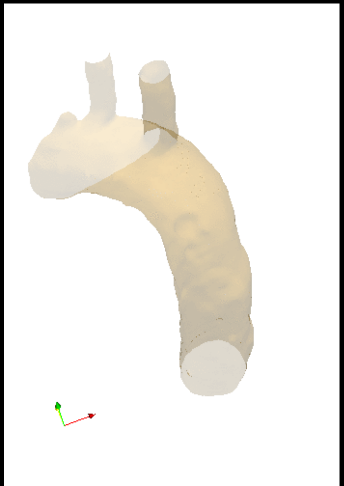
Target objects | Initialisations | Geodesic | GGVF | Proposed GPF

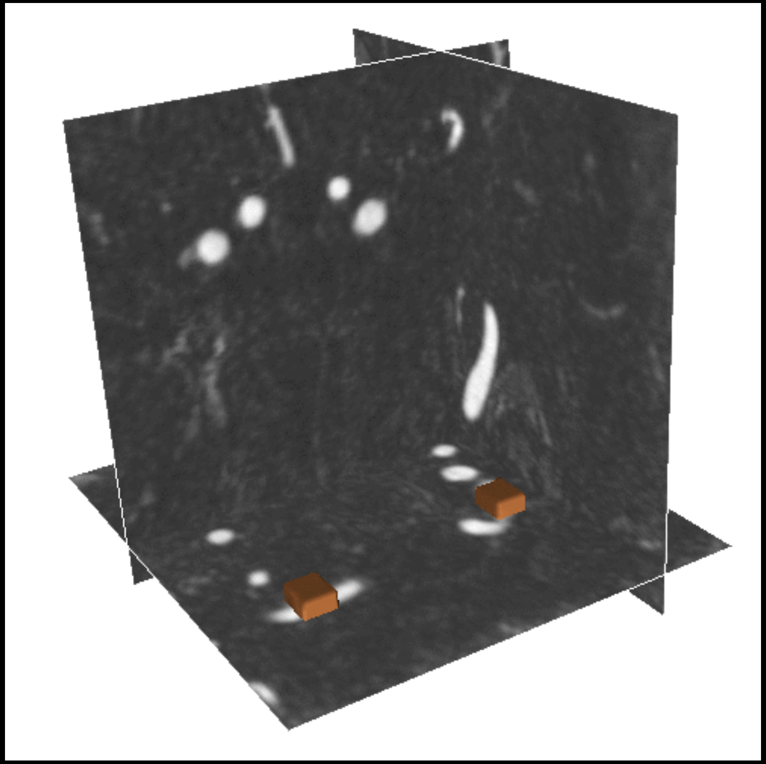


Yeo, Xie, Sazonov, Nithiarasu, GPF, *IEEE Trans. Image Processing* 2011.

