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Image Segmentation for Image Guided Interventions

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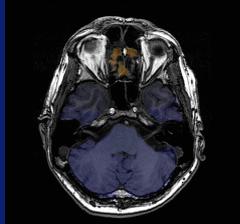
Delft University of Technology, Department of Imaging Science & Technology

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Segmentation

- Define objects in a dataset
- in order to
 - distinguish relevant and irrelevant data
 - quantitative measurements
 - visualization
- for image guided interventions
 - pre-operative planning
 - image guidance
 - per-operative updating of image guidance



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Segmentation techniques

- Low level
 - Pixel classification
 - Using intensities, gradients, texture
 - Grouping
- Physical- or Model- based
 - Snakes, deformable models
 - Level sets
 - Atlas-based segmentation
 - Active shape models (ASM) and Active appearance models (AAM)

Snakes

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$$C(s) = (x(s), y(s))$$

$$E = \int_0^1 [E_{\text{int}}(C(s)) + E_{\text{ext}}(C(s))] ds$$



- E_{int} is the internal energy at all points of the snake
- E_{ext} is the external energy formed by the external forces attracting the curve
- Objective: Find the curve that minimizes the energy functional

Snake optimization

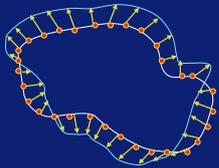
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- Euler Lagrange:

$$(\omega_1 C')' + (\omega_2 C'')' + F_{\text{int}} = 0$$

- (Local) minimum at steady state:

$$\frac{\partial C}{\partial t} = E'(C) = (\omega_1 C')' - (\omega_2 C'')' + F_{\text{int}}$$



Smoothness force

Image force

Snake advantages/disadvantages

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- Computationally efficient
- Flexible model, physically based
- Keeps initial shape (topology)
- May converge to local minimum
- Quite dependent on weighting parameters
- Numerical instability (may oscillate)
- Keeps initial shape (topology)
- Only constraints on smoothness of shape

Level sets: underlying idea

- Rather than evolving the curve/surface $C(s)$, embed the curve as a level set in a one-dimensional higher image:

E.g. $U(\vec{x}) = \pm d$

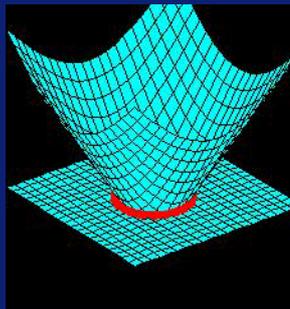
where d is the distance to the $C(s)$

- Evolve $C(s)$ implicitly by evolving $U(x)$

7	6	5	4	4	4	3	2	1	1	1	2	3	4	5
6	5	4	3	3	3	2	1	0	0	0	1	2	3	4
5	4	3	2	2	2	1	0	-1	-1	0	1	2	3	
4	3	2	1	1	1	0	-1	-2	-2	-1	0	1	2	
3	2	1	0	0	0	-1	-2	-3	-3	-2	-1	0	1	2
2	1	0	-1	-1	-1	-2	-3	-3	-2	-1	0	1	2	3
2	1	0	-1	-2	-2	-3	-3	-2	-1	0	1	2	3	4
2	1	0	-1	-2	-2	-2	-1	0	1	2	3	4	5	
3	2	1	0	-1	-1	-1	0	1	1	2	3	4	5	
4	3	2	1	0	0	0	1	1	1	0	1	2	3	4
5	4	3	2	1	1	1	1	0	1	2	3	4	5	
6	5	4	3	2	2	2	2	1	1	2	3	4	5	6

Level sets: change in topology

- Curves and surfaces are represented as level sets in a higher dimensional function



