Analysis of CT-scan images of the liver

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Overview

- Introduction
- Liver Segmentation
- Lesion and Vessel Segmentation
- Functional Segment Computation
- Applications based on Liver Reconstruction
- Conclusion

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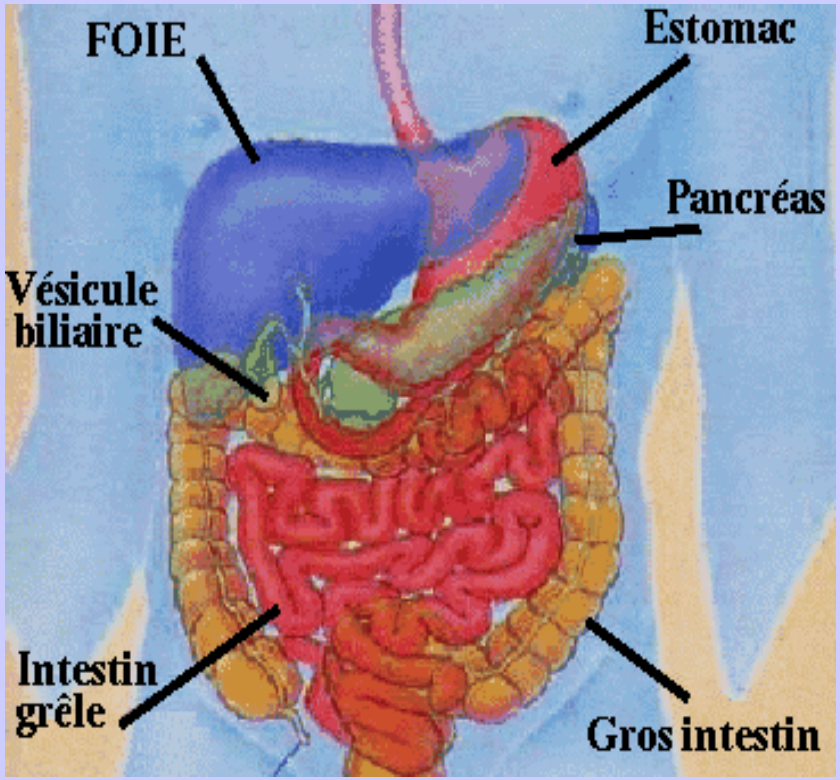
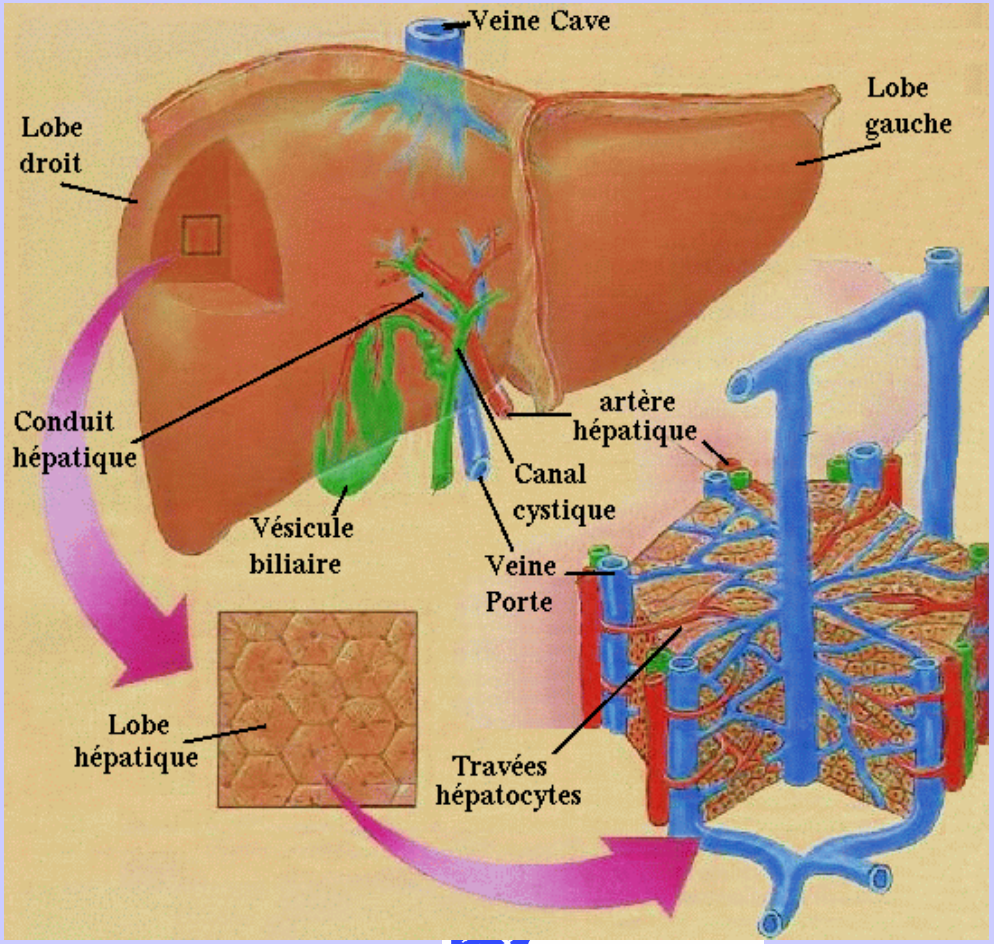
Hepatic Surgery

