An overview of segmentation algorithms in medical imaging

Hervé Delingette

Herve.Delingette@inria.fr

Overview

- (Short) Introduction to Medical Imagery
- Overview of image segmentation techniques
  - Different types of segmentation methods
  - Thresholding/classification
  - Deformable Models methods
- Limitations and perspectives

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Medical Imaging

Roentgen, 1895

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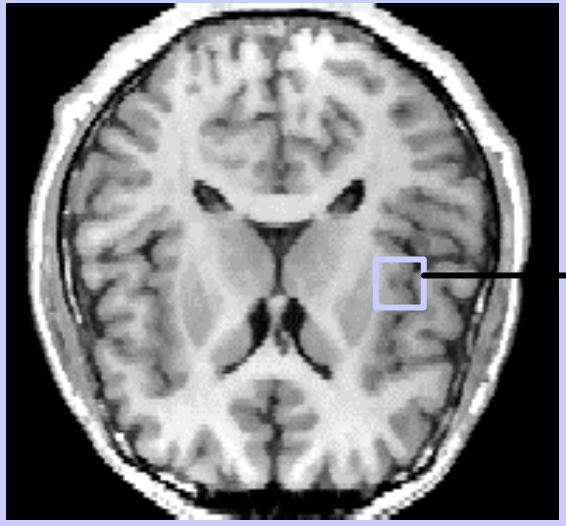
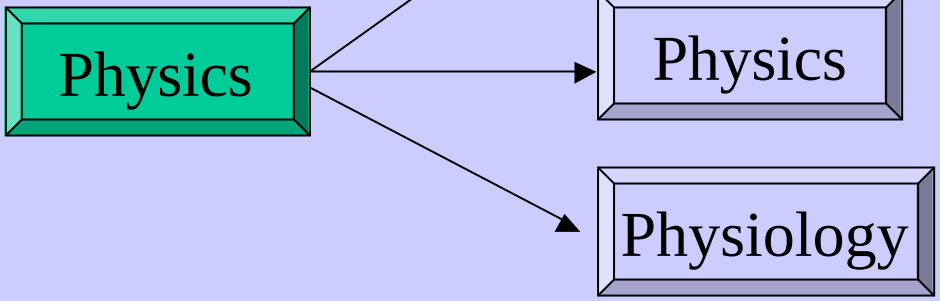
Characteristics of medical images (1)

Intensity values are related to physical tissue characteristics which in turn may relate to a physiological phenomenon





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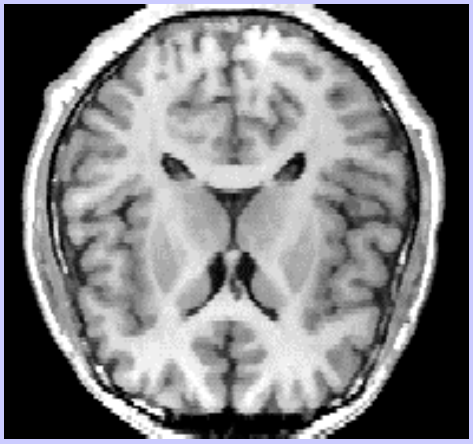
Main Imaging Modalities

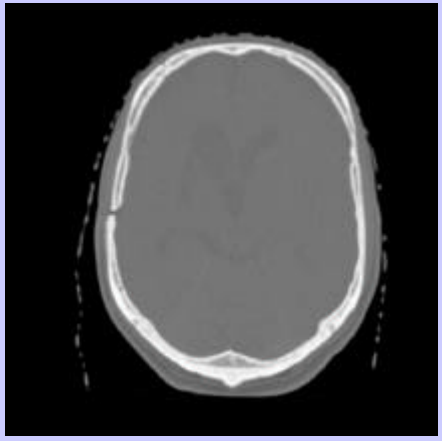
MRI

Density and structure of Protons



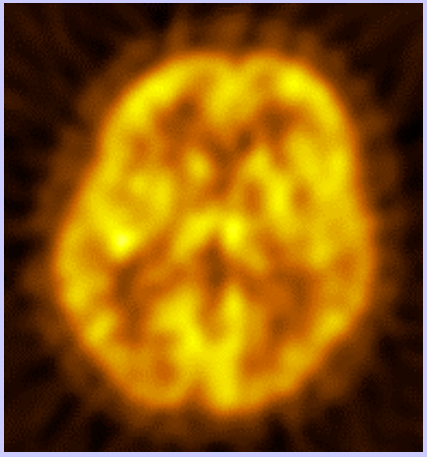
CT-Scanner

Density of X-Ray absorption



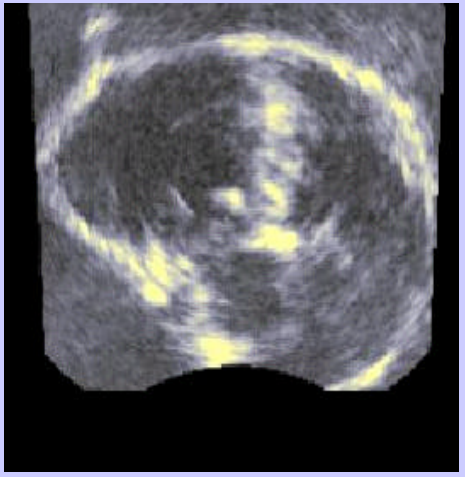
Scintigraphy

Density of injected isotopes



Ultrasound

Variations of Acoustic Impedance



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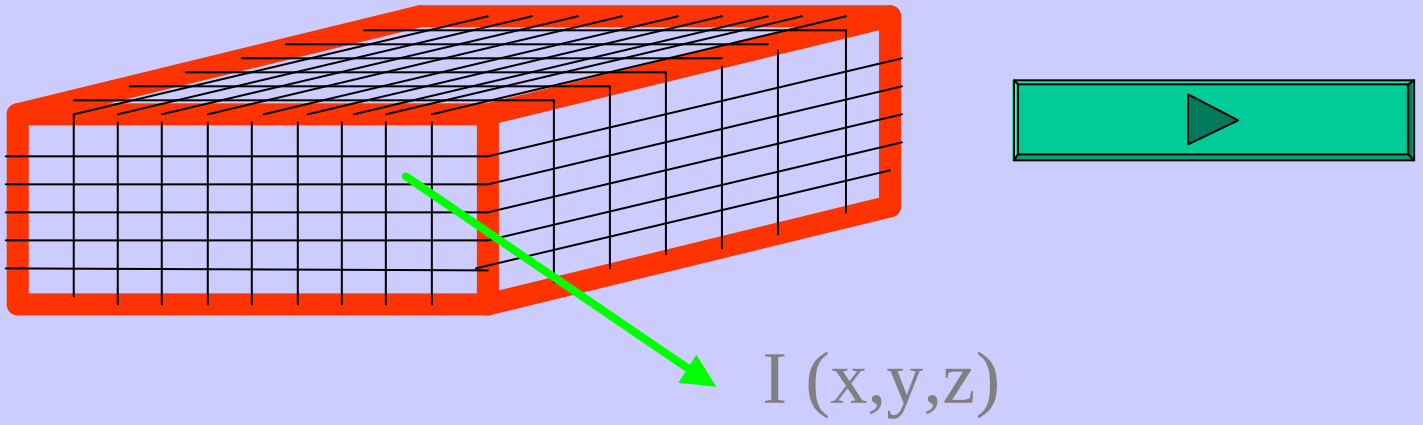
Characteristics of medical images (2)