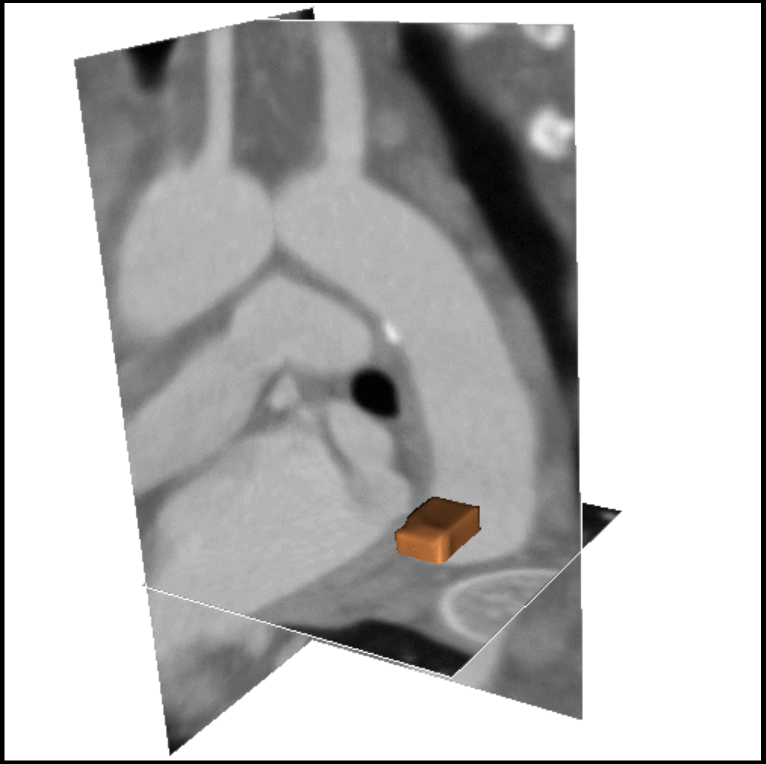
GPF model

- Medical 3D data segmentation





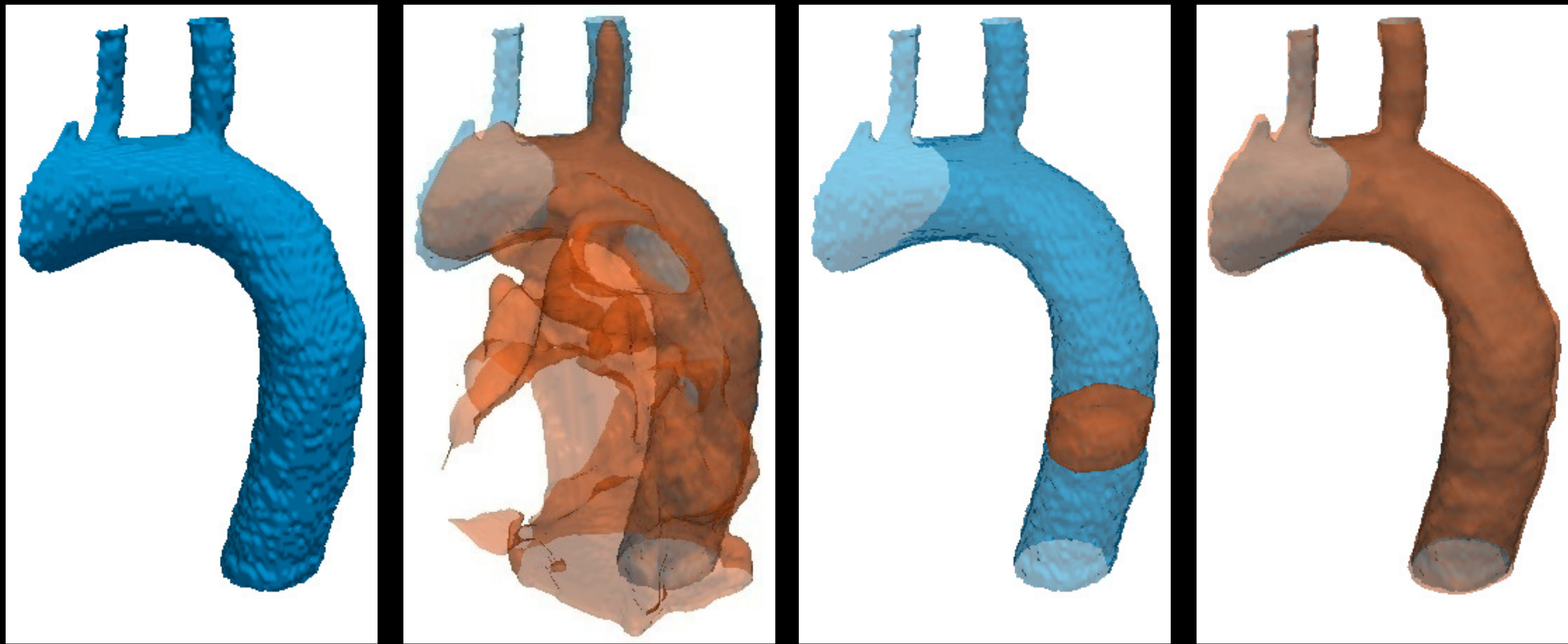
Aneurysm



Aorta

GPF model

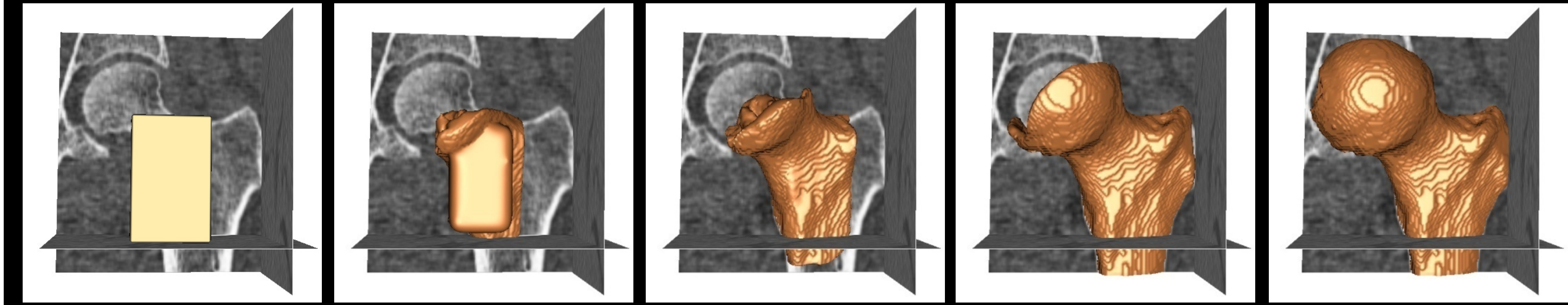
- Comparative analysis

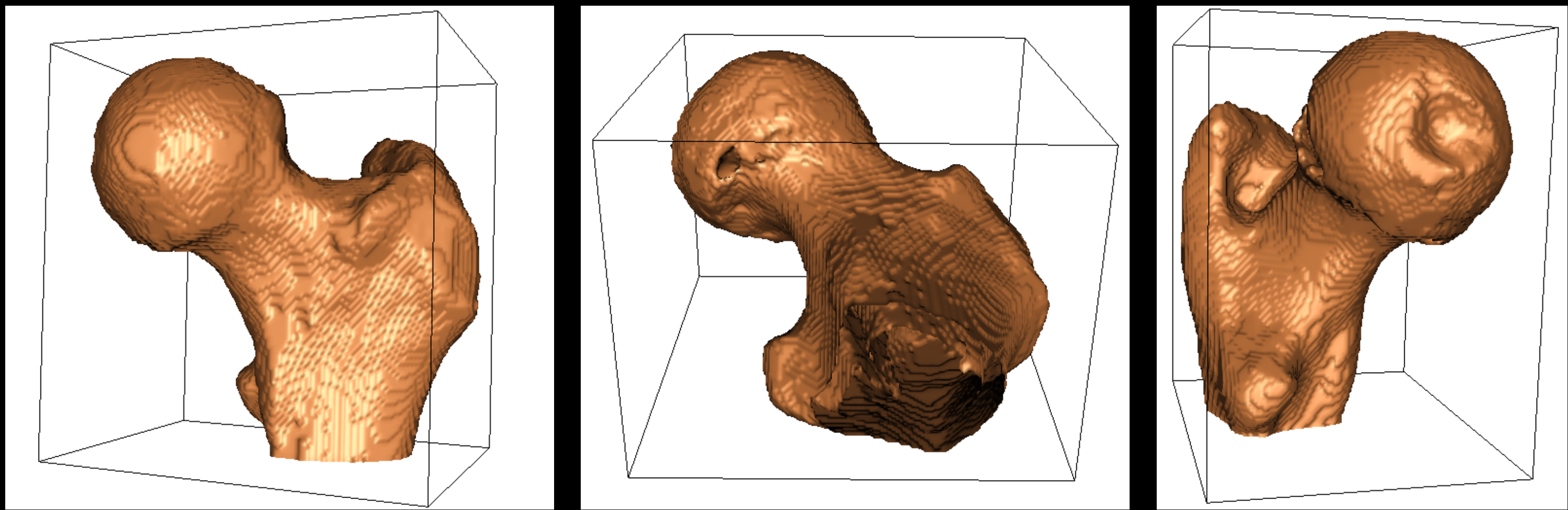


Ground-truth Geodesic GGVF Proposed GPF

GPF model

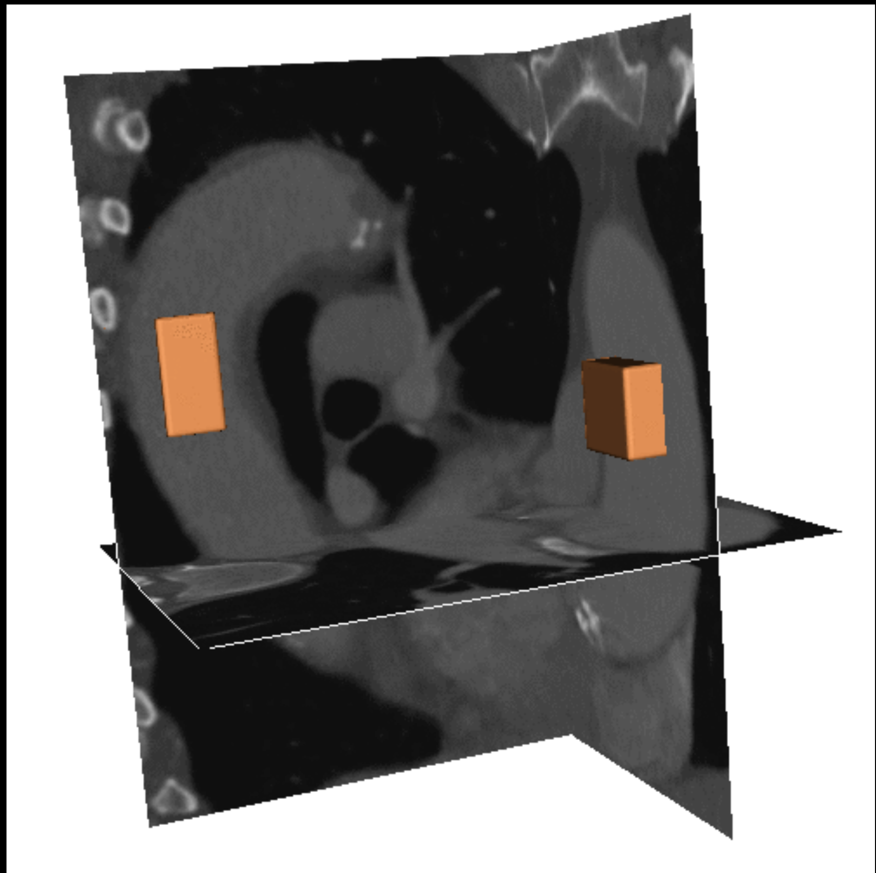
- Further examples



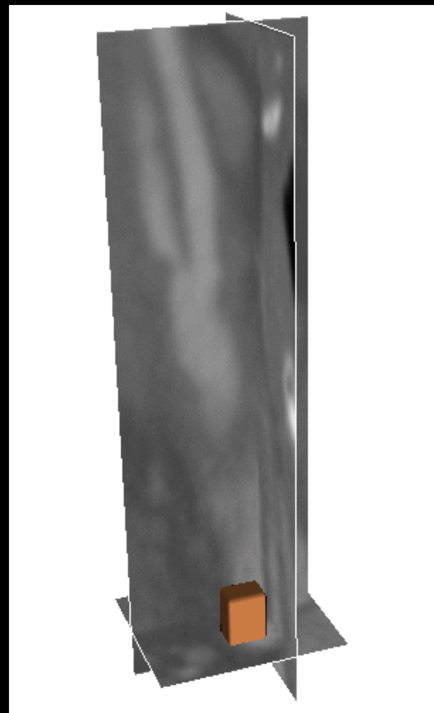


GPF model

- Further examples



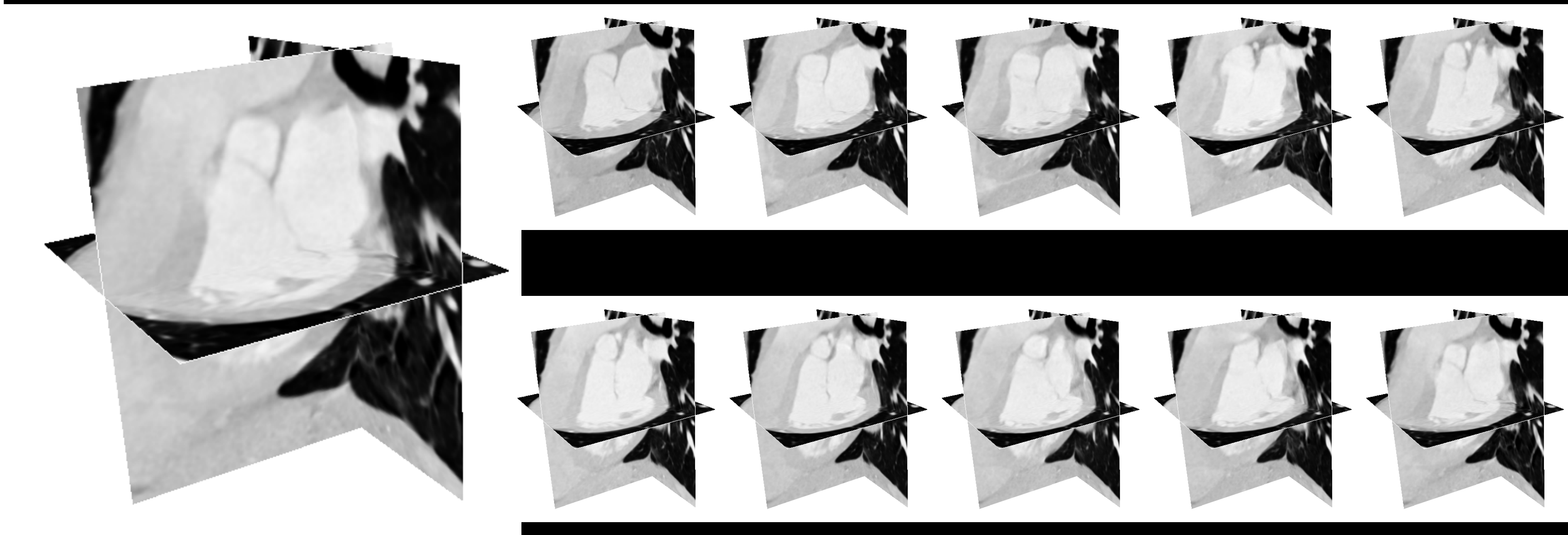
Human aorta (CT)



Human carotid (CT)

GPF model

- Direct sequential segmentation of temporal volumetric data



GPF model

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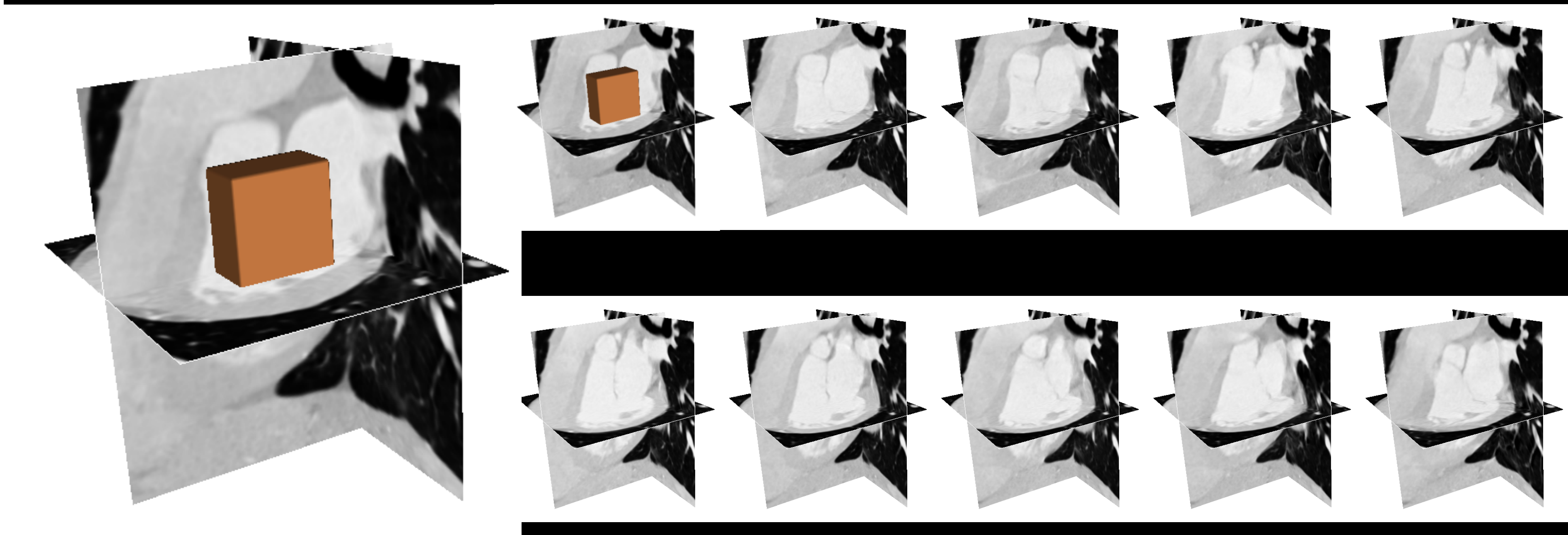

GPF model

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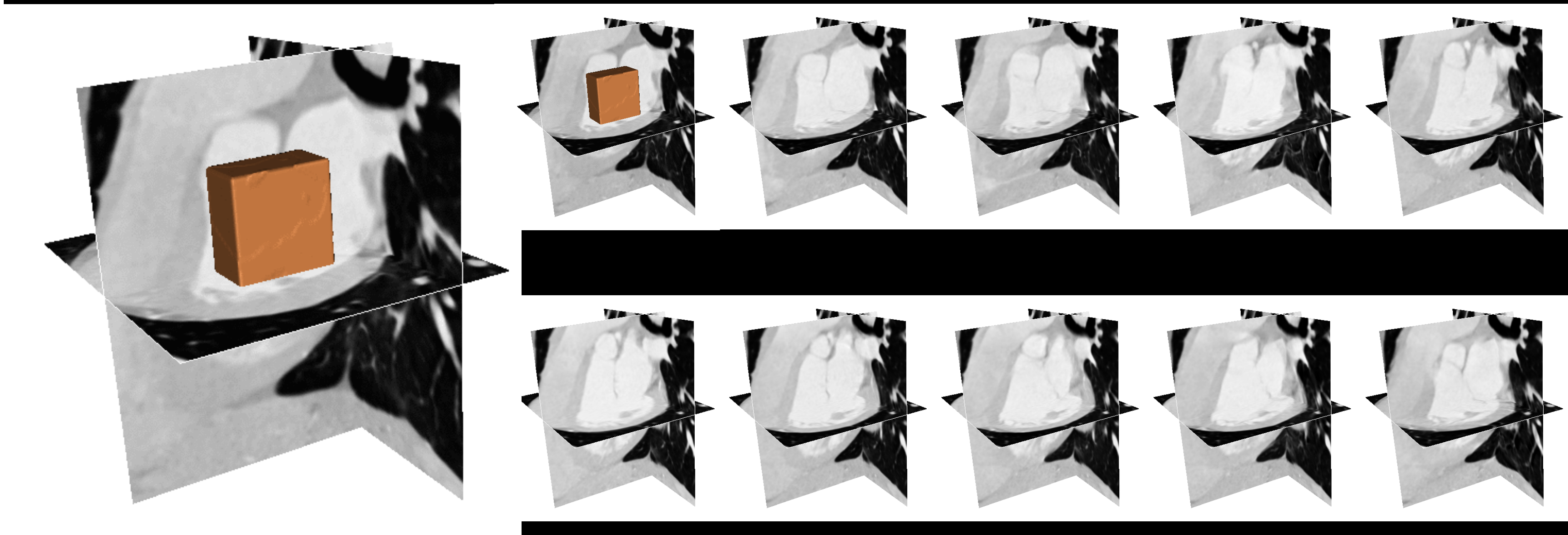

GPF model

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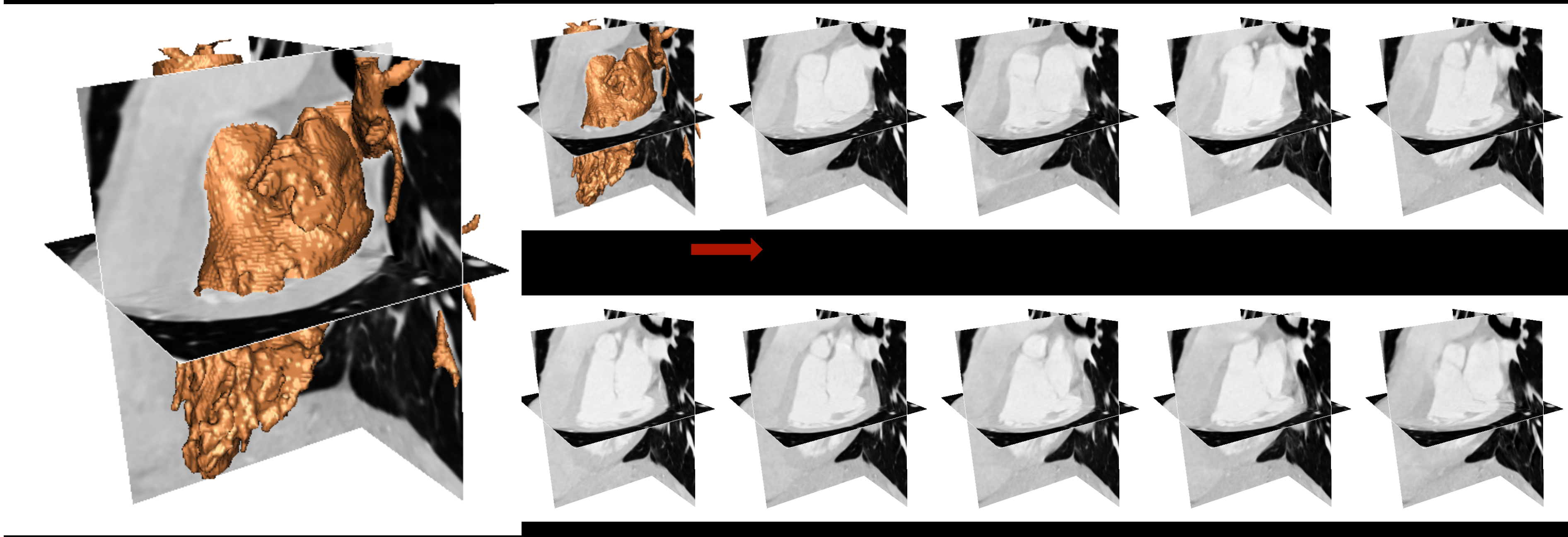