Hepatic Surgery Planning





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Research on Liver Segmentation

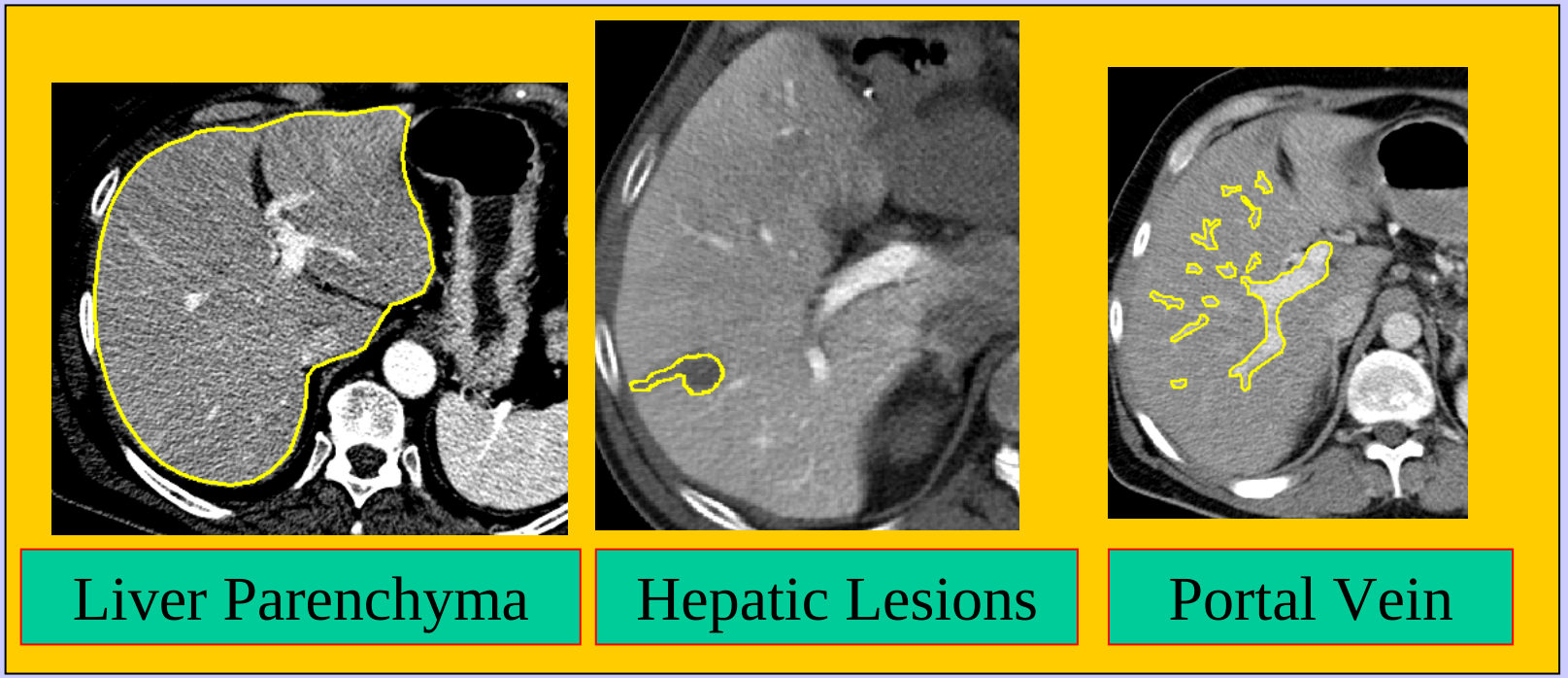
- Context
  - Eureka project MASTER 1995-1999
  - Subcontracted by IRCAD (J. Marescaux) in Strasbourg (France)
  - Two PhD thesis

Johan Montagnat
(1996-1999)

Luc Soler
(1996-1999)