- This has important advantages:
 - Topological changes can be handled naturally

J. Sethian, Berkeley

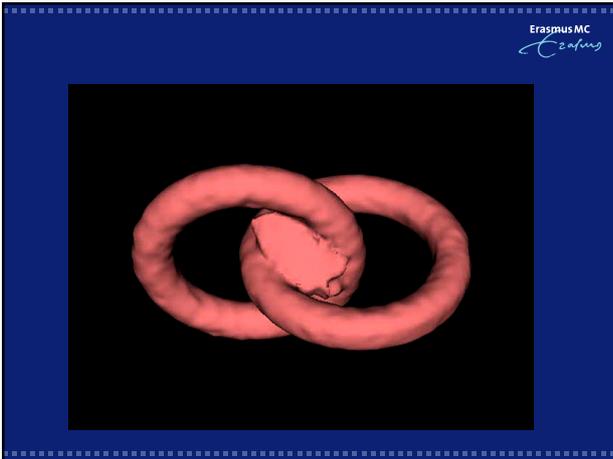
Implementation level sets

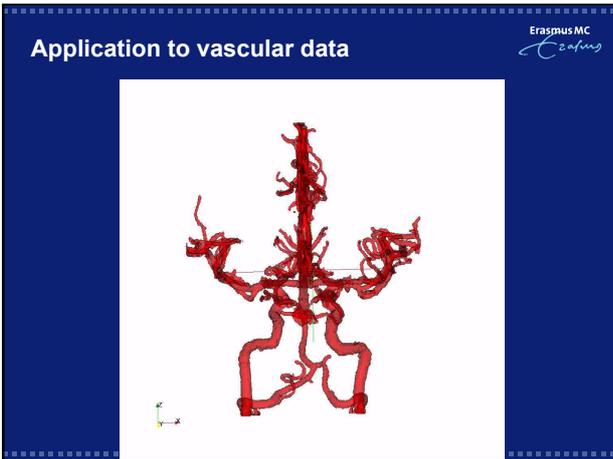
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2	1	0	-1	-2	-2	-2	-1	0	1	2	3	4	5	
3	2	1	0	-1	-1	-1	0	1	1	2	3	4	5	
4	3	2	1	0	0	0	-1	0	1	2	3	4	5	
5	4	3	2	1	1	1	1	0	1	2	3	4	5	
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7	6	5	4	4	4	3	2	1	1	1	2	3	4	5
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4	3	2	1	0	0	0	-1	0	1	2	3	4	5	
5	4	3	2	1	1	1	1	0	1	2	3	4	5	
6	5	4	3	2	2	2	2	1	1	2	3	4	5	6

$u(n)$

$u(n+1) = u(n) + \Delta t g \|\nabla u\|$





Advantages/disadvantage level sets

Advantages:

- Can change topology
- Flexible parameterization

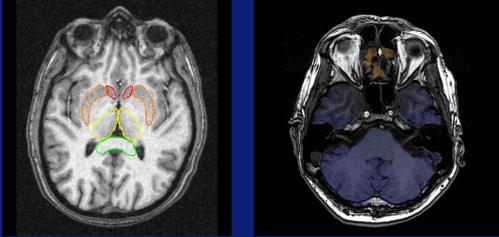
Disadvantages:

- Can change topology
- Computationally more expensive
- Only constraints on smoothness of shape