GPF model

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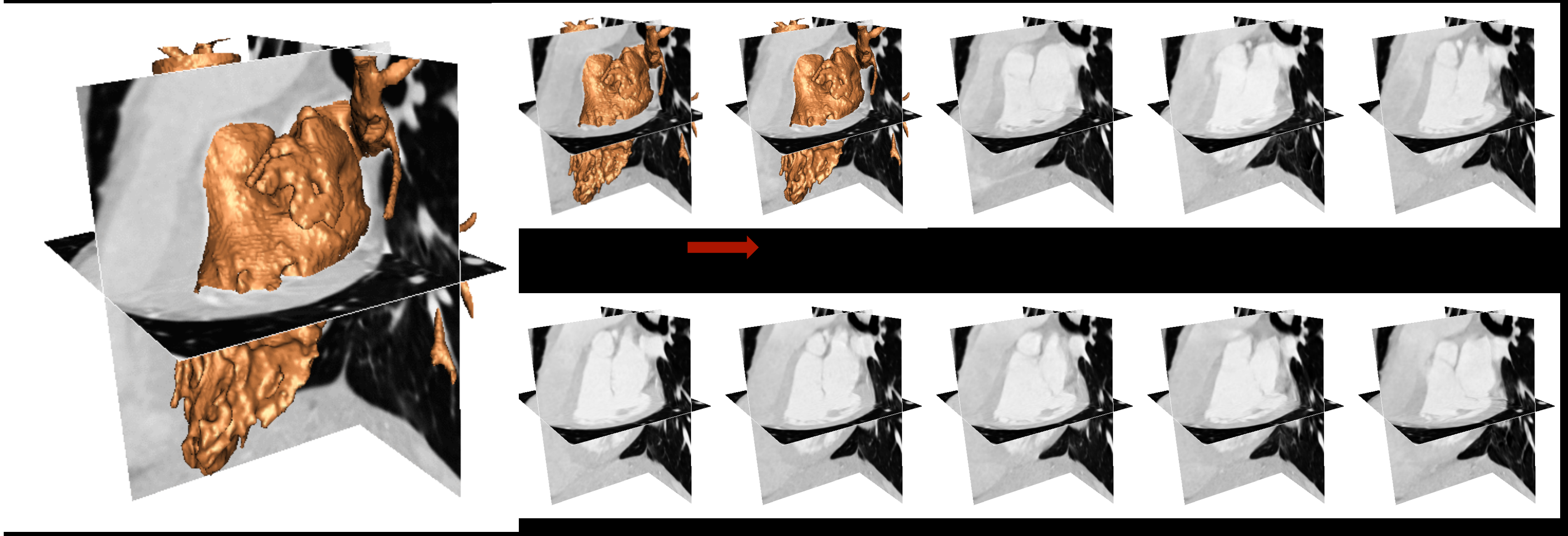

GPF model

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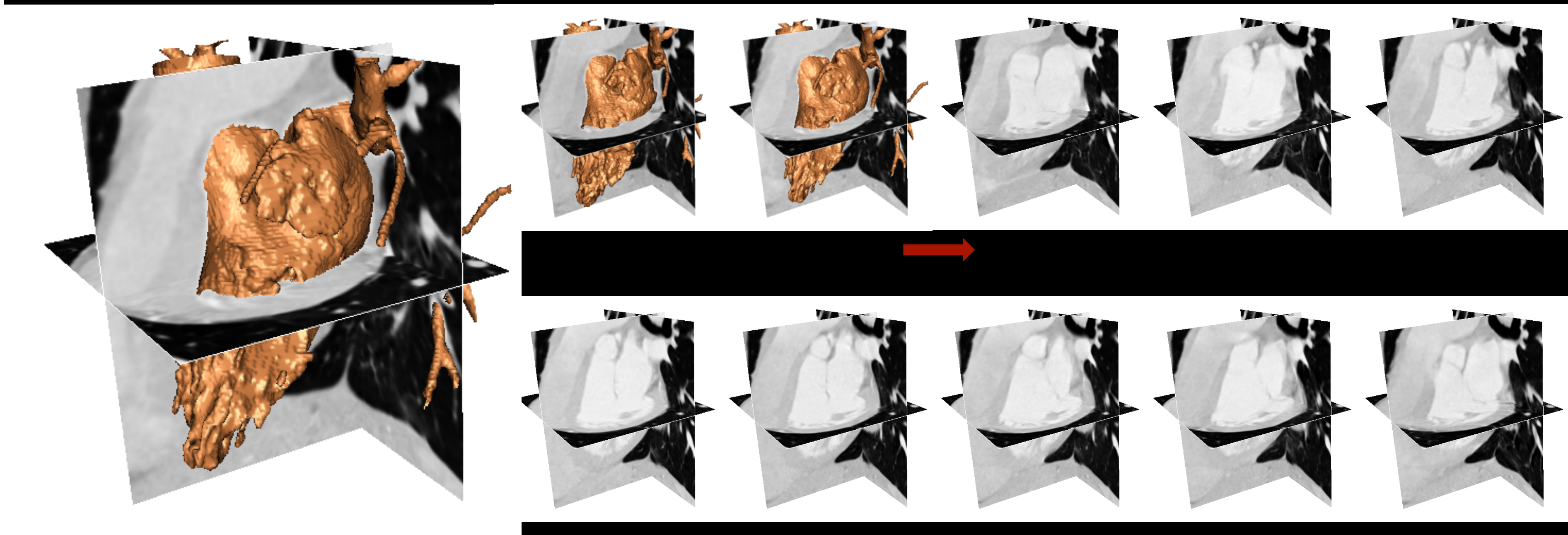
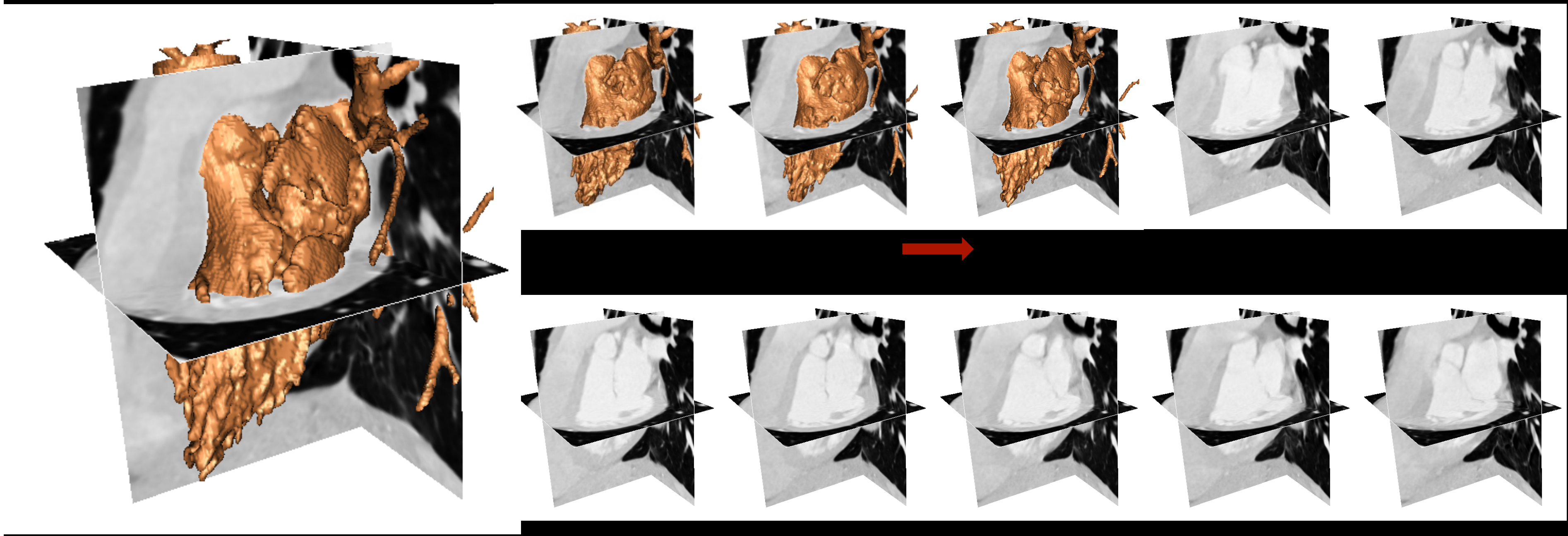