Objectives

- Objective 1: Delineation of structures



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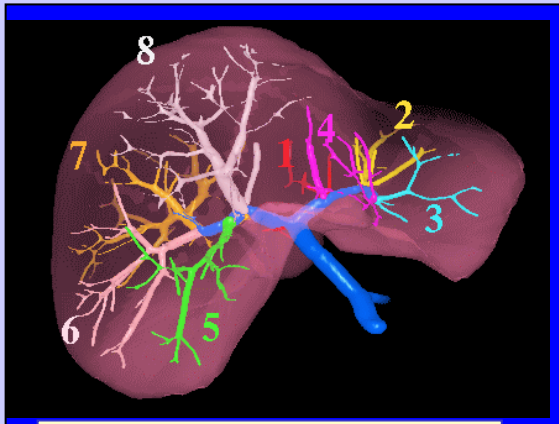
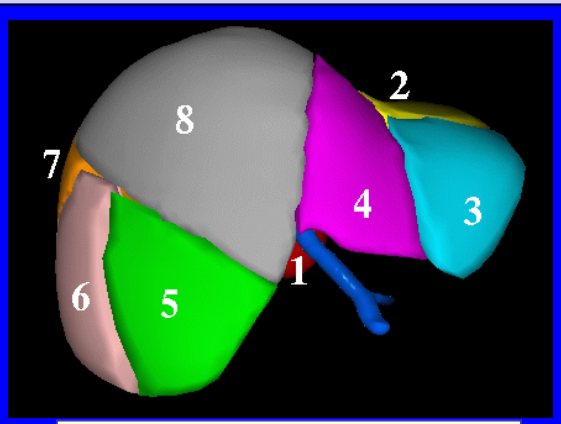
Objectives

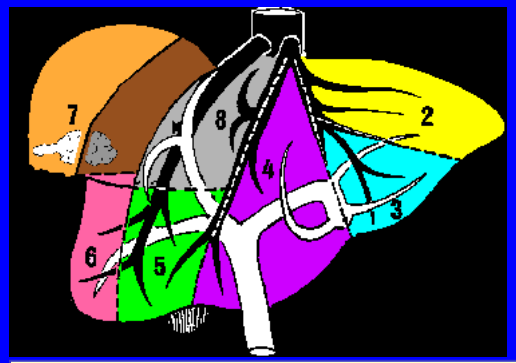
- Objective 2: Functional Analysis of the liver



Labeling of the Portal Vein



Couinaud Segmentation



Finding Segments to be resected

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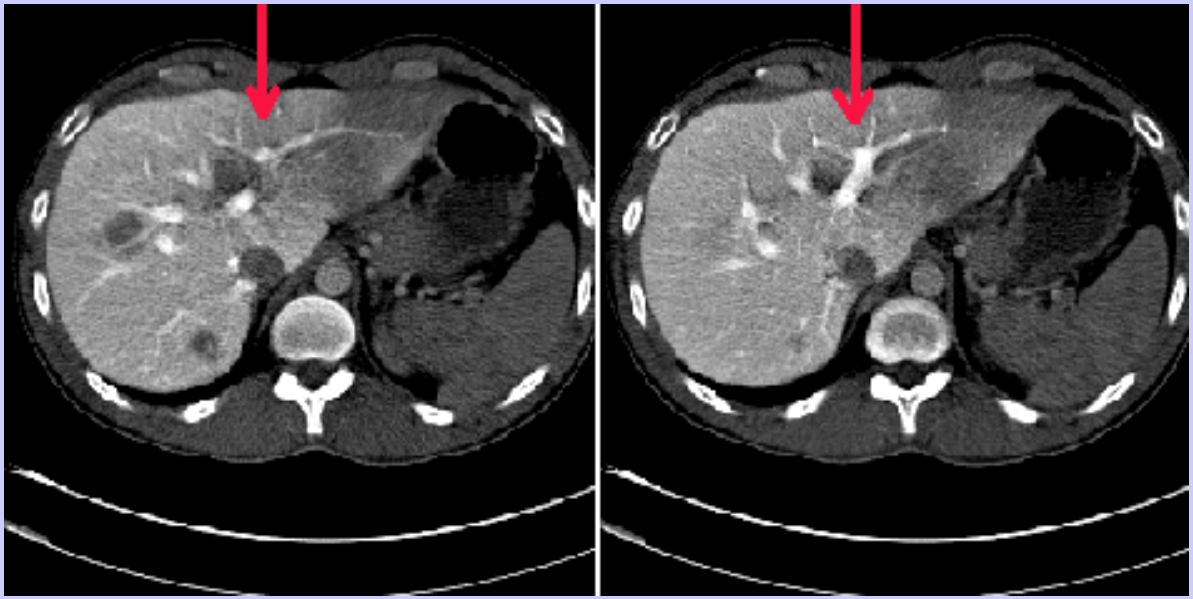
Input Images

- Source : Hospital of Strasbourg, Mulhouse
- Contrast Agent Injection :