- Very often medical images are volumetric

Voxel Representation



- 3D Image reconstructed from projections with computed tomography algorithms

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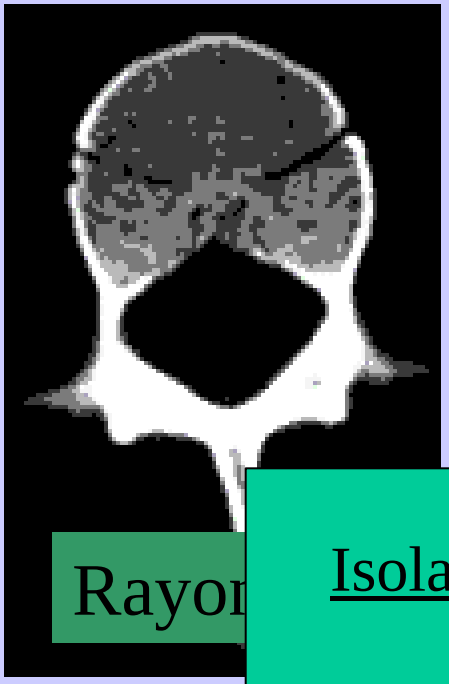
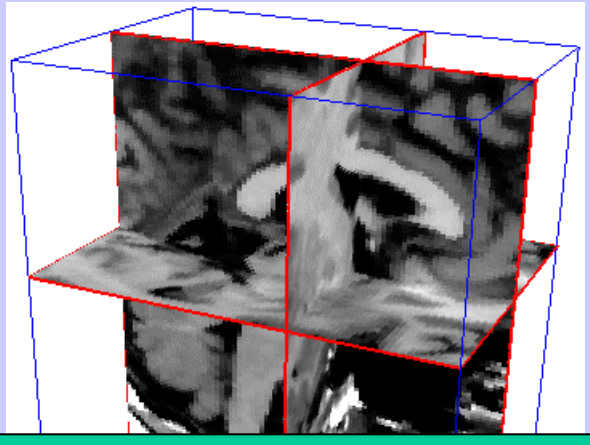
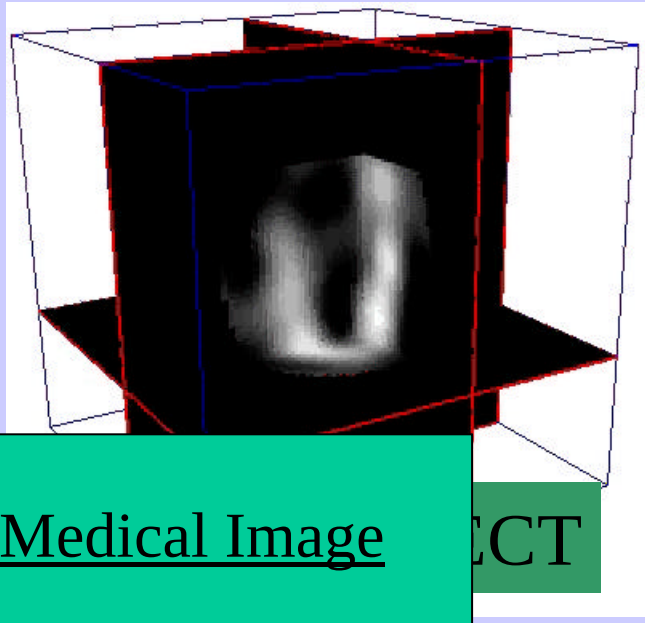
Image Segmentation



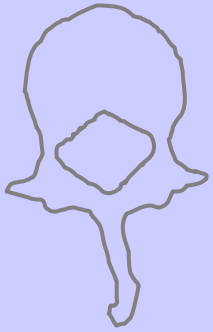


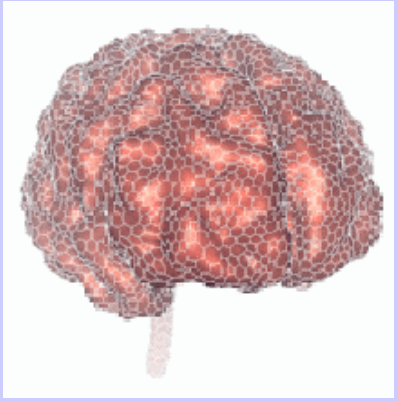


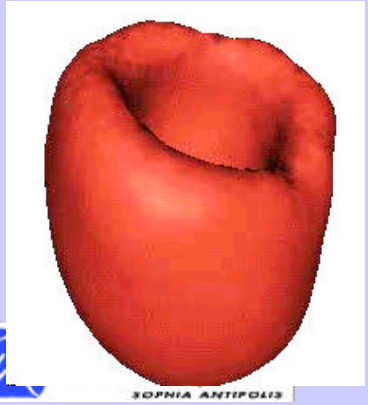
Rayon ECT

Isolate a Region of Interest in a Medical Image

2D 3D 4D (3D+T)







Segmentation Task

- Huge number of available algorithms
- Possible classifications :
  - Generic vs task-oriented
  - Bottom-up vs Top-down approaches
  - Boundary vs Region approaches
  - Explicit vs Implicit A priori knowledge

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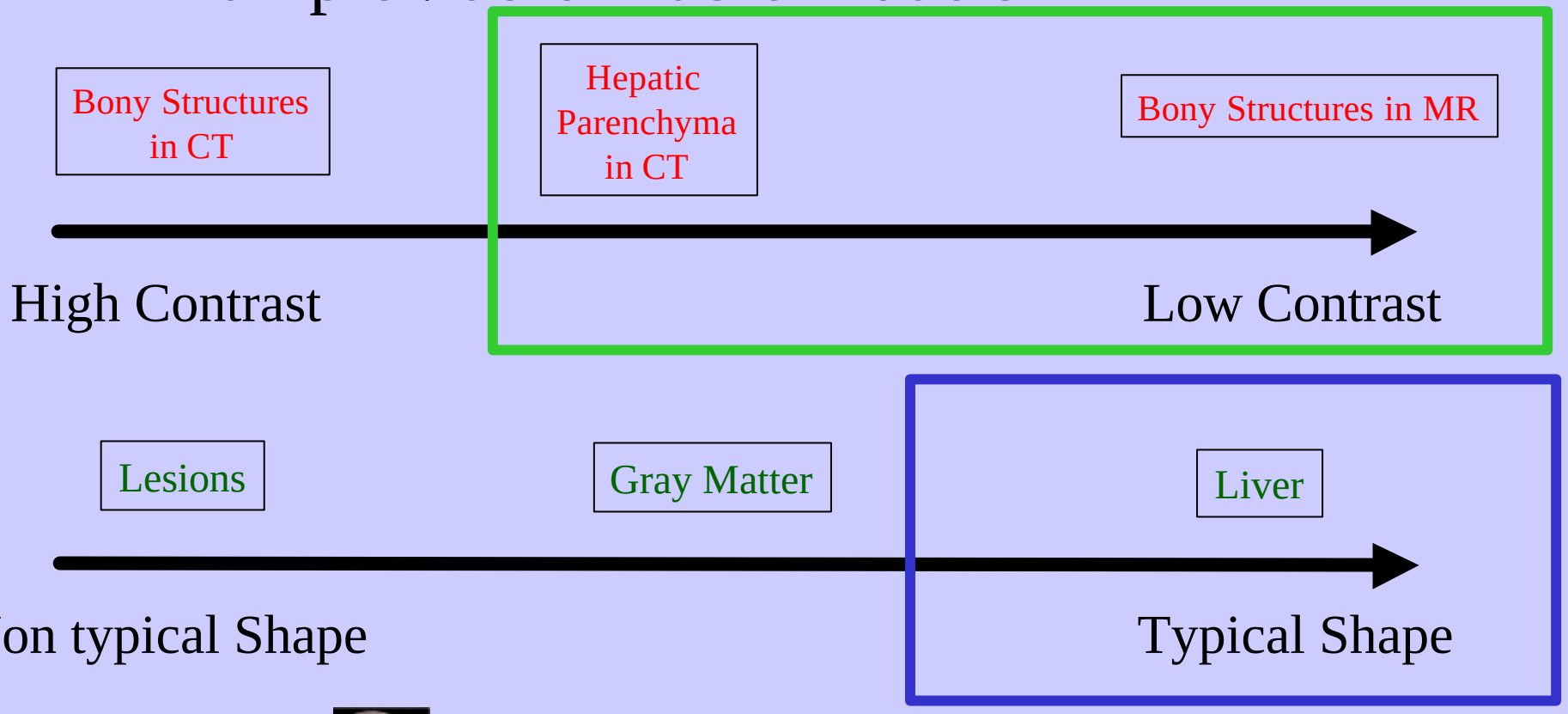
No Universal Segmentation Algorithm

- A segmentation algorithm has a limited range of application
- Example : deformable models



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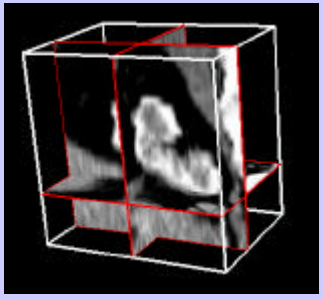
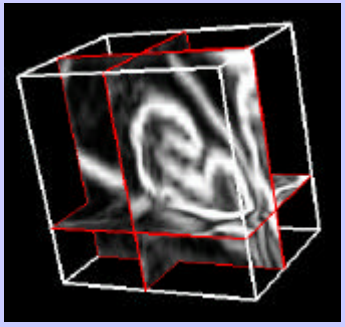
Bottom-up Approach