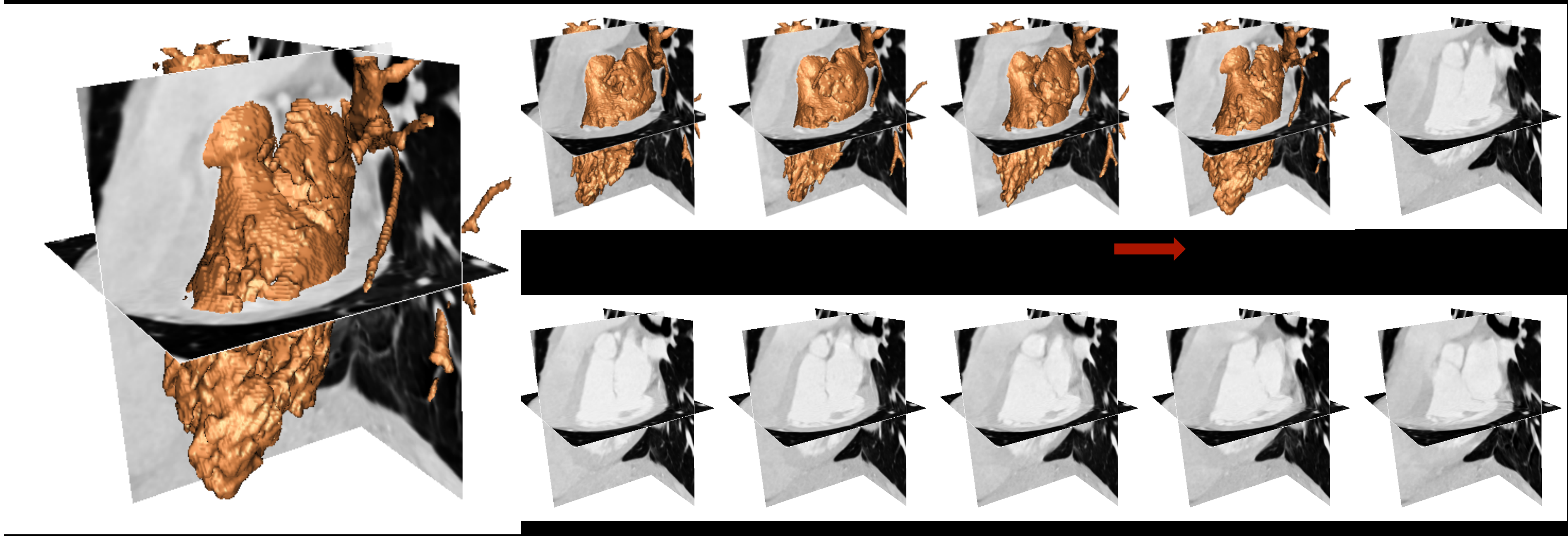
GPF model

- Direct sequential segmentation of temporal volumetric data



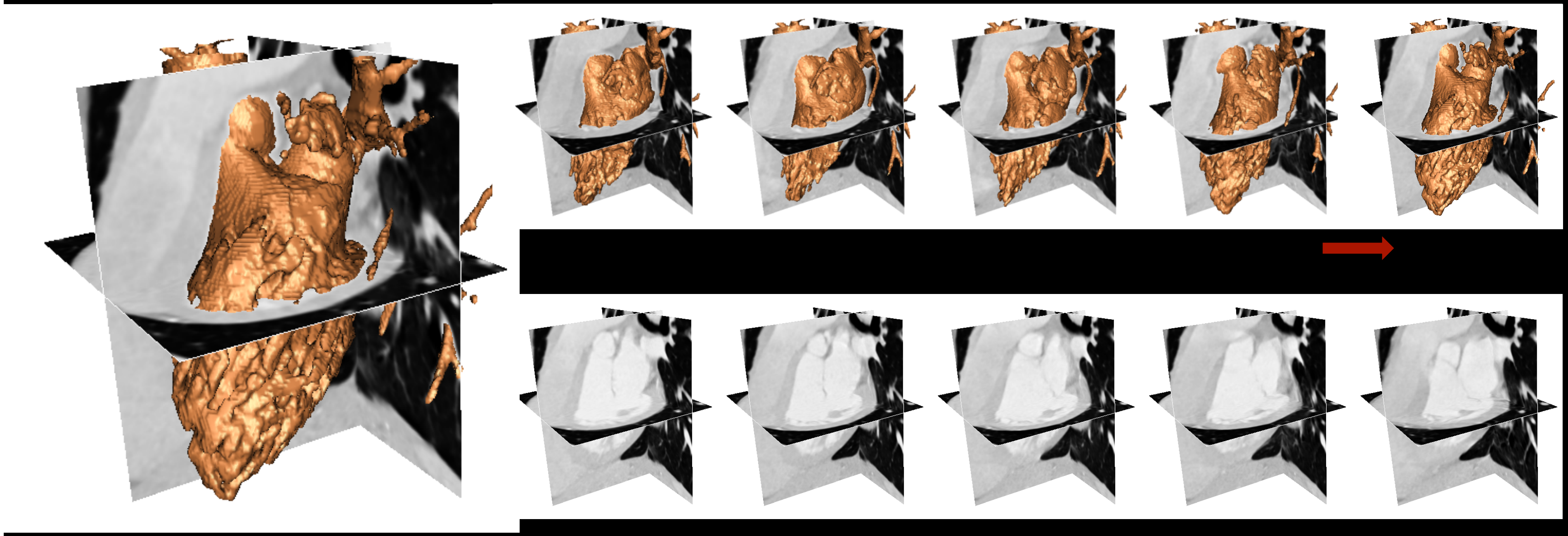
GPF model

- Direct sequential segmentation of temporal volumetric data



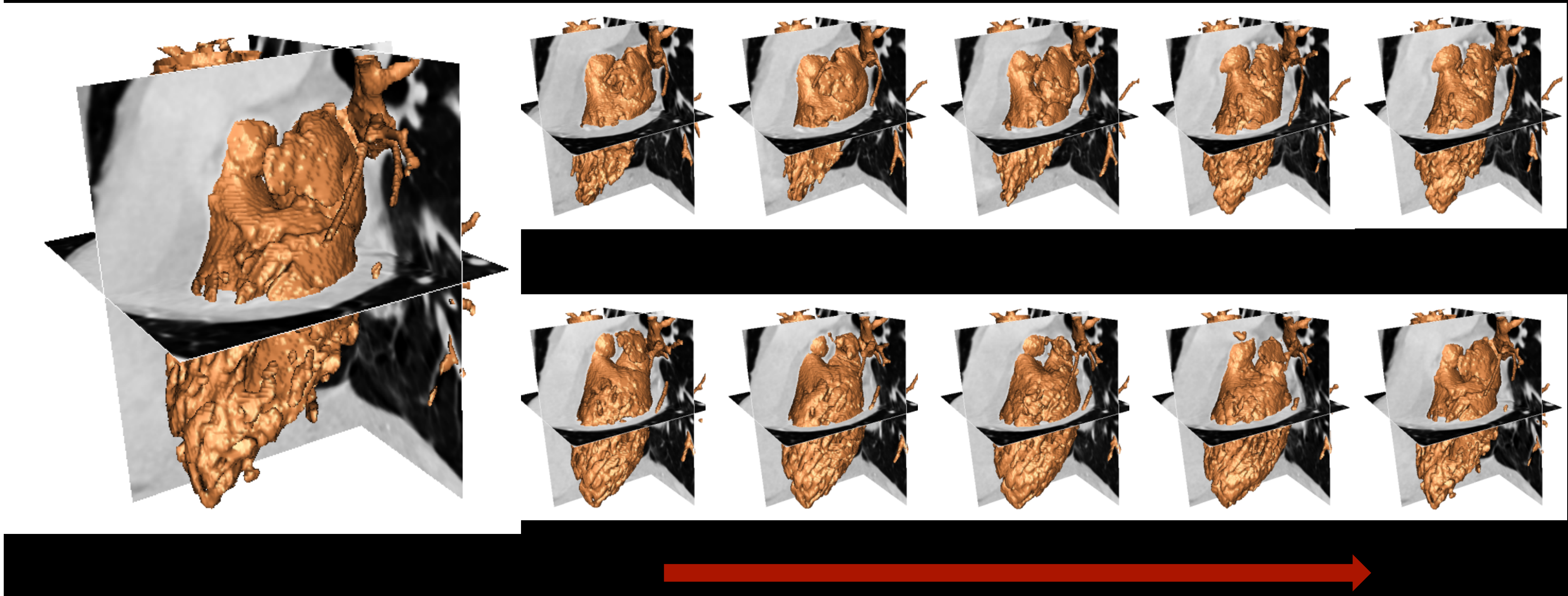
GPF model

- Direct sequential segmentation of temporal volumetric data



GPF model

- Direct sequential segmentation of temporal volumetric data



GPF model

- Direct sequential segmentation of temporal volumetric data

GPF model

- Segmentation using statistical shape prior

$$\hat{\phi} = \arg\max p(\phi|I)$$
$$\propto \arg\max \left(p(I|\phi) \cdot p(\phi)\right)$$

$$E(\phi) = -log(p(I|\phi)) - log(p(\phi))$$
$$= E_{image}(\phi) + \alpha E_{shape}(\phi)$$

$$\hat{\phi} \;=\; \arg\max p(\phi|I, \tilde{\phi}, \tilde{I})$$

GPF model

- Segmentation using statistical shape prior

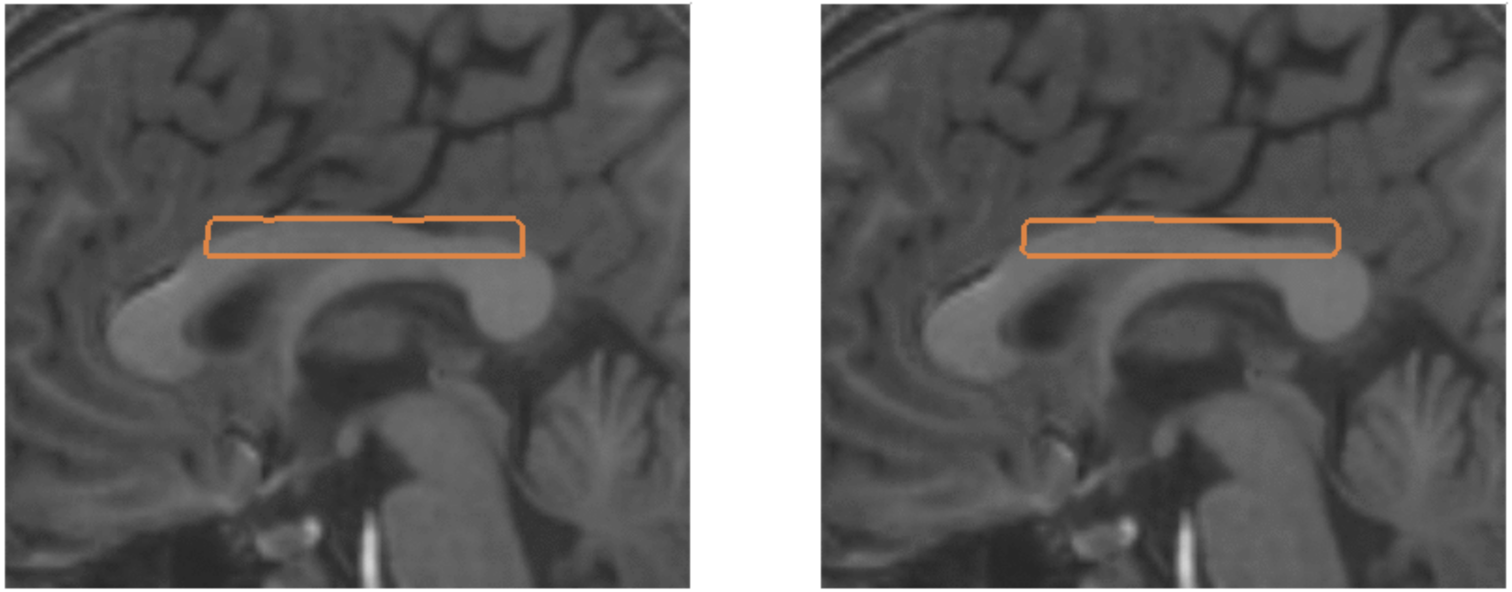


Image based energy

Image and shape based energy

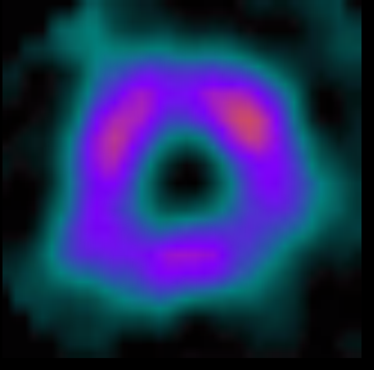
Segmentation of corpus callosum from MRI

- 3D+T (4D) constrained SPECT segmentation

Yang, Mirmehdi, Xie, Hall, CI2BM, MICCAI workshop 2009. (MIA under-review)

4D SPECT Segmentation

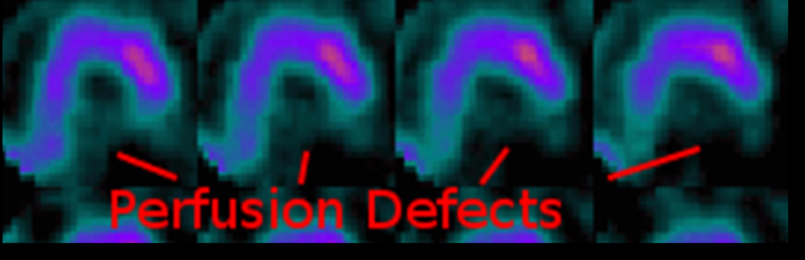
- Segmentation of LV borders allows quantitative analysis of perfusion defects and cardiac function.

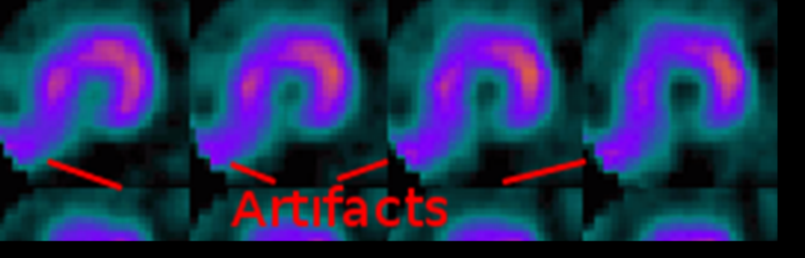


SPECT slice of the LV

Cardiac motion (mid-slice)

A Doughnut



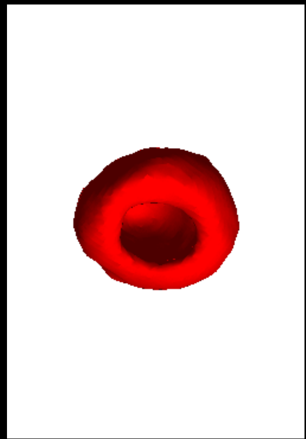


Yang, Mirmehdi, Xie, Hall, CI2BM, MICCAI workshop 2009. (MIA under-review)