~~Directly in the Portal Vein~~

Better Contrast

More Invasive

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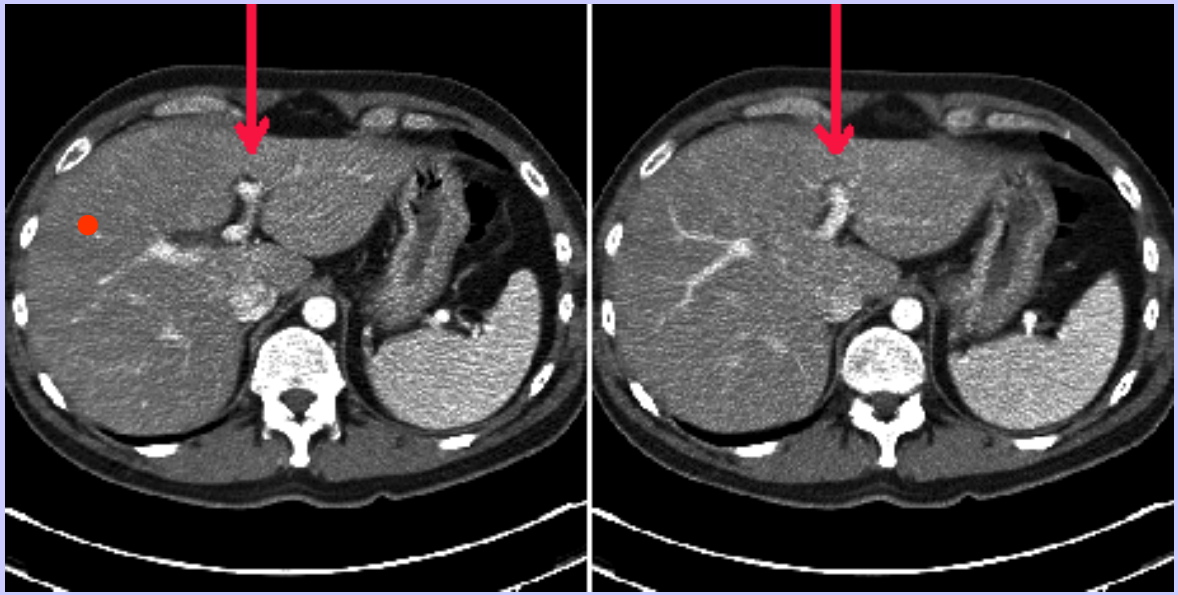
Input Images

- Source : Hospital of Strasbourg, Mulhouse
- Contrast Agent Injection :



Intravenous Injection

Low Contrast

Less Invasive

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Main Difficulties

- Source of Image Contrast
- Image Texture
- Large Inter-Patient Variability

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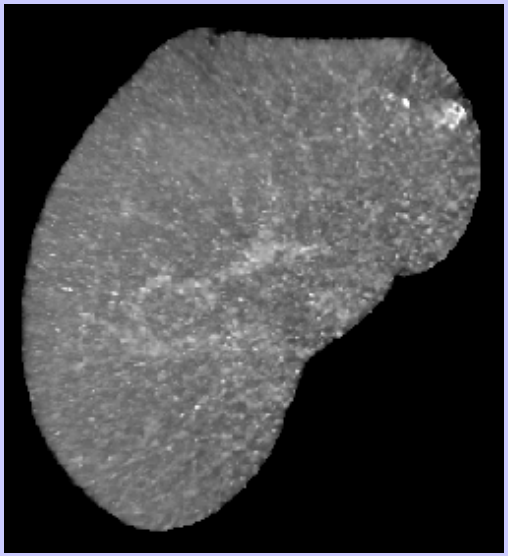
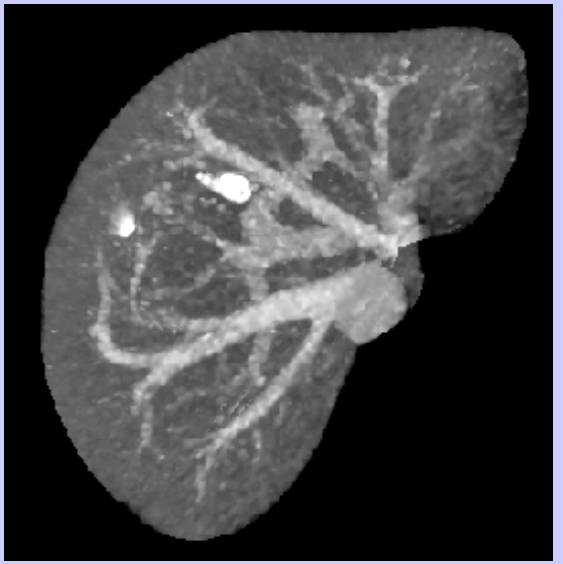
Image constrast