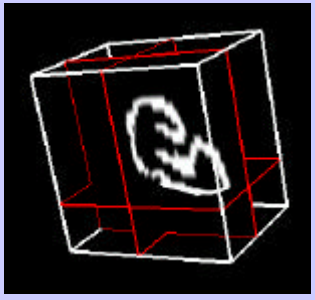
Medical Image



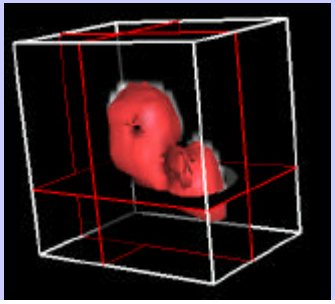
Feature Extraction

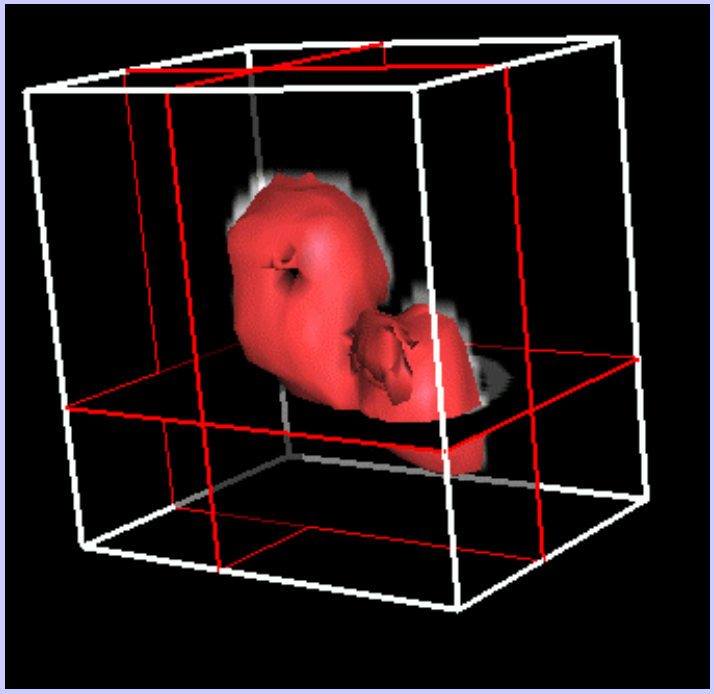


Feature Grouping



Region/Boundary Extraction





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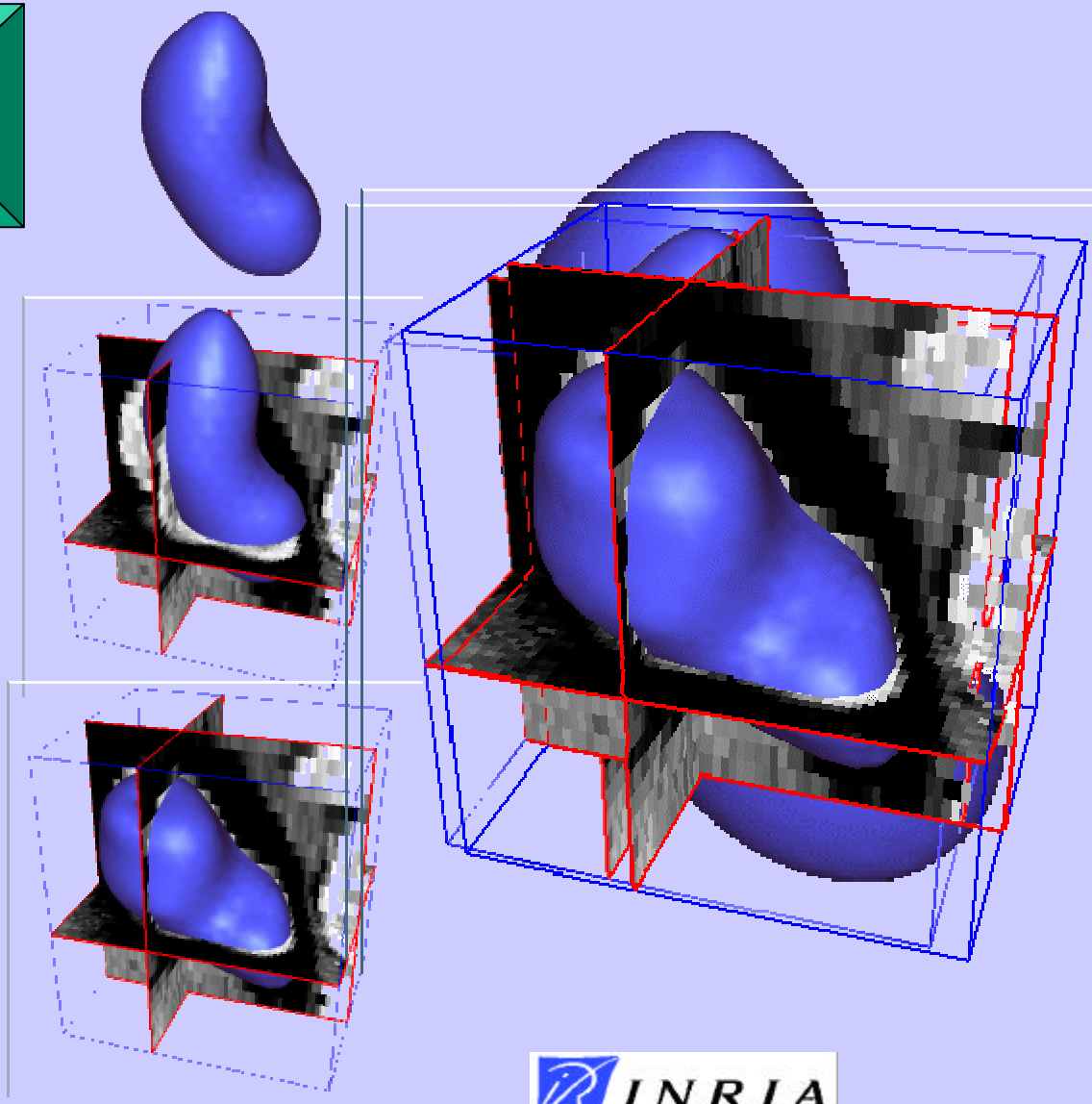
Top-down approach

Model Construction :
Shape and Appearance

Model Initialisation

Model Matching



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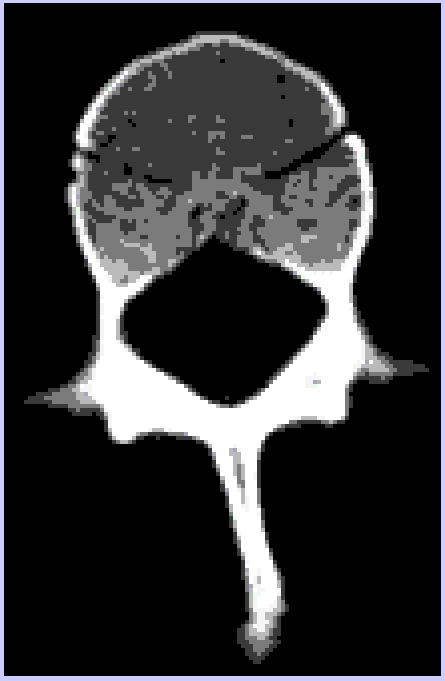
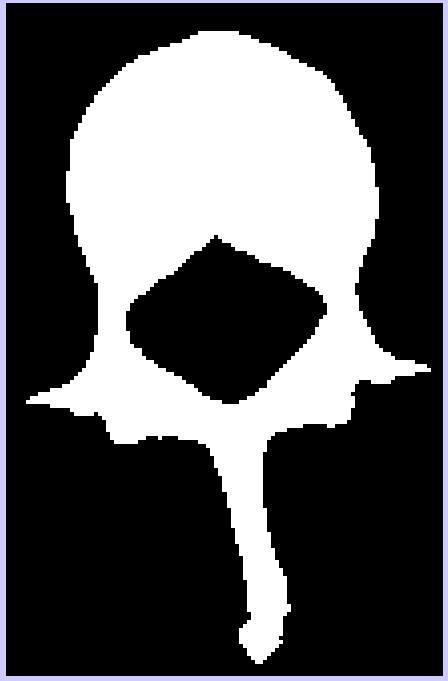
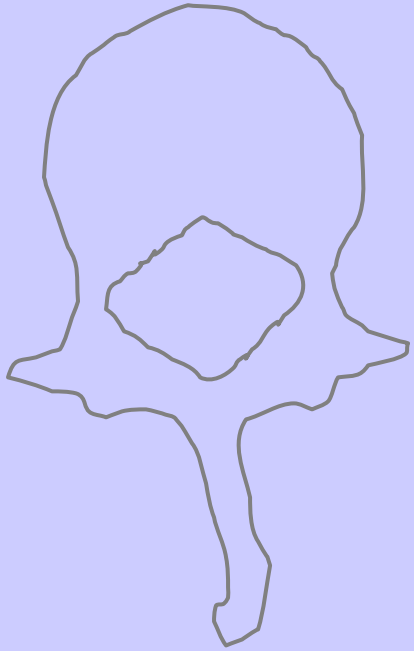
Region vs Boundary Methods