4D SPECT Segmentation

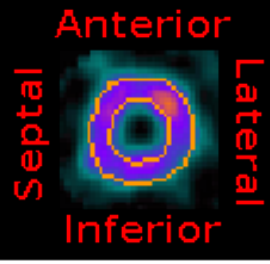
Frontal view of opaque surface

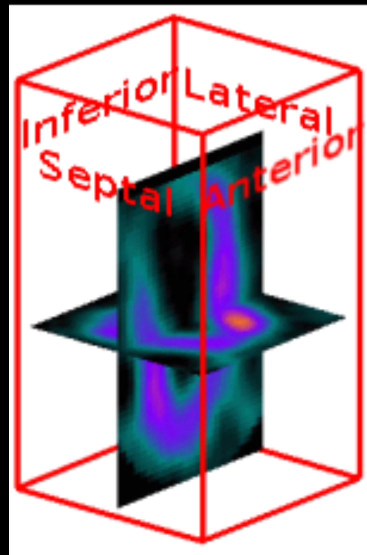
Top view of opaque surface



Correspondence between short-axis slice and 3D frontal view

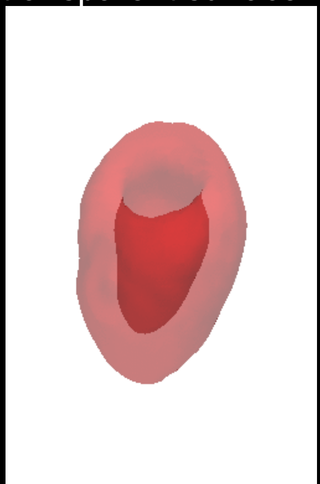
Short-axis view



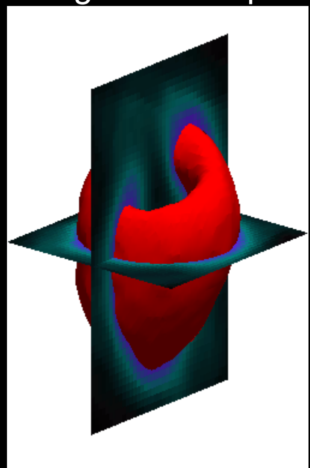


Frontal view

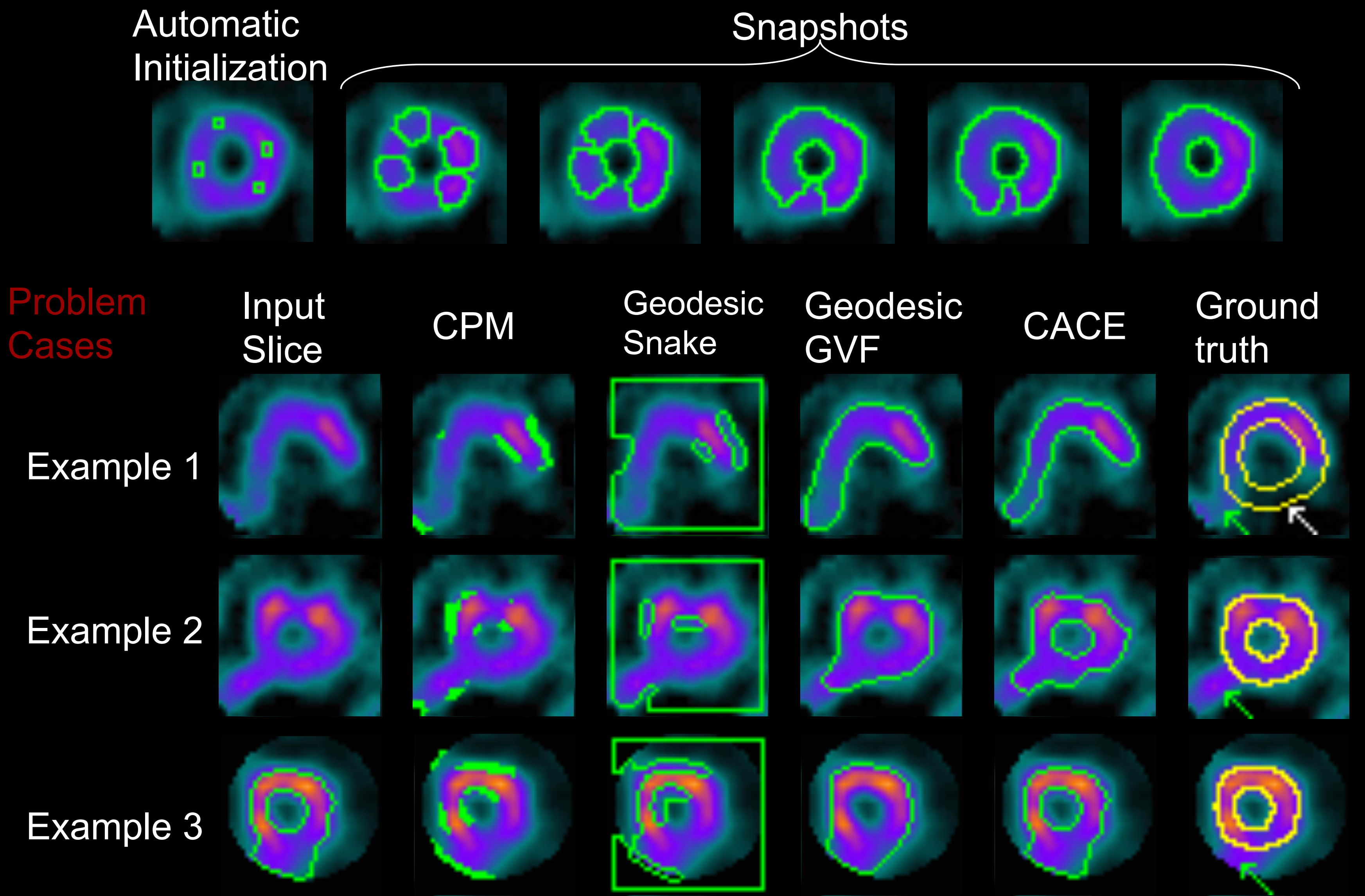
Frontal view of transparent surface



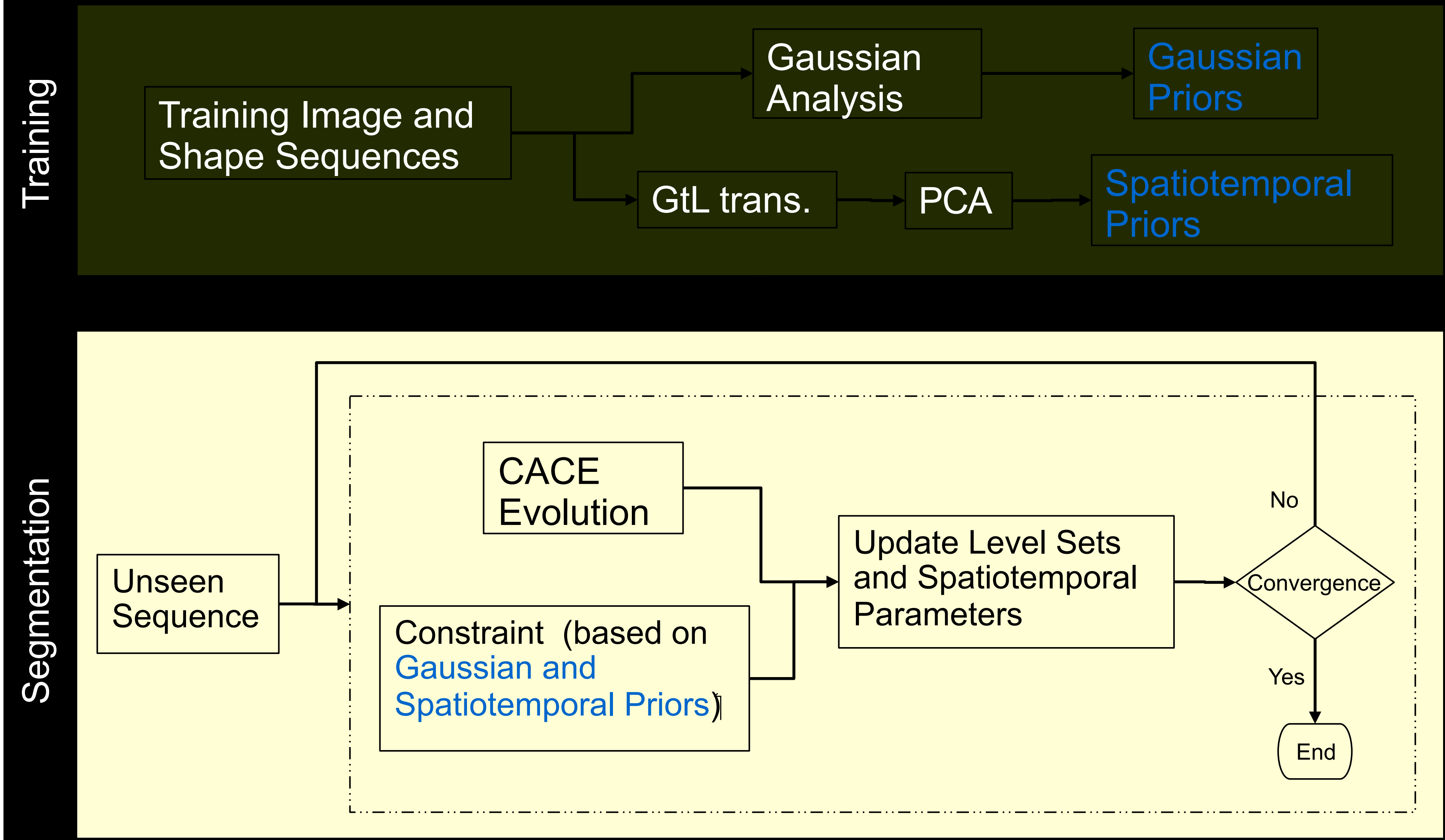
Frontal view of opaque surface overlaid on orthogonal slice planes



4D SPECT Segmentation



4D SPECT Segmentation

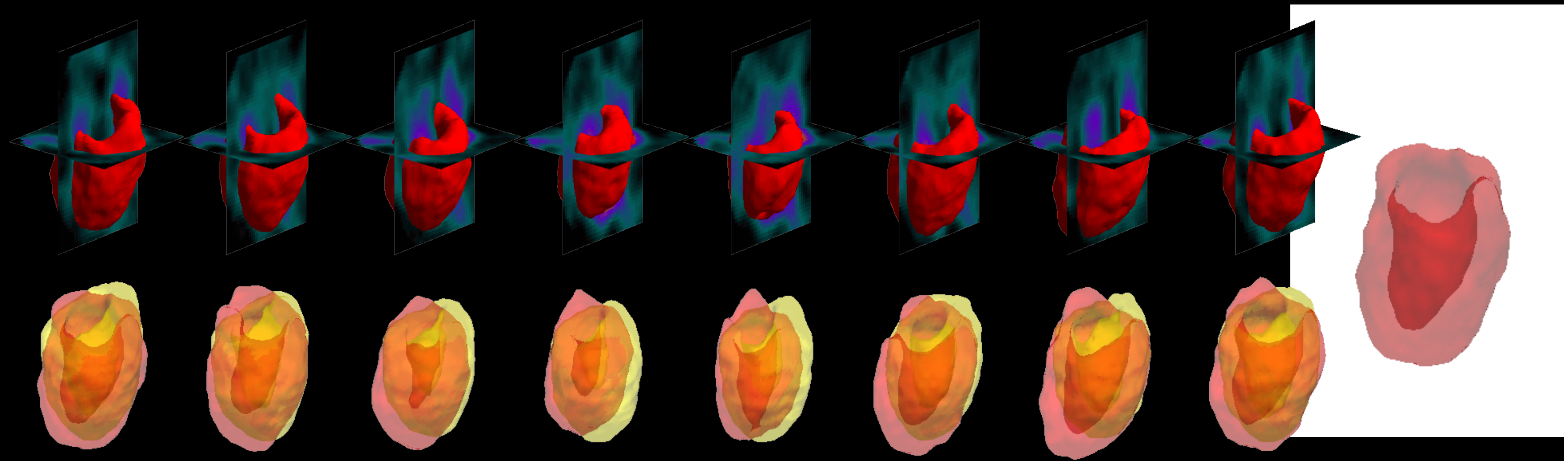


4D SPECT Segmentation

SCMS: 63.1%

Results on input image

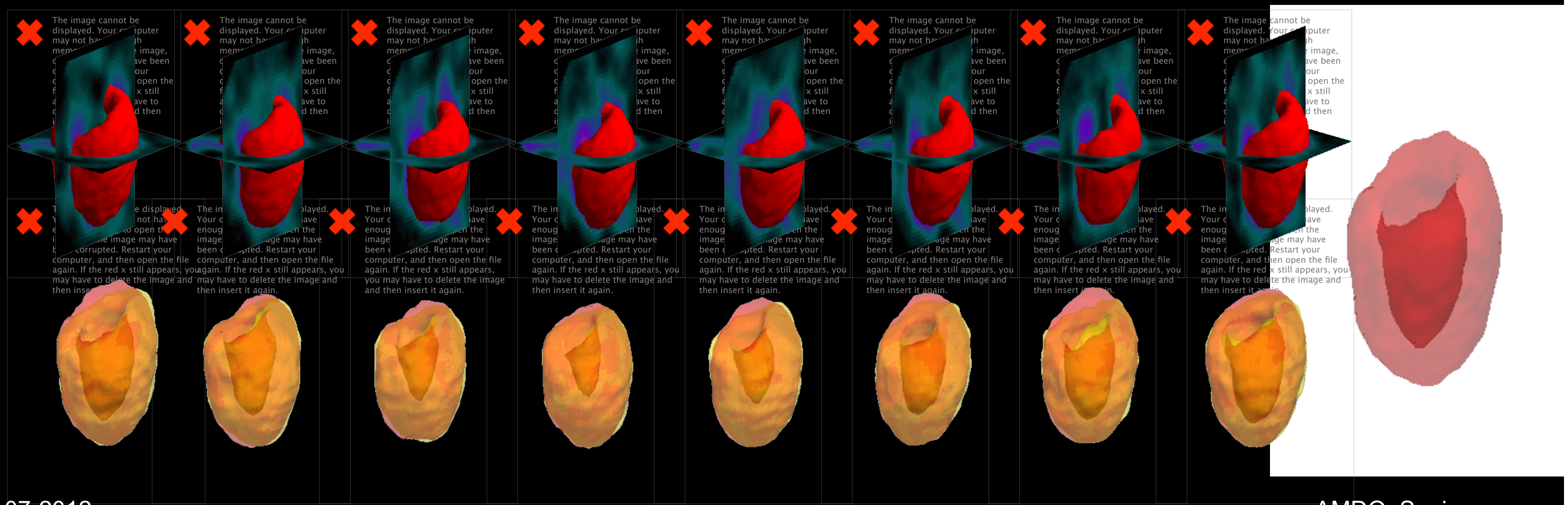
Results against ground truth



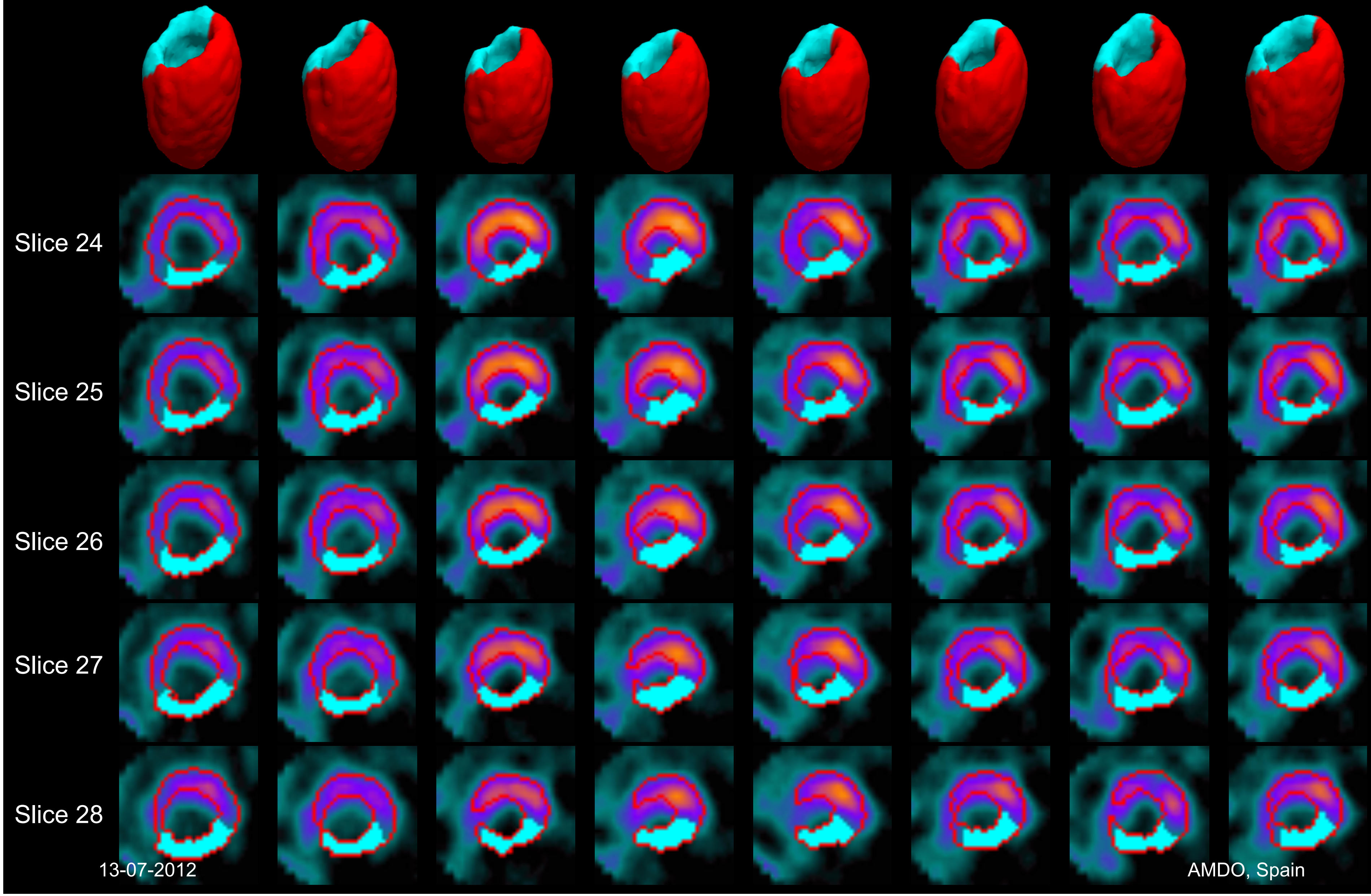
CCACE: 85.8%

Results on input image

Results against ground truth



4D SPECT Segmentation – defect detection

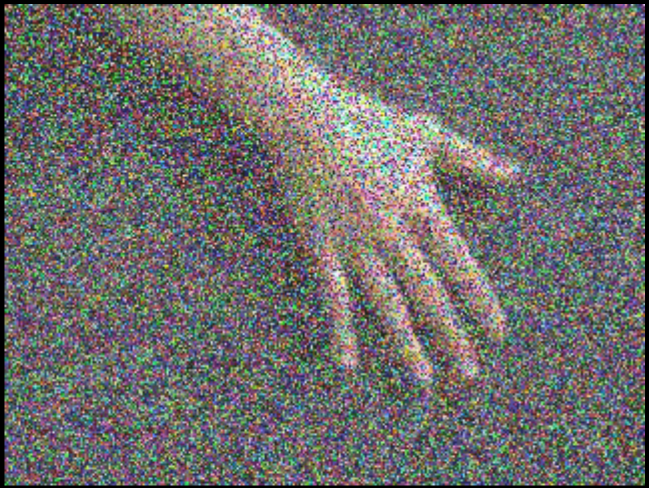


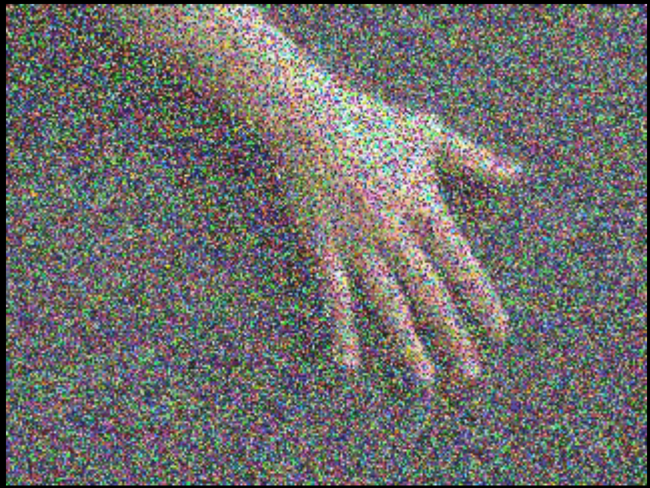
- Tracking using implicit representation