Atlas-based segmentation of individual neurostructures

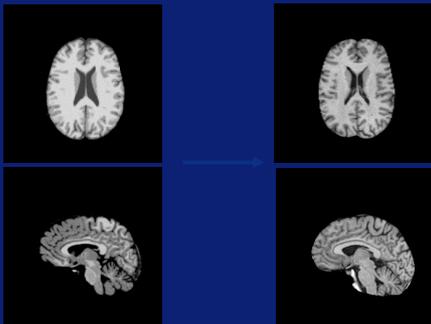


- Segmentation of multiple neurostructures



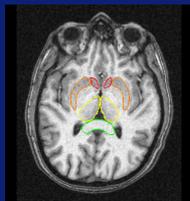
Labeled atlases

Automatic, atlas registration based training

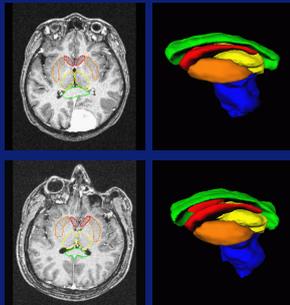


Courtesy: Rueckert et al., Imperial College

Atlas-based segmentation of individual neurostructures

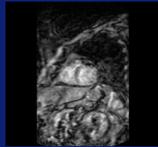
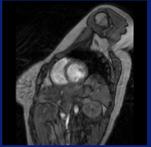
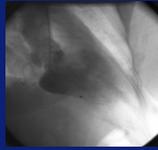
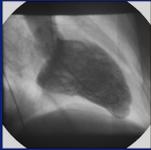


Labeled atlas



Active shape and appearance models: Integrating knowledge

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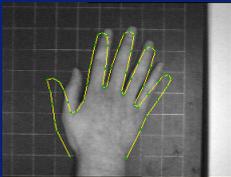



AAM/ASM slides
from Boudewijn
Lelieveldt, LUMC
Leiden

Active Shape Models

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- Introduced by Cootes and Taylor
- Matching local appearance



Movies: Tim Cootes



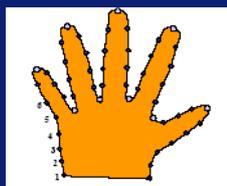
Point distribution models

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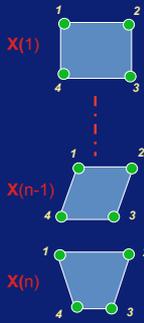

- Acquire manually drawn contours
- Define landmarks
- Define denser point correspondence



Cootes et al.



ASM construction: 2D example



- Shapes are represented by a vector of "landmarks" and their connectivity

$$\mathbf{x} = \{P1, P2, P3, P4\}^T$$

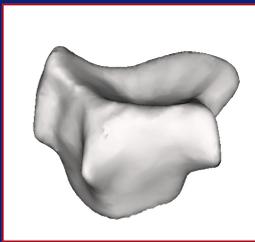
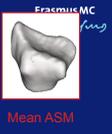
- The mean shape is the average vector

$$\bar{\mathbf{x}} = \frac{1}{n} \sum_{i=1}^n \mathbf{x}(i)$$

- Variability is computed by PCA of the covariance

$$\mathbf{S} = \frac{1}{n-1} \sum_{i=1}^n (\mathbf{x}(i) - \bar{\mathbf{x}})(\mathbf{x}(i) - \bar{\mathbf{x}})^T$$

Natural variation can be modeled



1st Mode

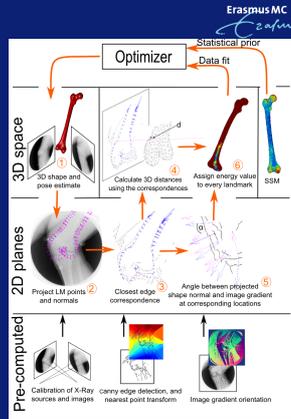
Mode is varied between -5σ and $+5\sigma$

Shape model fitting

Energy optimization, based on edges and orientation

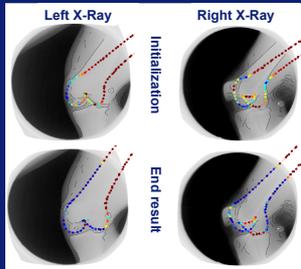
Two-stage approach:

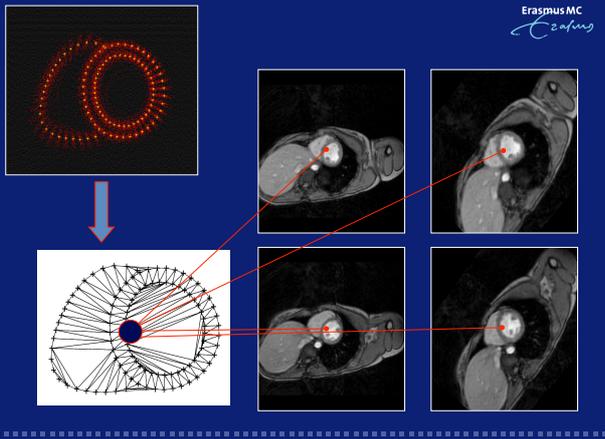
1. Pose estimation with mean shape
2. Simultaneous pose and shape optimization