Image



Region-based segmentation



Boundary-based segmentation

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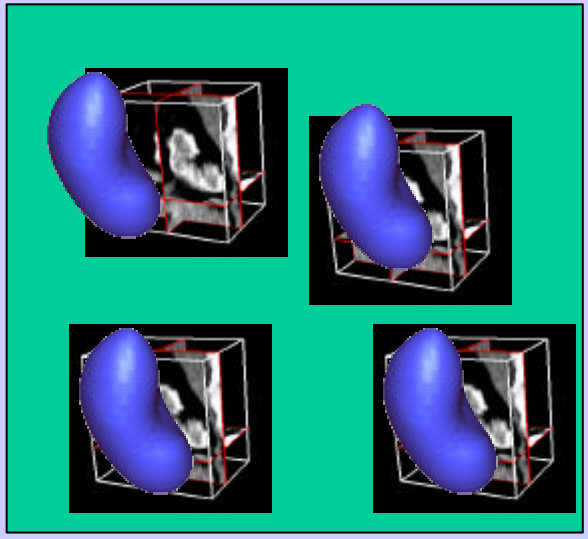
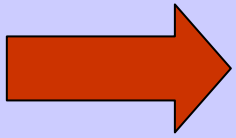
Computational vs Explicit A priori knowledge

- A priori knowledge about the structure to segment is the key to enhance robustness
- Computational knowledge : statistical analysis





Statistical classifier

Neural Networks

Principal Component Analysis

…..

Image + structure Database

Training

Explicit knowledge

- Explicit knowledge : expert system
  - Define rules of delineation from expert
  - Translate predicate into high/low level image processing
  - Combine rules in a probabilistic framework

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Two Segmentation Methods

Focus on 2 segmentation methods :

- **Bottom-up** : Thresholding /Classification
- **Top-down** :3D and 4D deformable models

	Thresholding /Classification	Deformable Models	Markov Random Field
Shape Information	None	Important	local
Intensity Information	Essential	Important	Important
Boundary / Region	Region	Boundary	Region

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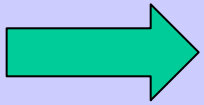
Thresholding and classification

- Basic idea :

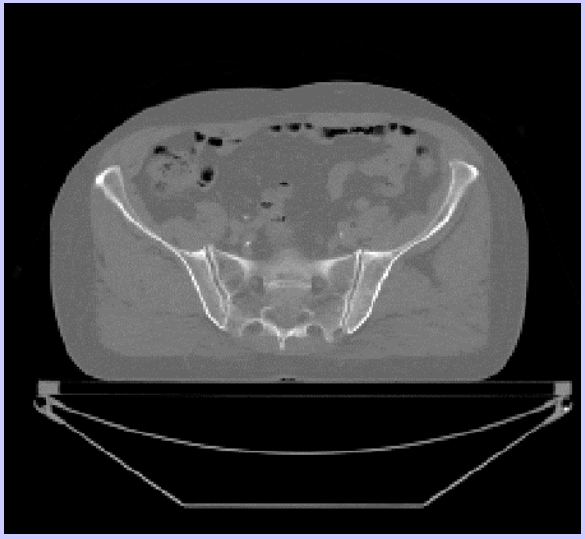
  a structure is uniquely characterized by its intensity values in the image



Valid for highly contrasted structures

- Basic thresholding algorithm :
  - Thresholding between two grey-levels (windowing)
  - Mathematical morphology operations [Serra82]
    - Erosion and Dilation
    - Closure and Opening
    - Connected components extraction

Thresholding
Example (1)



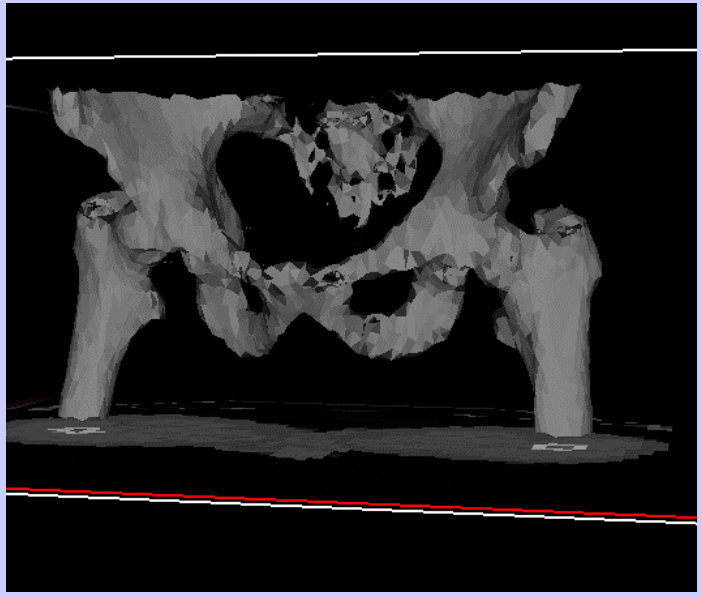
Interactive thresholding

Abdominal CT scan Image

Thresholded Image

Thresholding
Example (2)

Isosurface



After mathematical morphology operations

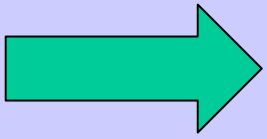
Isosurfacing (Marching Cube)

+ decimation algorithm

Limitation of thresholding

Thresholding :

- Choice of threshold can be computed from grey-level histogram
- Does not assume any spatial correlation of voxel intensity
- Does not take into account the effect of **partial volume effect** (PVE)



Use of classification methods

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Deformable Model Segmentation

- A deformable model is a container of prior knowledge about the Shape and Appearance of anatomical structures in medical images
- Two levels of prior knowledge :

	Weak Prior	StrongPrior
Shape	C1 or C2 continuity constraint Initialize with generic shape (sphere, …)	Shape continuity constraint Initialize with mean shape
Appearance	Use gradient, edge or region information	Use intensity profile or block matching information