Chiverton, Xie & Mirmehdi, *BMVC* 2008 & 2009. (TIP under-review)

Tracking & Online Shape Learning

- Prior independent snake tracking
- Contour based tracking
  - Probably more difficult than box based tracking
  - No prior knowledge
  - Online shape learning and dynamic updating





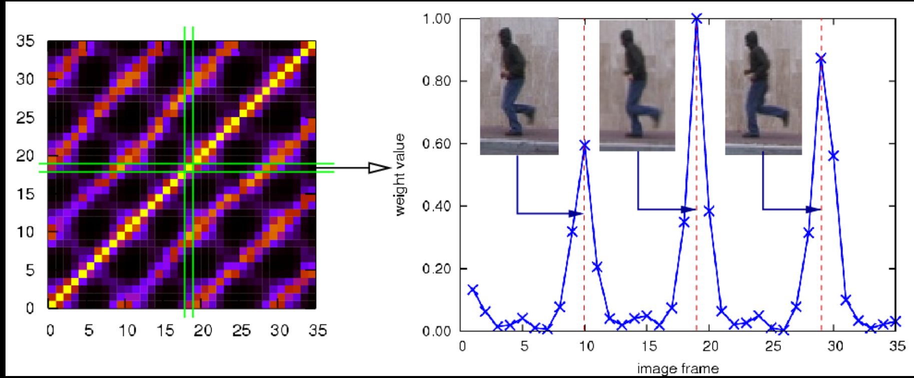
60% random noise

Tracking & Online Shape Learning

- Prior independent snake tracking
- Contour based tracking
  - Probably more difficult than box based tracking
  - No prior knowledge
  - Online shape learning and dynamic updating

Tracking & Online Shape Learning

- Contour based object tracking
- Online shape learning
- Self-imposed shape regularisation



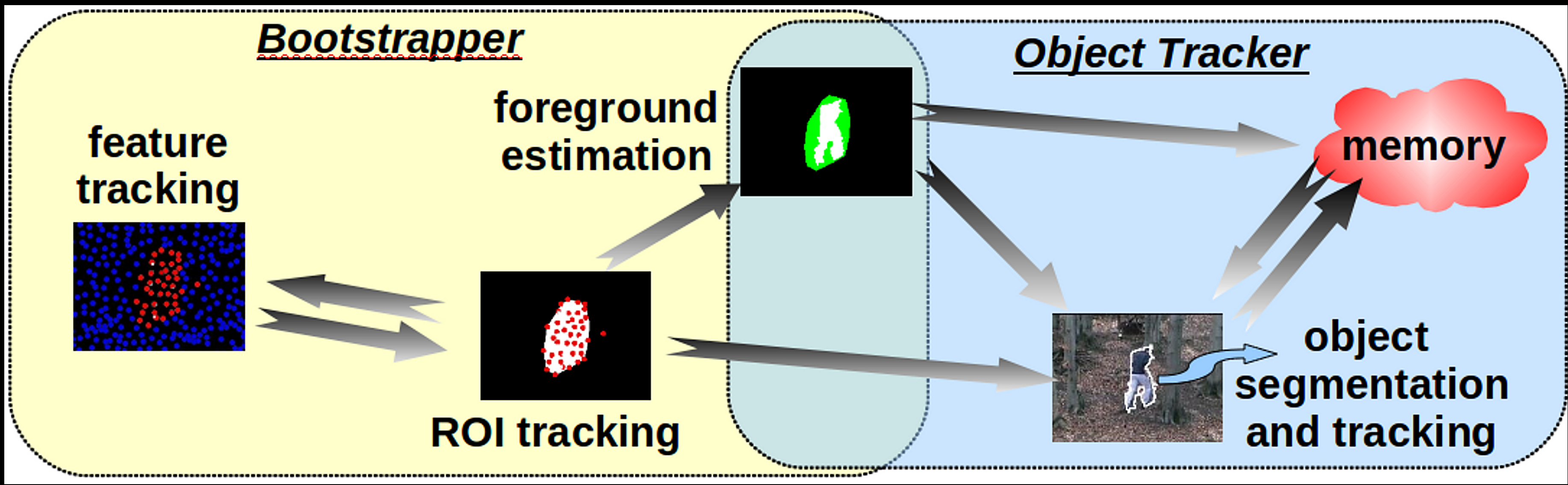
Without online shape self-regularisation

Proposed method

Chiverton, Xie & Mirmehdi, *BMVC* 2008 & 2009.

Automatic Bootstrapping & Tracking

- Online shape learning coupled with automatic bootstrapping
- Finite size shape memory
- Statistical shape modelling
- Level set based tracking – similar to previous approach



Chiverton, Xie & Mirmehdi, *IEEE T-IP 2012*.

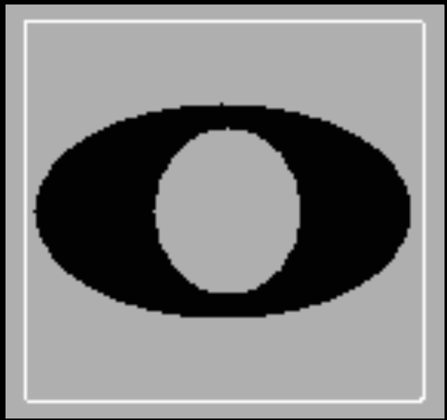
- RBF-Level Set based Active Contouring

Xie & Mirmehdi, *Image and Vision Computing* 2011 & BMVC07.

Conventional level set technique

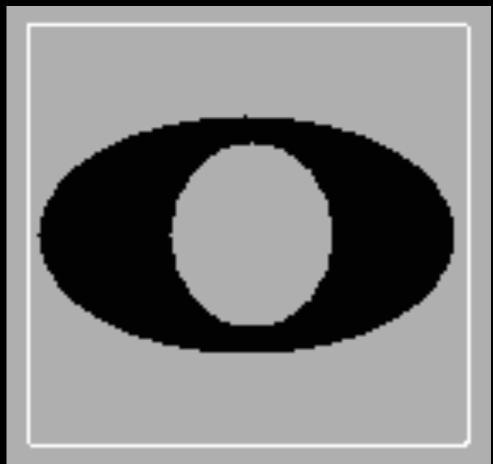
- Problems
  - Computational complexity
    - Dense computation grid, particularly expensive in 3D
    - Some solutions: fast marching, narrow band, AoS schemes, …
  - Can’t handle more sophisticated topological changes
    - Usually requires re-initialisation to maintain a smooth surface to prevent numerical artefacts contaminating the solution
    - Perturbations away from the zero level set are missed

Conventional level set:
The hole is missed!

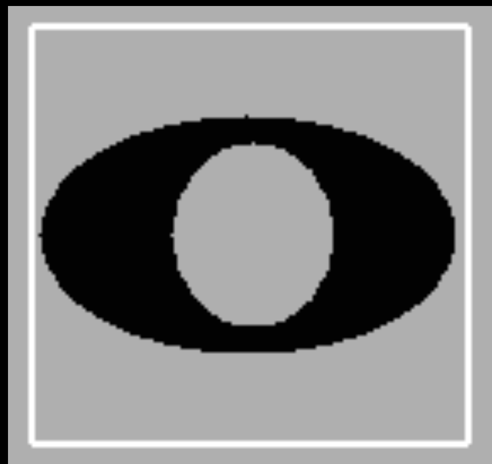


RBF-Level Set snake

- RBF-Level Set
  - Use radial basis function to interpolate level set
  - Updating expansion coefficients to deform level set
  - Transfer PDE to ODE: efficient
  - Much coarser computational grid, even irregular
  - More complex topological changes readily achievable



Conventional level set



Proposed method

RBF-Level Set snake

- RBF-Level Set
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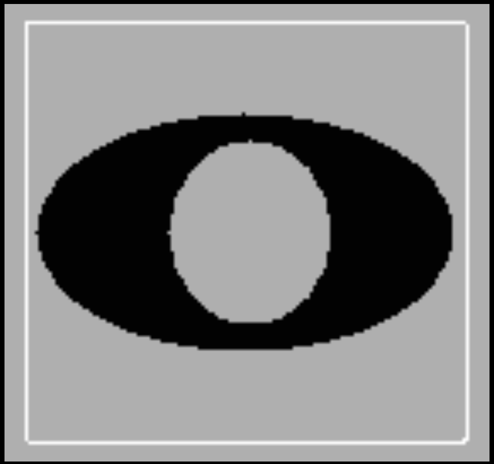
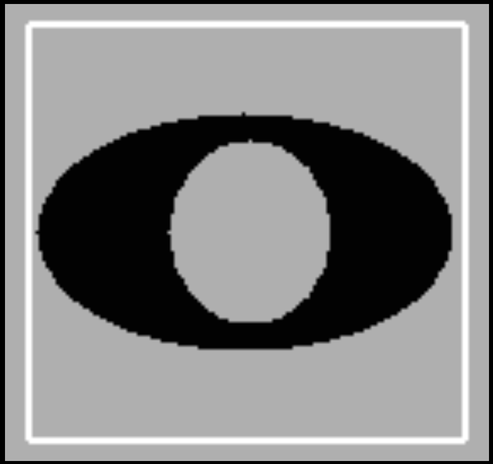