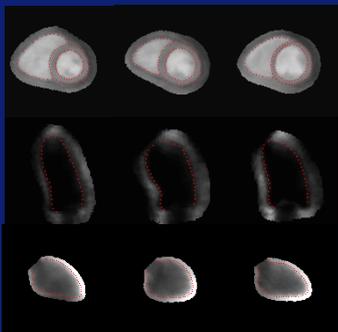
3D shape reconstruction

3D statistical shape model fitting to the Canny edge-map, and automatic selection of the relevant bony edges

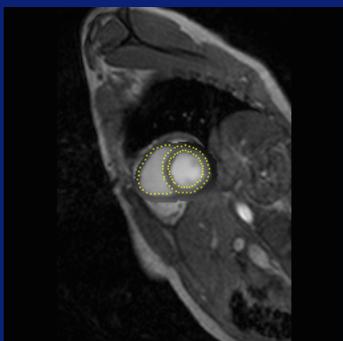




Intensity / shape modeling



Matching examples: cardiac MR



Matching examples: cardiac MR

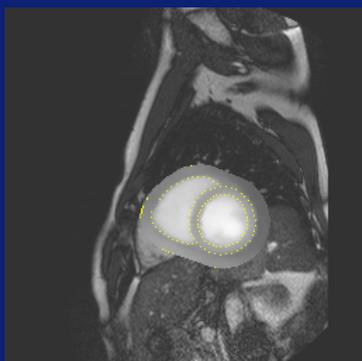


Image guided interventions

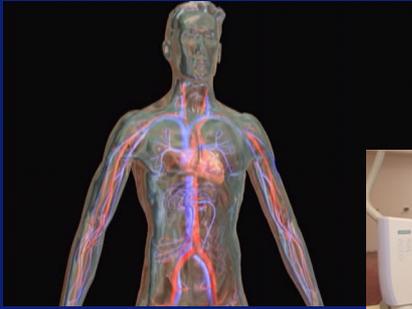


- Objective
 - Improve visual feedback by bringing 3D images of diagnostic quality to the heart catheterisation room
- Visual feedback from
 - CT, IVUS, other modalities
- Challenges
 - 2D/3D registration
 - Motion modeling
 - Vessel segmentation



Navigation and guide wire steering

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Courtesy: Stereotaxis

Preoperative imaging

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Computed tomography (CT)

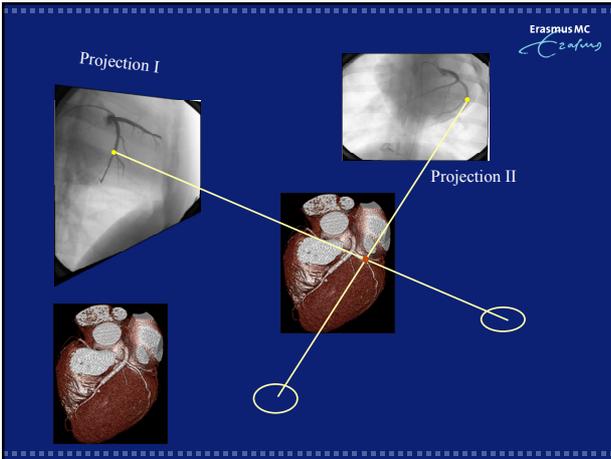


Courtesy Nico Mollet, Radiology, Erasmus MC

4D Coronary artery segmentation

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Discussion

- Segmentation crucial in pre-operative planning and image guidance
- Level set segmentation suitable for complex shapes and shapes with unknown (or deforming) topology
- Shape models (AAM/ASM) suitable for per-operative updating

Acknowledgements

- Boudewijn Lelieveldt (slides on ASM/AAM)
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