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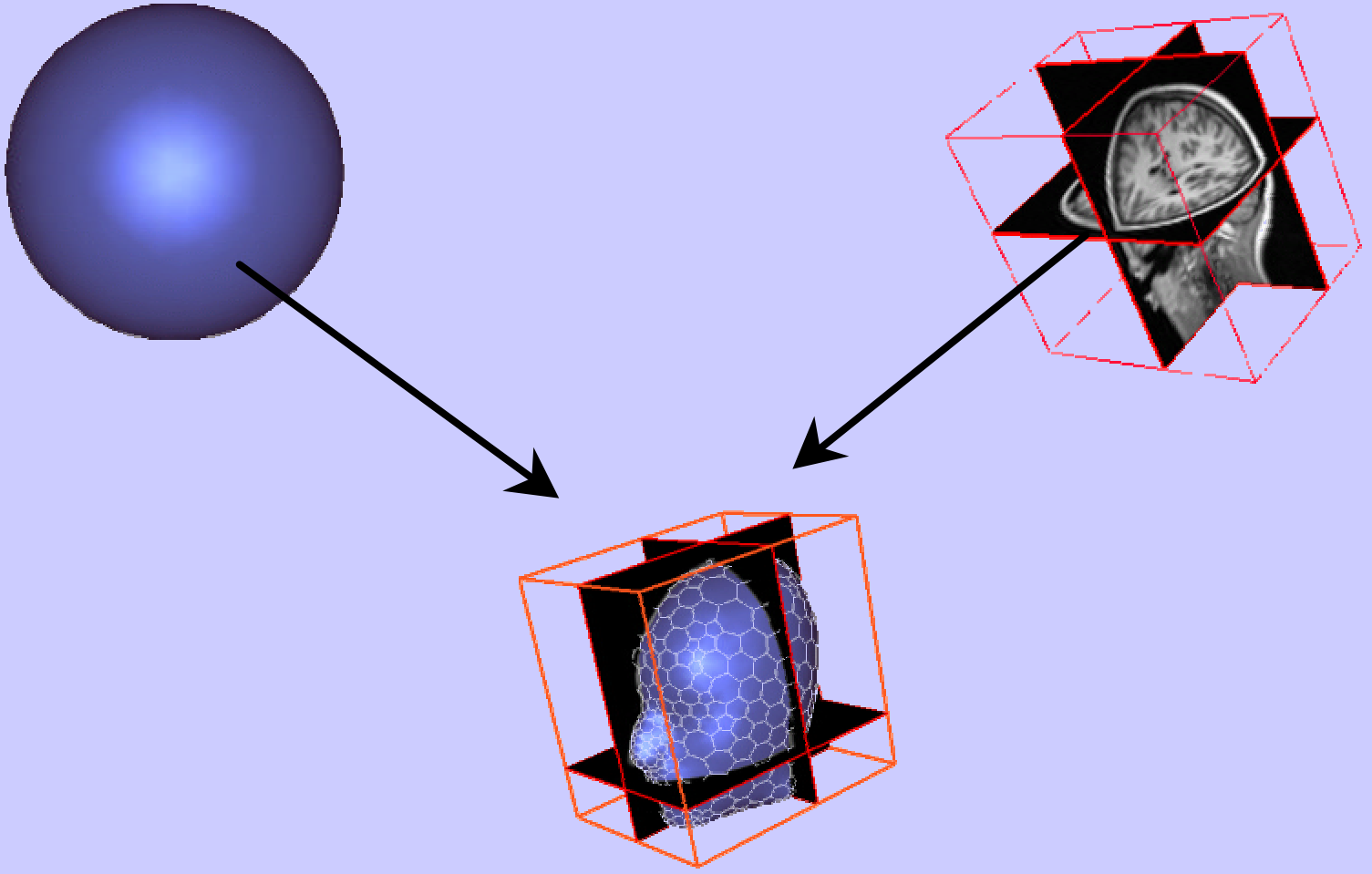
Weak prior deformable model



- Valid for highly contrasted structrures
- May require user interaction

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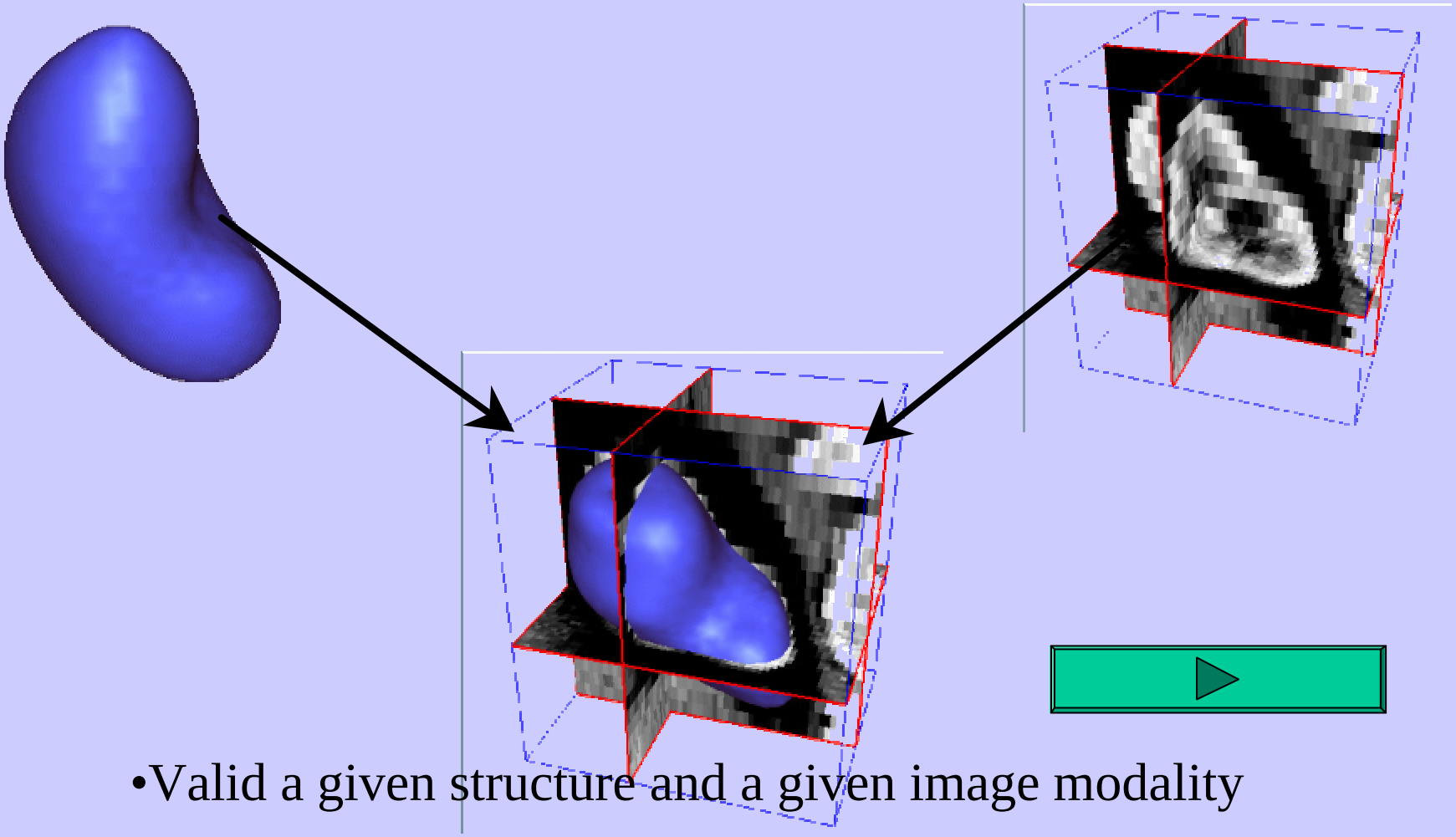
Strong prior deformable model



- Valid a given structure and a given image modality
- More robust except with abnormal shapes

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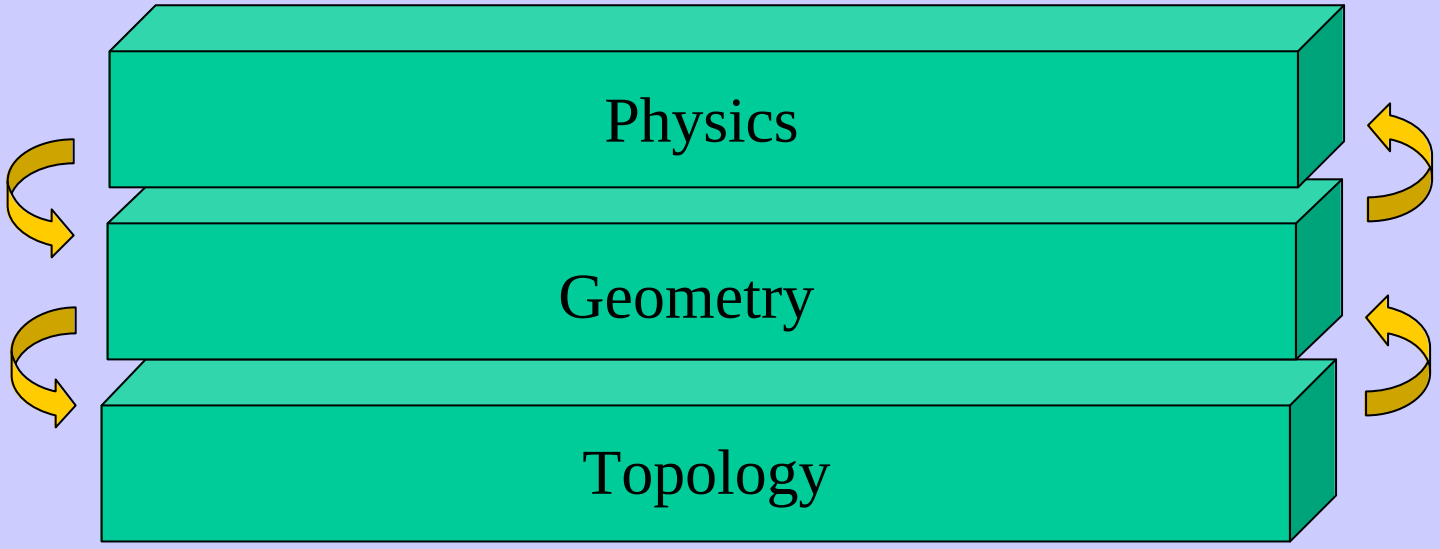
Deformable Models