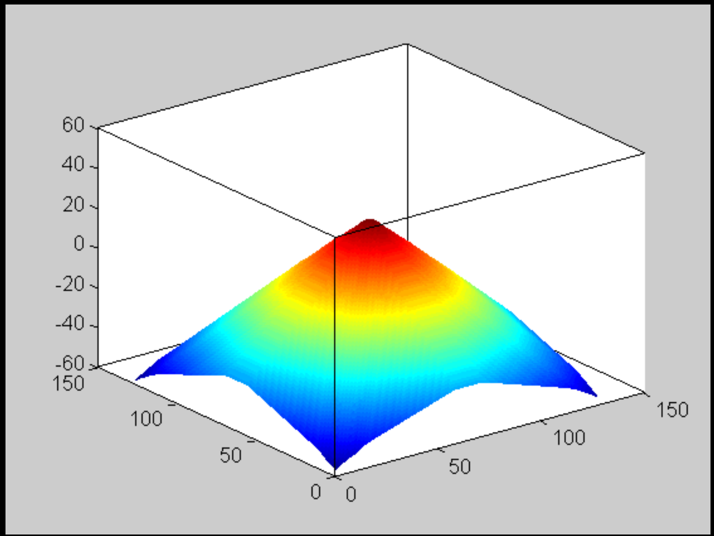
Conventional level set



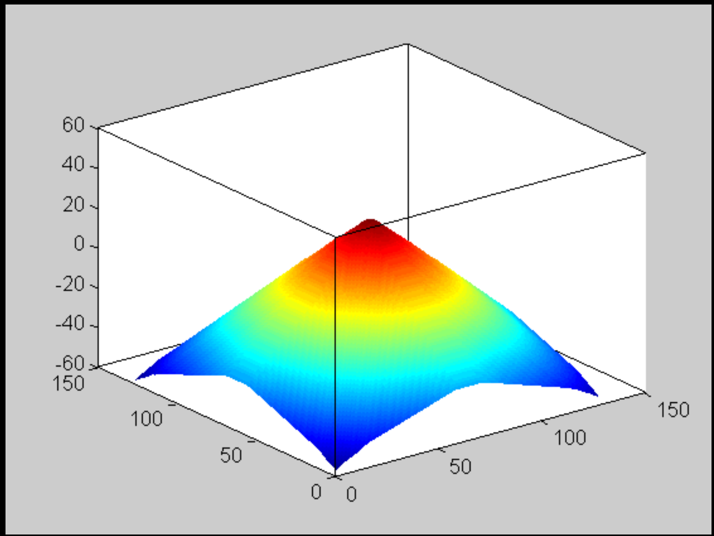
Proposed method

RBF-Level Set snake

- Prevent self-flattening



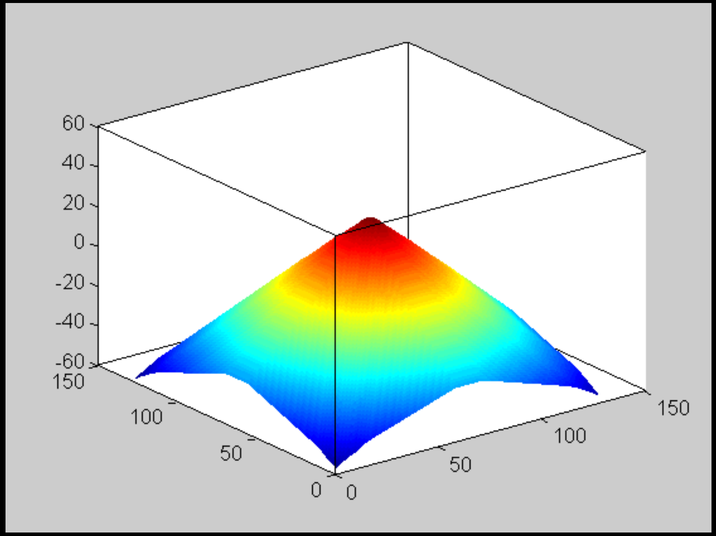
Non-normalised



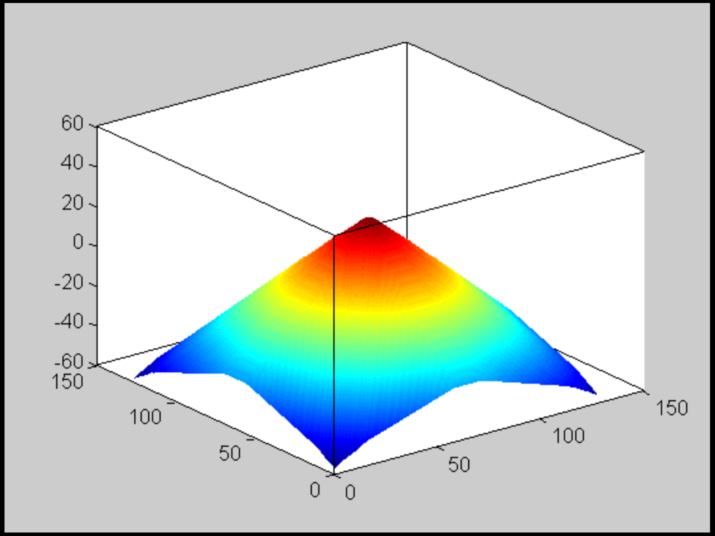
Normalised

RBF-Level Set snake

- Prevent self-flattening



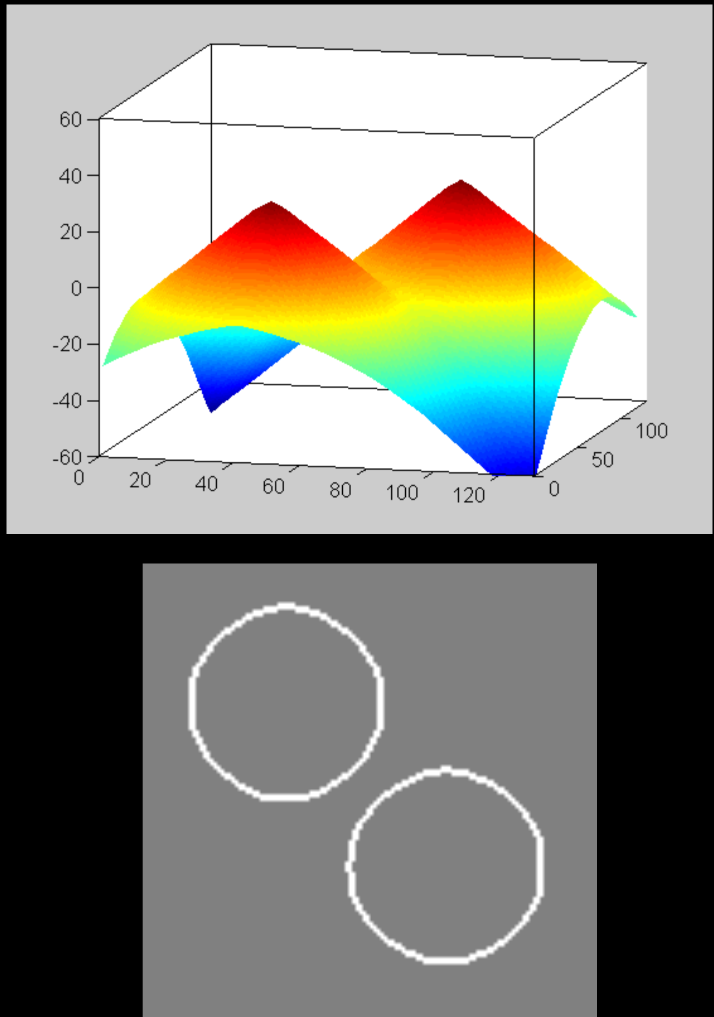
Non-normalised



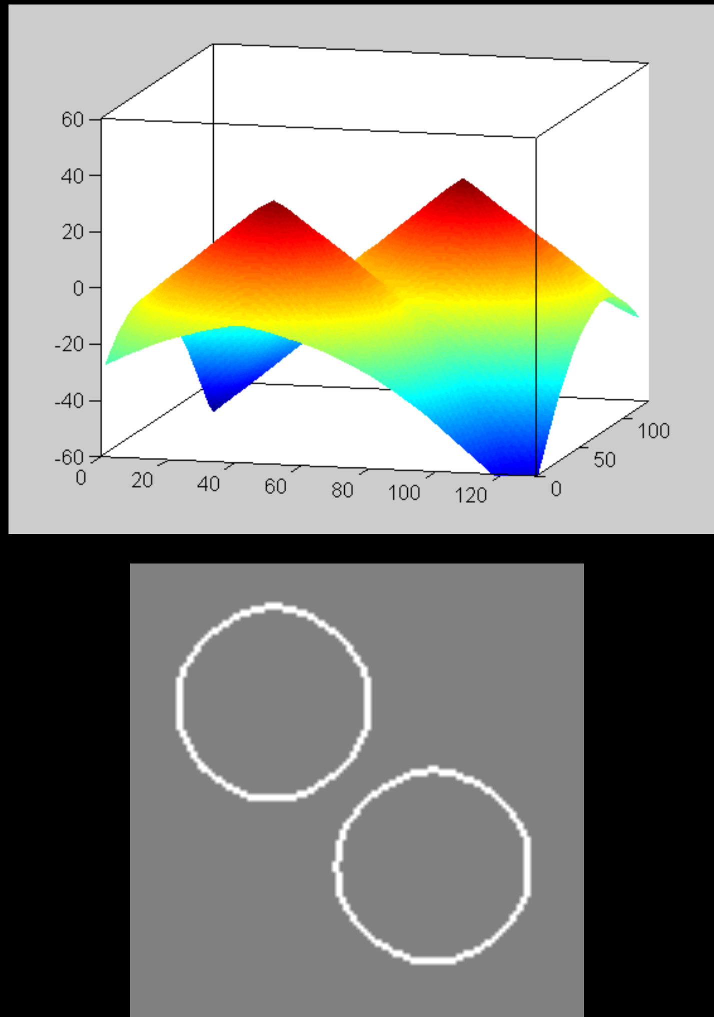
Normalised

RBF-Level Set snake

- Prevent self-flattening



Non-normalised



Normalised

RBF-Level Set snake

- Active modelling using RBF level set
  - A region based approach
  - Texem based modelling
  - Active contour formulation:

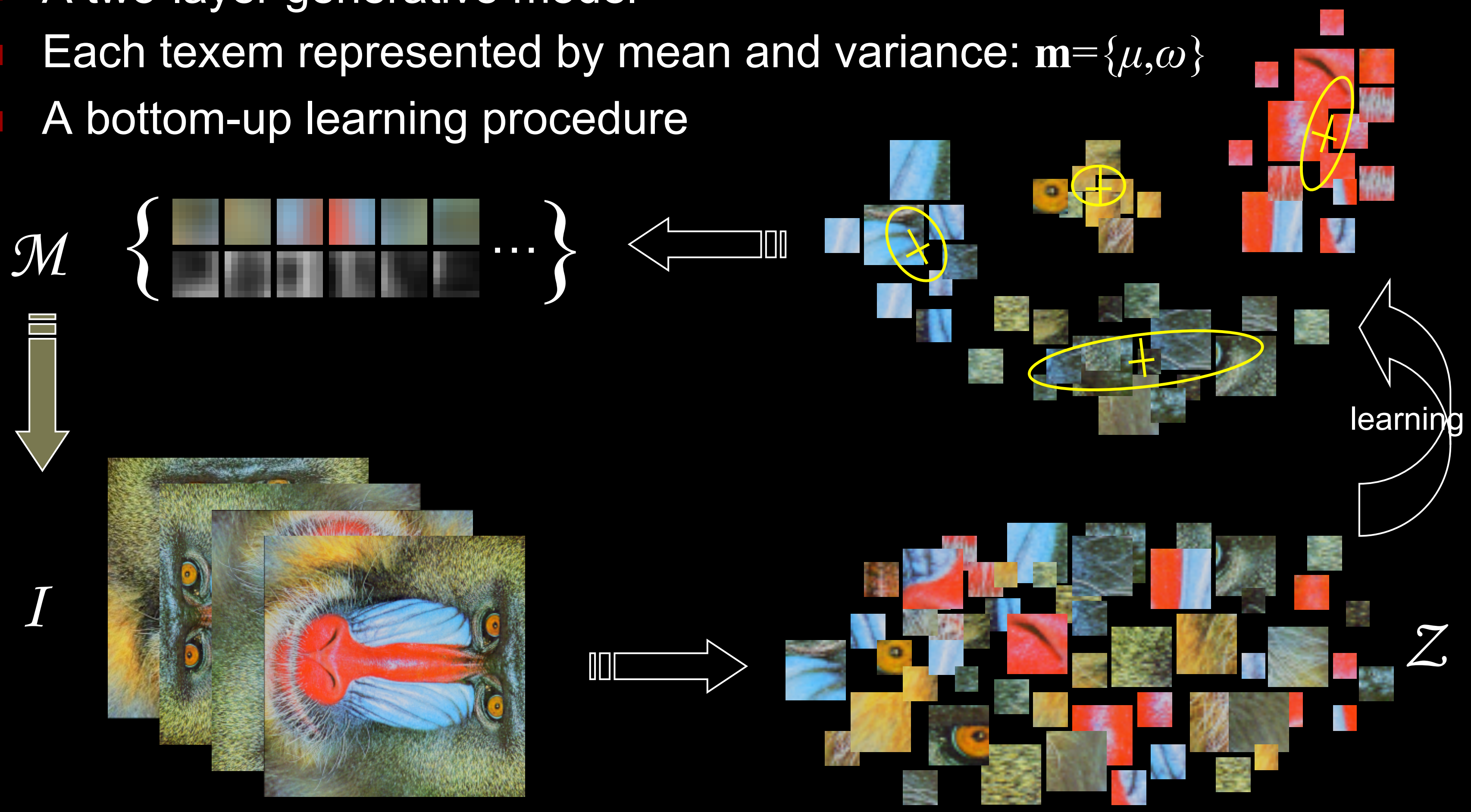
$$\frac{dC}{dt} = (u - \frac{1}{m})\mathcal{N}$$

    - m is the number of classes
    - 1/m is the average expectation of a class
    - u is the posterior of the class of interest
  - Level set representation:

$$\frac{\partial \Phi}{\partial t} = (u - \frac{1}{m})|\nabla \Phi|$$

RBF-Level Set snake

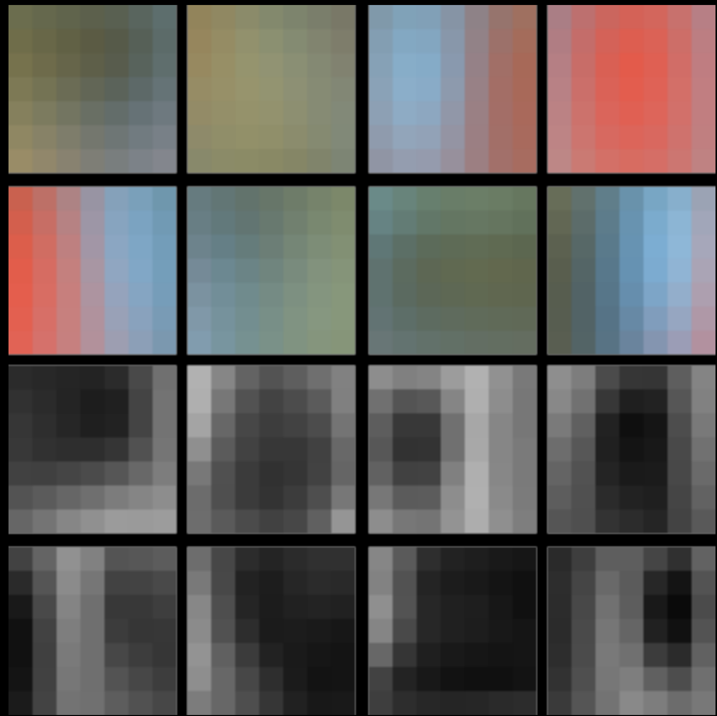
- Texems are image representations at various sizes that retain the texture or visual primitives of a given image.
- A two-layer generative model
- Each texem represented by mean and variance: $\mathbf{m}=\{\mu,\omega\}$
- A bottom-up learning procedure



Xie-Mirmehdi, *IEEE T-PAMI*, 29(8), 2007.