- Parenchyma appearance depends on the delay between injection and acquisition



Acquisition too early

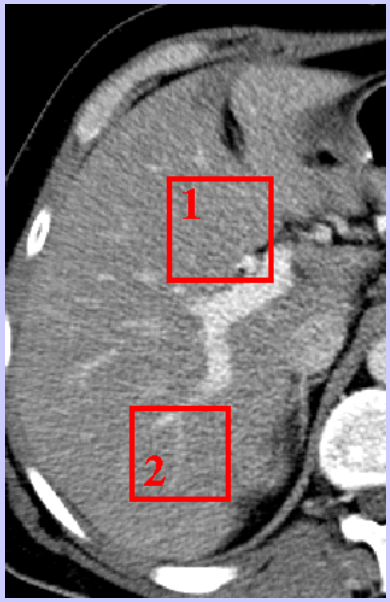
Acquisition OK

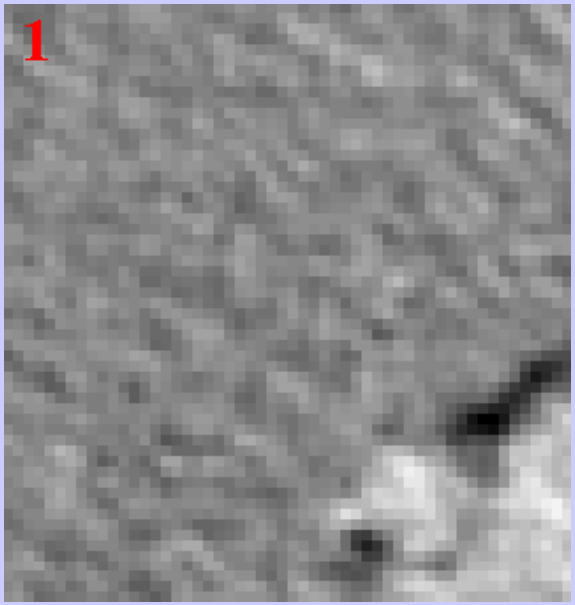


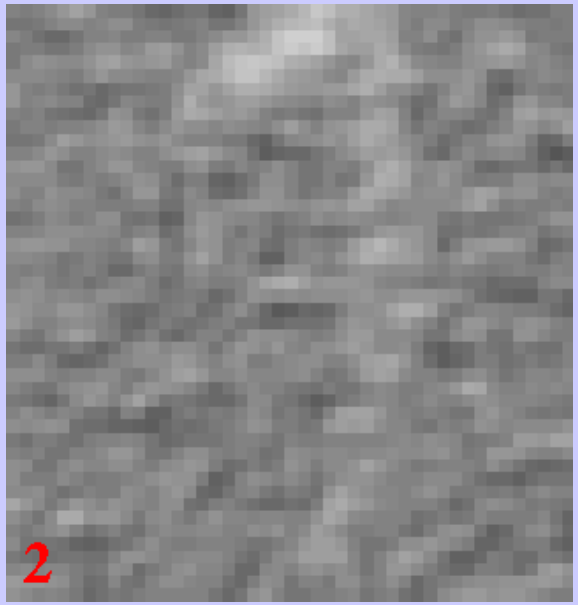
Acquisition too late

Image Texture

- Textured Aspect







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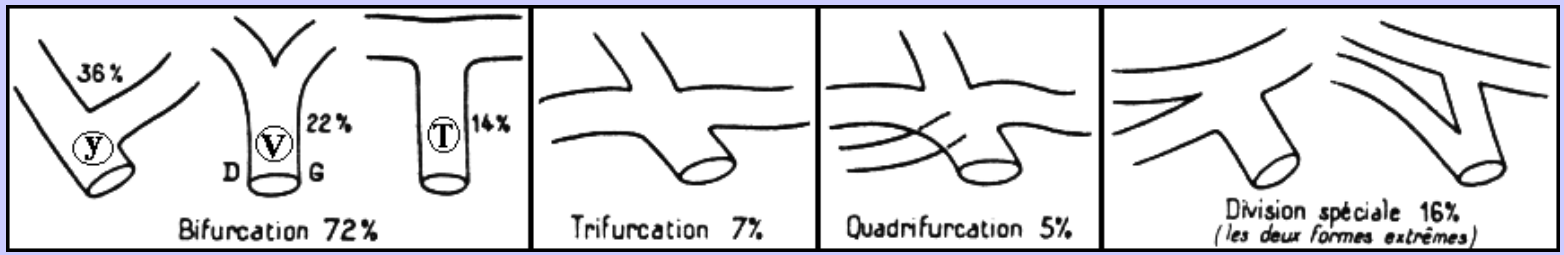
Inter-Patient Variability (1)

- From Textbooks (Couinaud Thesis)

Liver Variability (40 cases)