- 3 different aspects of deformable models



- Each aspect should be as independent as possible

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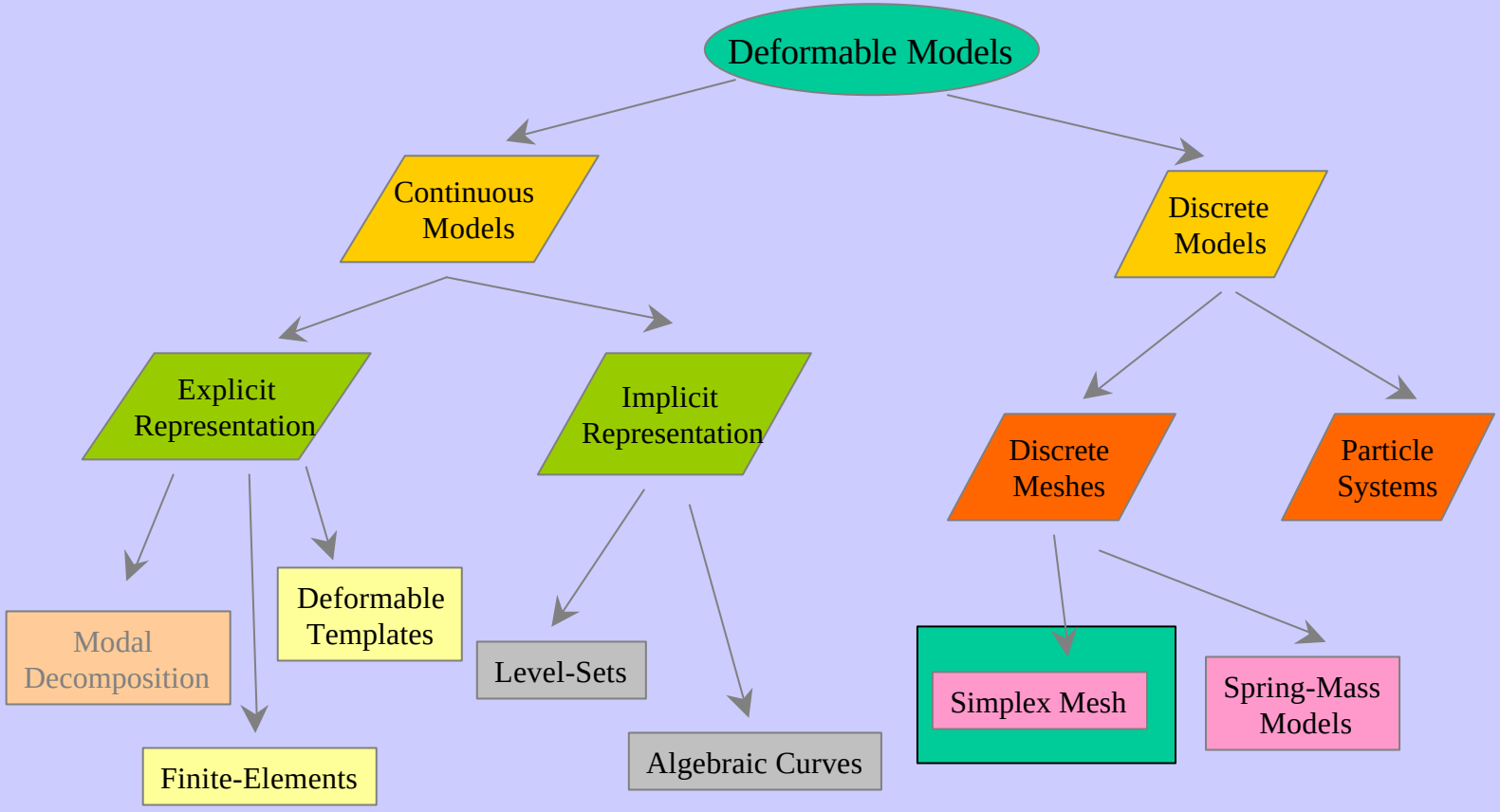
Deformable Model Geometry (3)



[Montagnat2001]

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Discrete Meshes

- Avantages :
  - Avoid the parametrisation problem
  - No restriction on topology
  - Limits the number of parameters -> increased efficiency
  - Leads to “intrinsic”deformation
- Limits :
  - Geometric information not available everywhere

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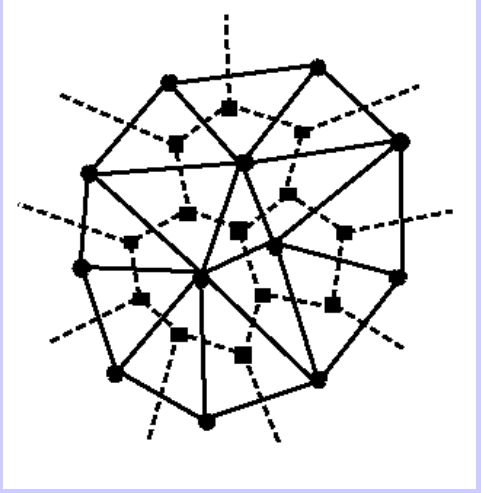
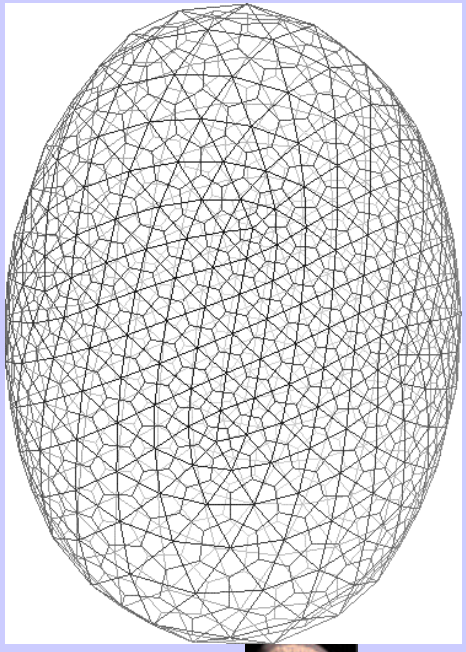
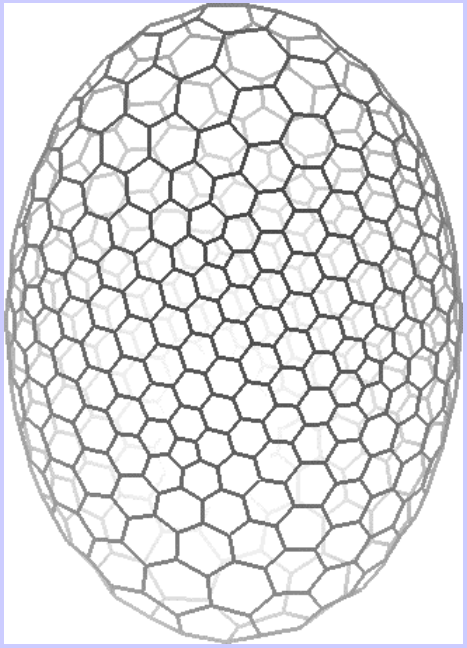
Simplex Meshes (1)

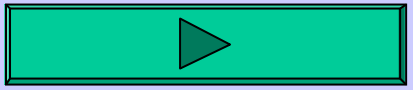
- Topology
- Follow Euler Relation :

  V-E+F= 2(1-g)