RBF-Level Set snake

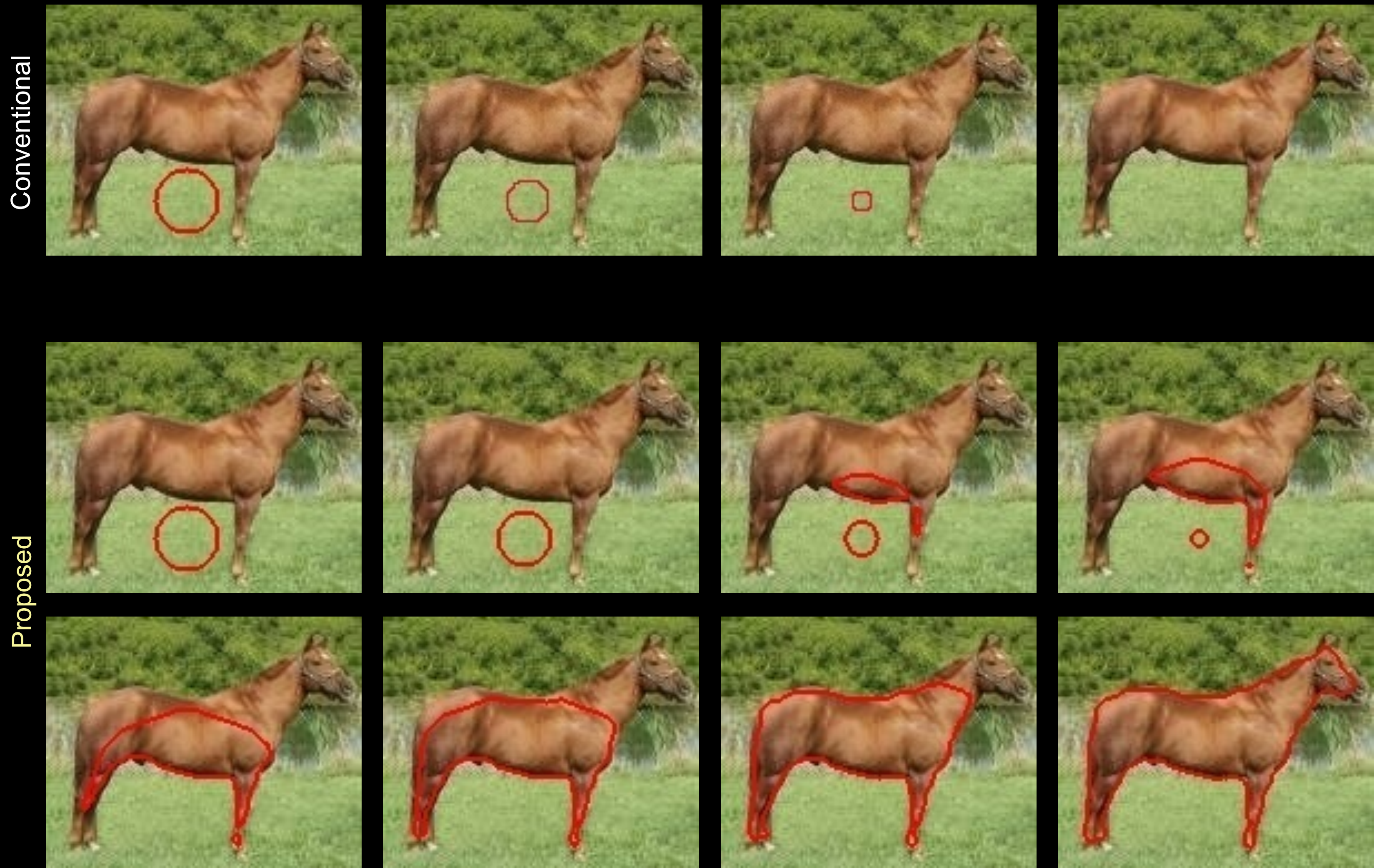
- Example learnt texems (7x7)



- Multiscale branch based texems
- Texem grouping for multi-modal regions

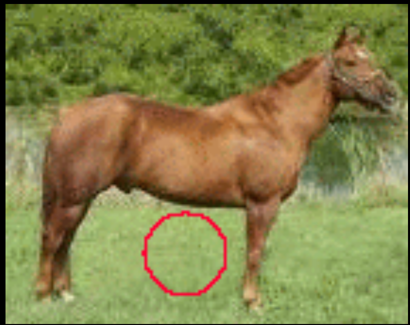
Xie-Mirmehdi, *IEEE T-PAMI*, 29(8), 2007.

RBF-Level Set snake

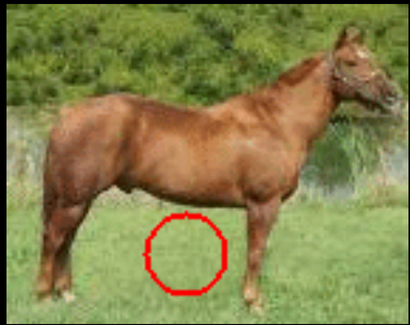


RBF-Level Set snake – new results

- On real images



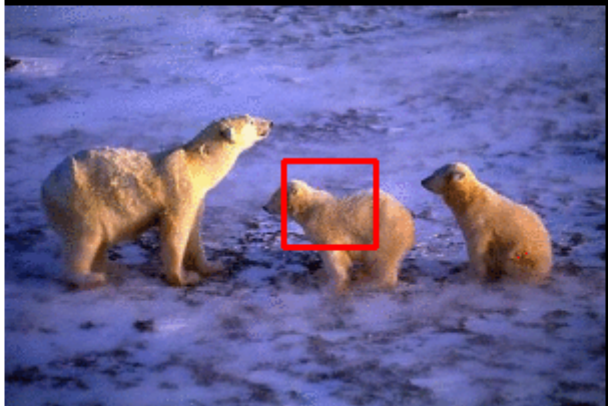
Conventional level set

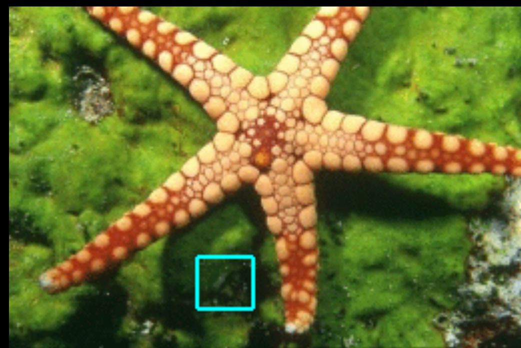


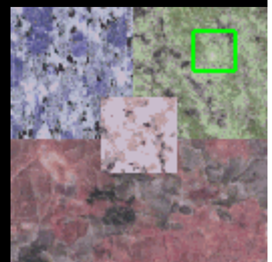
Proposed method

Conventional level set

Proposed method



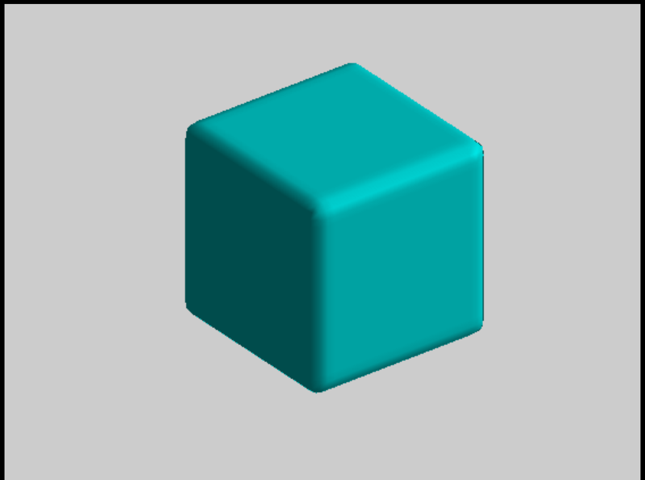




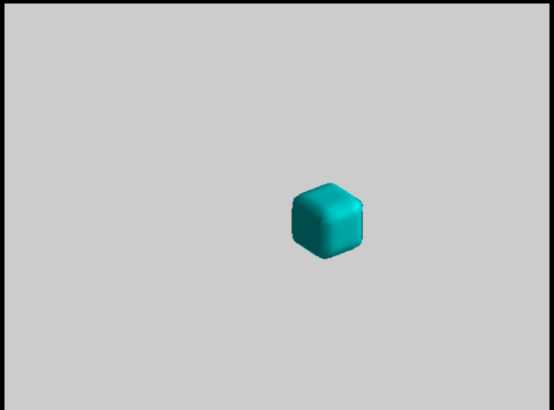
Proposed method

RBF-Level Set snake

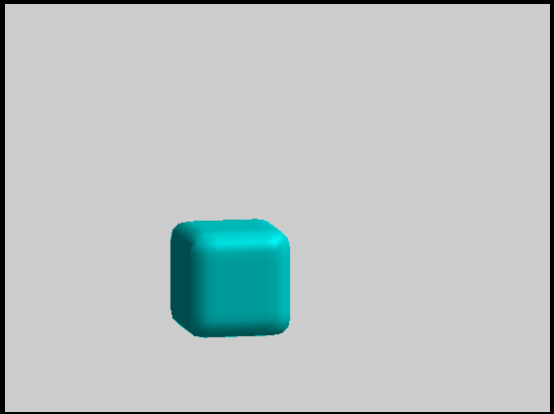
- Deformable modelling in 3D



Recover a hollow sphere



Initialised outside the target object



Complex geometry

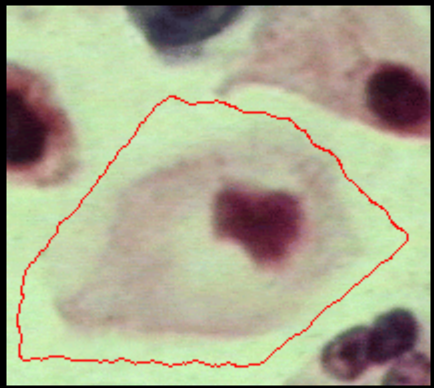
Xie & Mirmehdi, *Image & Vision Computing 2011 & BMVC* 2007.

- Hybrid Approach

Xie & Mirmehdi, *IEEE Trans. Image Processing*, 2004.

RAGS model

- Region-aided (RAGS) model
  - Bridge boundary and region-based techniques
  - Fusing global information to local boundary description
  - Improvements towards weak edges
  - More resilient to noise interference



Geodesic snake

GGVF snake

Proposed method

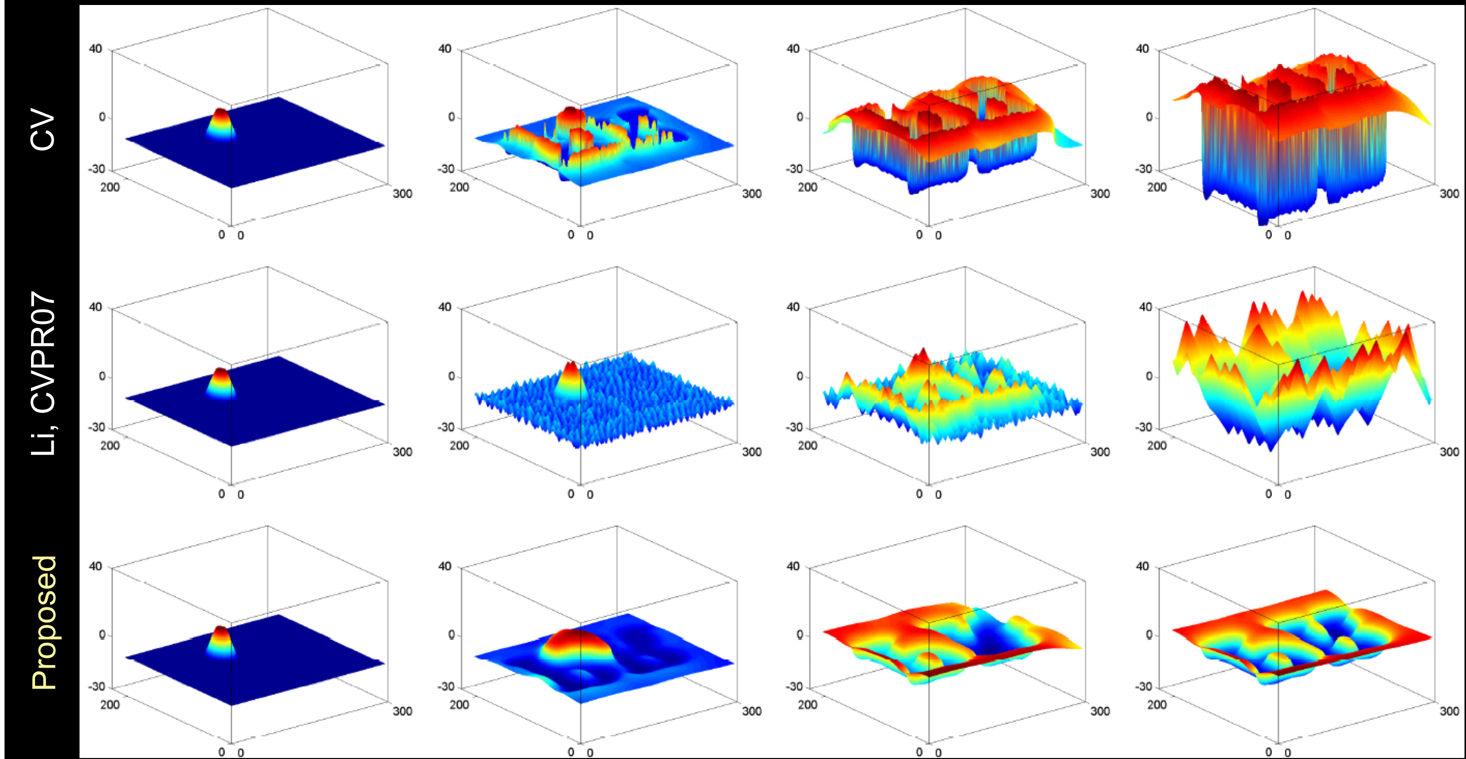
Xie & Mirmehdi, *IEEE Trans. Image Processing*, 2004.

- Invariant edge based active contouring

Xie, IEEE Trans. Image Processing, in press.

Invariant Active Contouring

- Intrinsic level set regularisation
- Initialisation invariant
- More complex topological changes



Xie, IEEE Trans. Image Processing 2011.

Conclusions

- Conclusions:
  - Edge based can be a viable alternative to regions based techniques
  - Initialisation invariance
  - Use priors whenever available
  - Level set based tracking is difficult
- Acknowledgement
  - Academics
    - M. Mirmehdi, I. Sazonov, P. Nithiarasu
  - PhD & RA
    - S. Yeo, R. Yang, J. Chiverton, H. Zhang
  - Clinicians
    - A. Ionescu, David Hall
  - Funder:
    - NISCHR, WORD, Leverhulme Trust
- Further information:
  - http://www.cs.swan.ac.uk/~csjason/snakes/
  - MAC Software: x.xie@swansea.ac.uk

Questions

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