Vein Branching Variability

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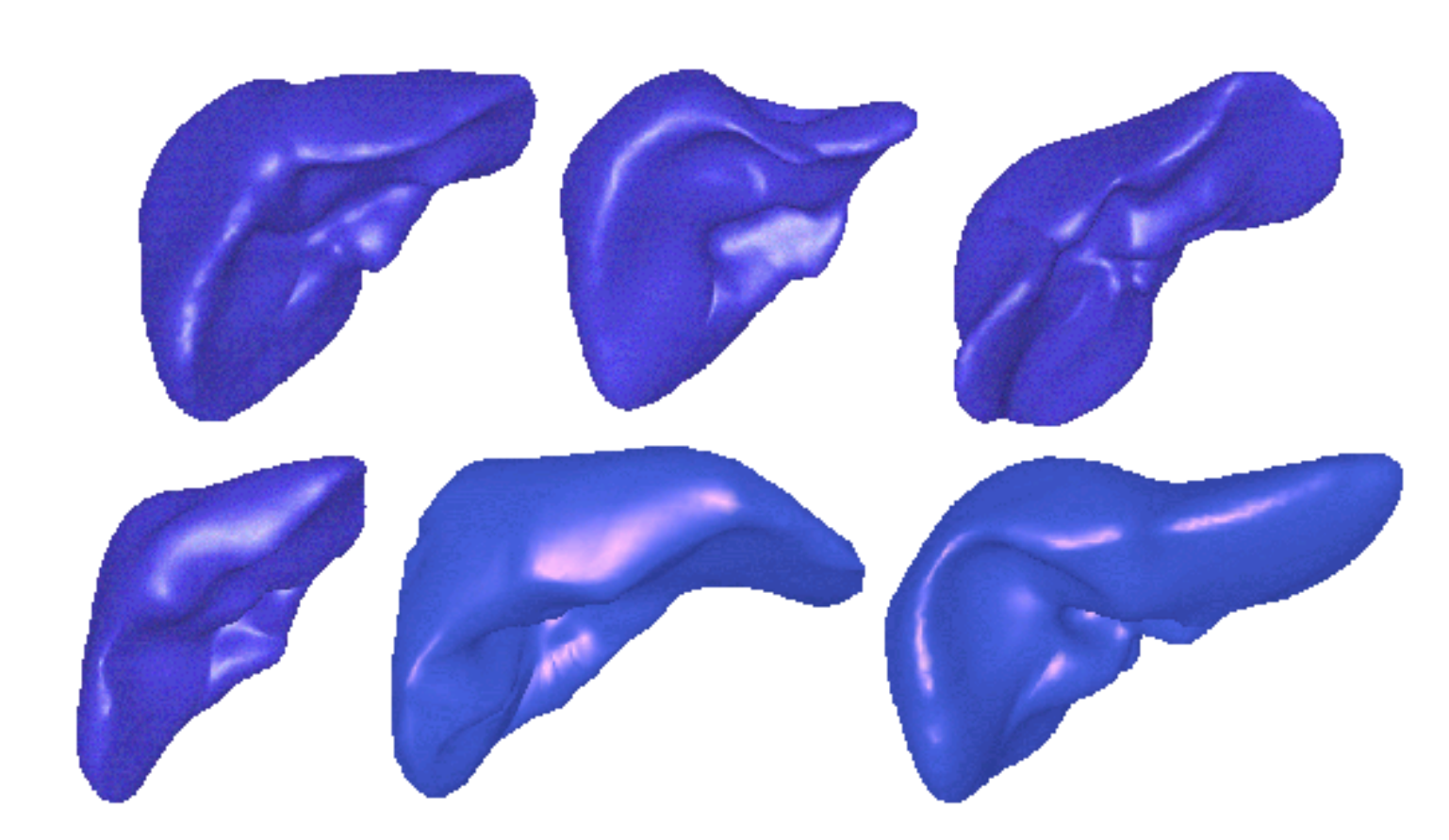
Inter-Patient Variability (2)

- From real cases :



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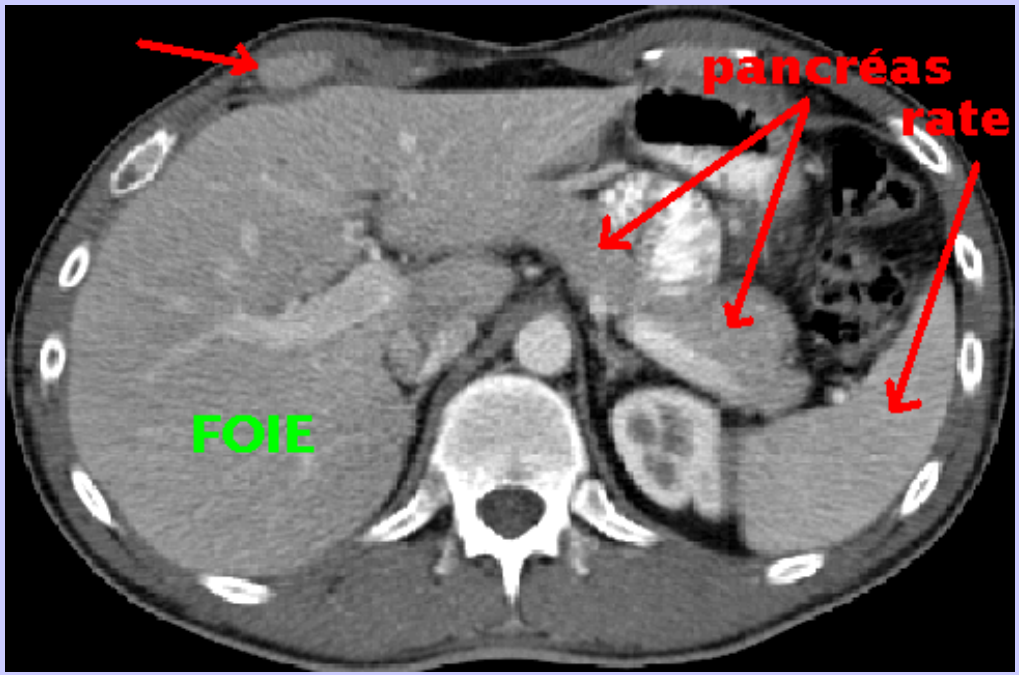
Segmentation of the Liver