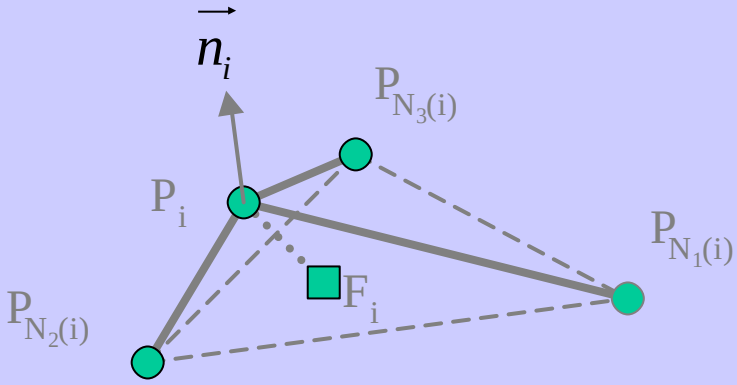






Simplex Meshes (4)

- Geometric Definitions :
  - Normal at vertices



Normal

$$\vec{n}_i = (P_{N_1(i)}, P_{N_2(i)}, P_{N_3(i)})^{\perp}$$

Metrics Parameters

$$F_i = e_i^1 P_{N_1(i)} + e_i^2 P_{N_2(i)} + e_i^3 P_{N_3(i)}$$

$$e_i^1 + e_i^2 + e_i^3 = 1$$

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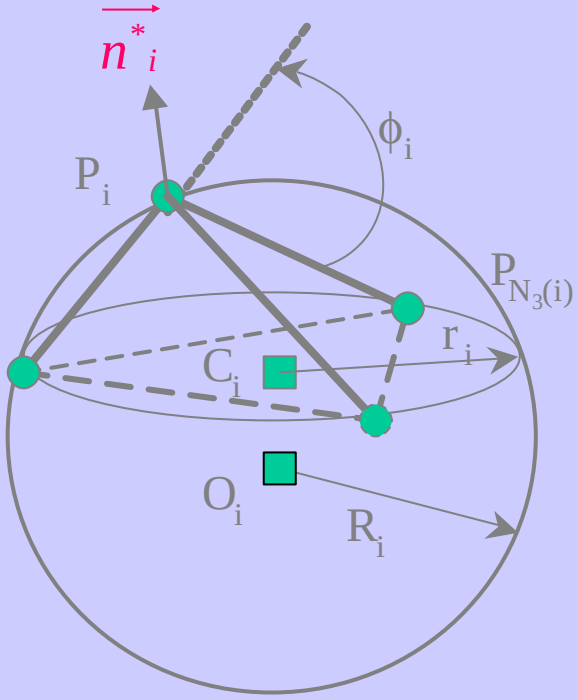
Simplex Meshes (5)

- Definition of curvature



Conjugated Normal $\overrightarrow{n^*}_i$

Simplex Angle f_i

Definition of discrete curvature

$$H_i = \frac{1}{R_i} = \frac{\sin f_i}{r_i}$$

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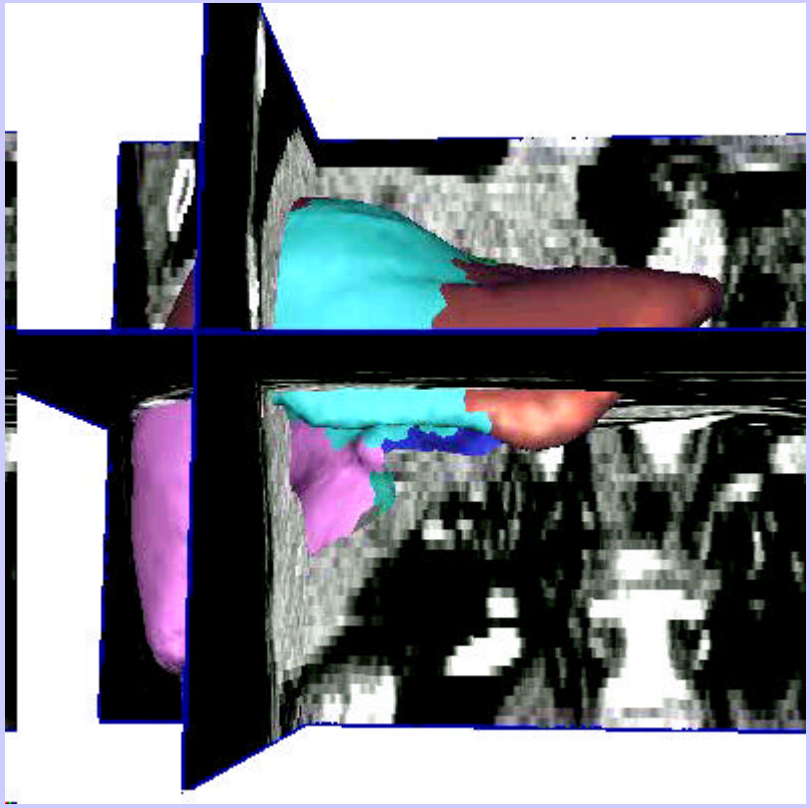
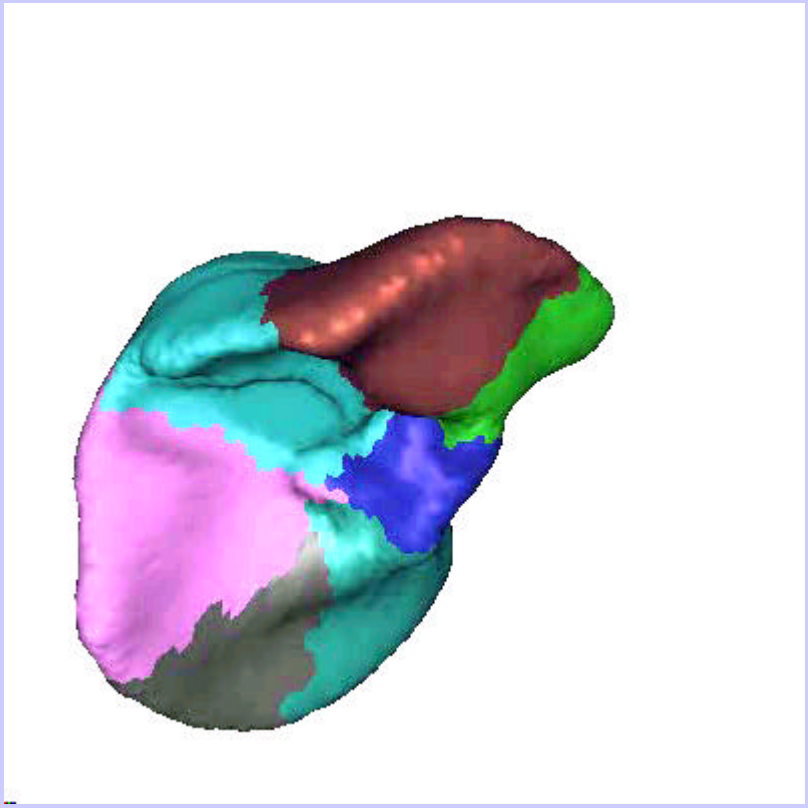
Segmentation: liver