- Challenges
  - Texture aspect
  - No clear boundary between neighboring structures



Segmentation of the Liver

- Main Approach : combine
  - 1) Low level image boundary detection

→ Accurate Localization of Boundaries

  - 2) High Level Shape Constraint

→ Robust Reconstruction

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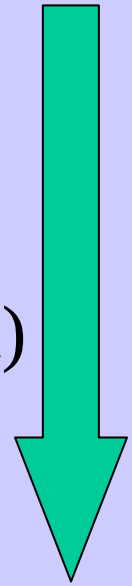
Segmentation of the Liver (2)

- Finding Liver Boundaries :
  - Gradient Information
  - Region Information (Intensity+Gradient)
  - Texture Analysis (Markov Random Field)
  - Correlation of Intensity Profiles



Increasing Level of A Priori Knowledge

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Segmentation of the Liver (3)

- High Level Shape Constraint :
  - Use of Deformable Models (Simplex Mesh).
  - Minimize the sum of two energies :
    - Internal Energy : to constraint the shape of the surface
    - External Energy : to fit the apparent boundary from the image

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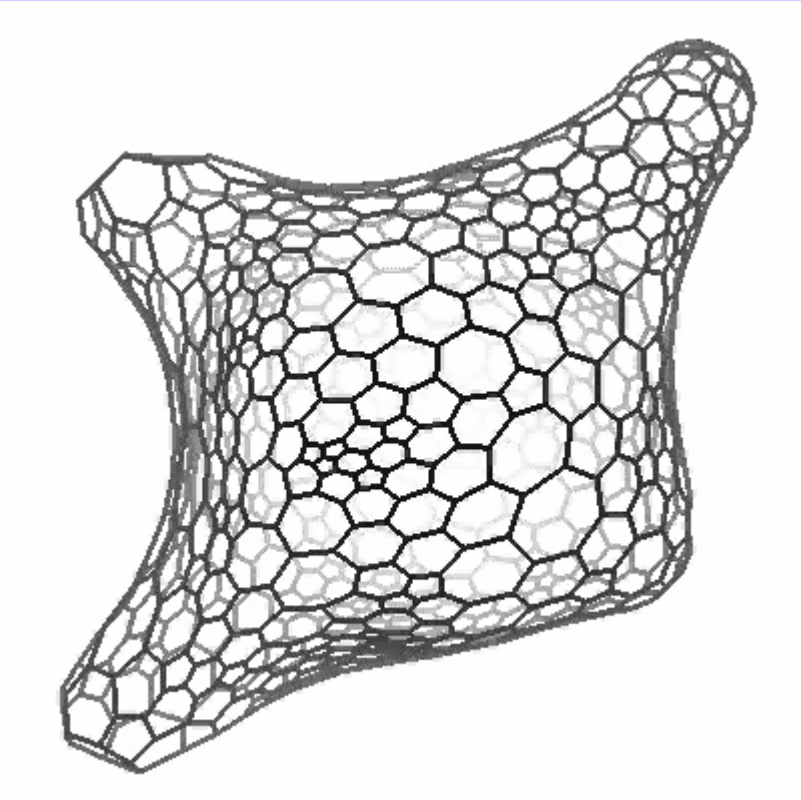
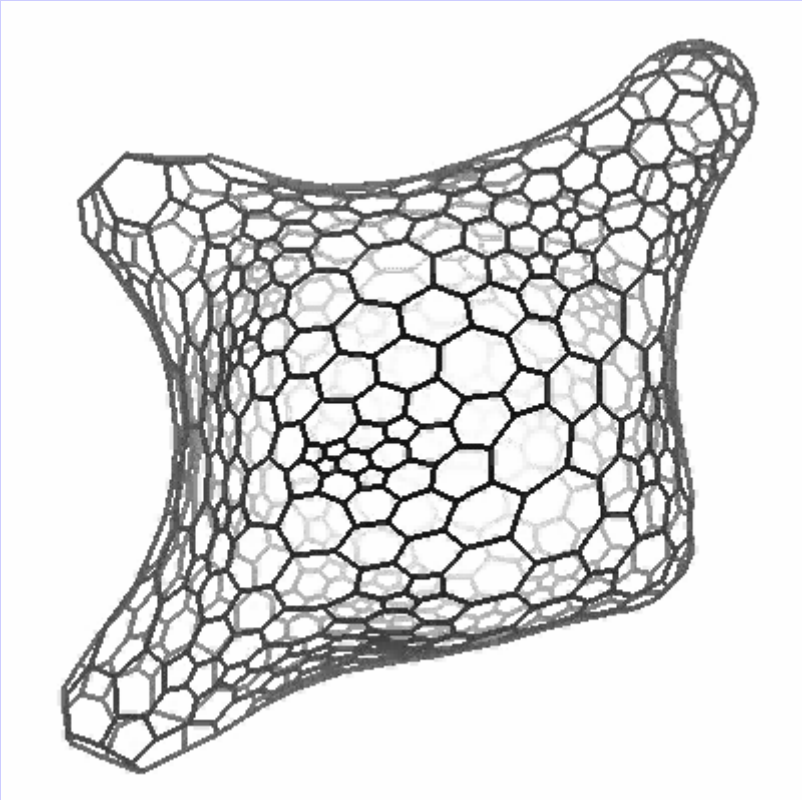
Segmentation of the Liver (4)