CT scan image of the abdomen





Time of convergence : 2 mn 12 s

Extraction of Couinaud segments

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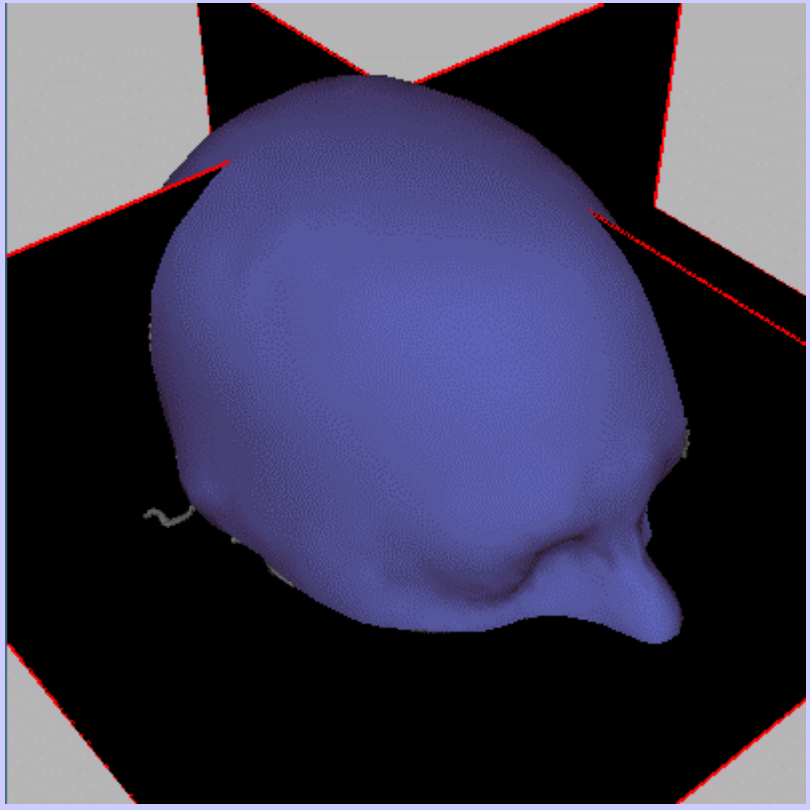
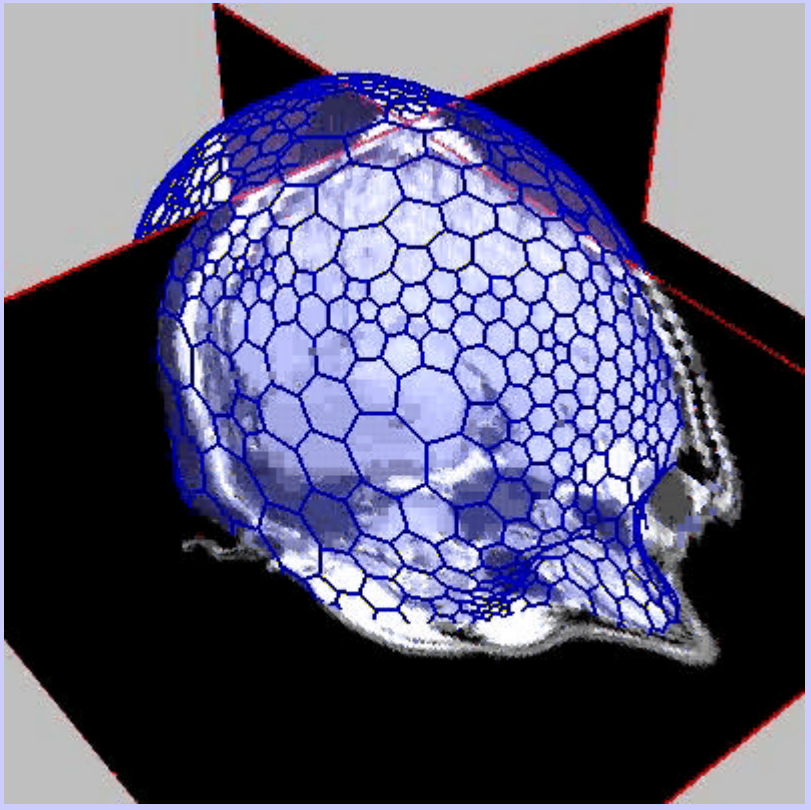
Recalage multimodal CT-IRM T1



CT



IRM - T1

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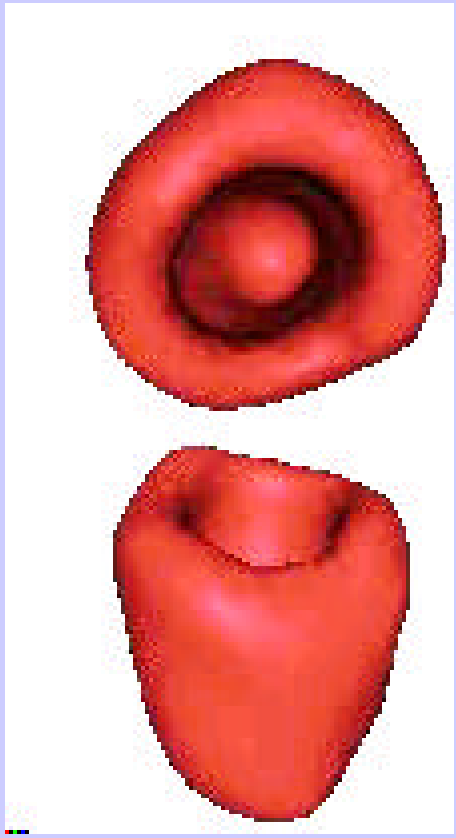
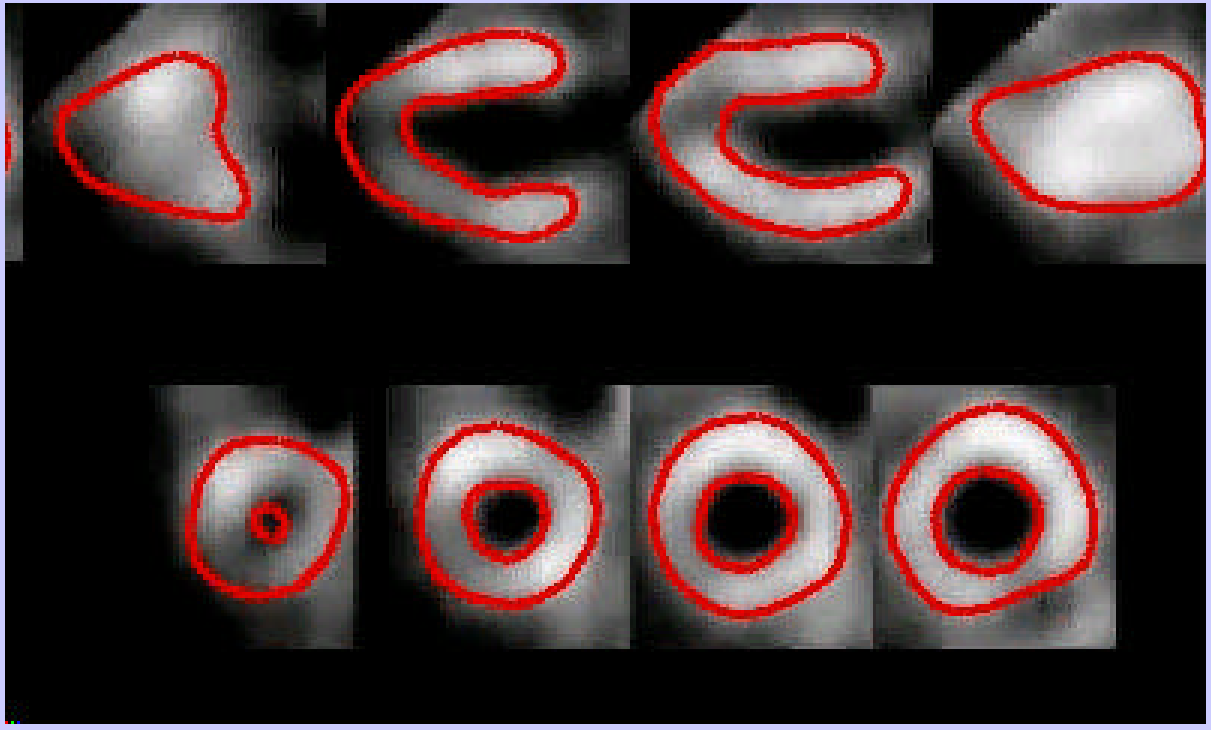
Deformed model

Pathological case





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Main difficulties in segmentation algorithms

- Ill-posed problem
  - Boundaries between structures may not be seen on images
  - Strong variability between experts for validation
- Most algorithms are dependent on the acquisition protocole and image modality
- Robustness required in the presence of pathologies

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Use of Image Segmentation Software

- Segmentation software is not widely available in current medical practice :
  - Diagnosis (low demand):
    - Currently almost no quantitative analysis in performed even in oncology
  - Therapy planning (high demand)
    - Bottleneck stage in radiotherapy or surgery planning

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Perspectives (1)

- Current trends in medical imaging
  - Number of image modalities is exploding
  - Image resolution is increasing
  - Image quality is improving
  - IT is invading hospitals (PACS)
  - More patients less doctors

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Perspectives (2)

- Applications of segmentation :
  - Diagnosis
    - demand for very fast and automated algorithms with degree of confidence
  - Planning - Prediction -Prevention
    - demand for accurate but potentially not fully automated algorithms combined with high quality meshing
  - Clinical Research
    - demand for automated and accurate algorithm for use with large database (grid computing)

INRIA SOPHIA ANTIPOLIS

Perspectives (3)

- Segmentation techniques is more and more split between :
  - Registration techniques :
    - registration with a anatomical/physical/physiological model
    - registration with a set of images (data fusion)
  - Low-level techniques :
    - anisotropic filtering, watershed, mathematical morphology

Need to define a unifying framework

INRIA SOPHIA ANTIPOLIS