- Effect of Internal Energy



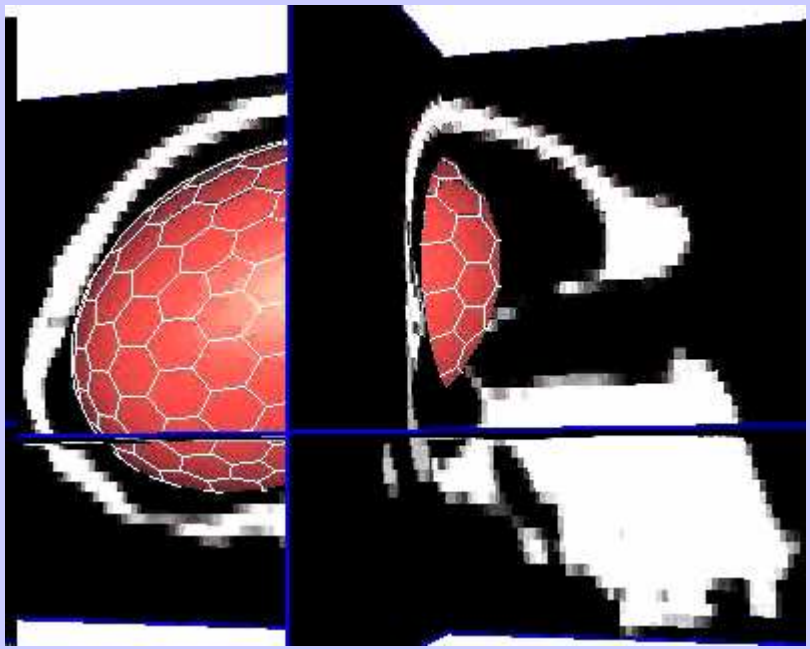
Smoothness Constraint

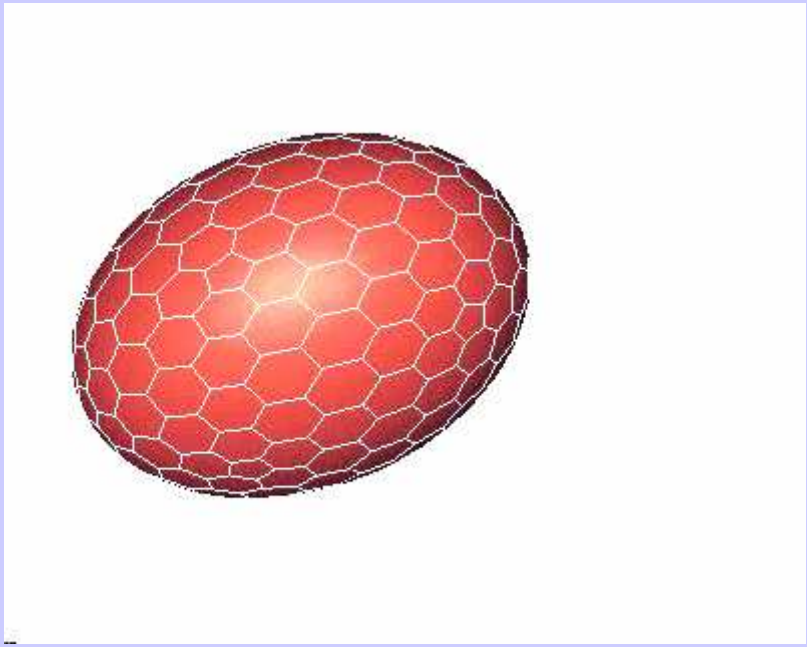


Shape Constraint

Segmentation of the Liver (5)

- Combination of Internal and External Energy





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Segmentation of the Liver (6)

- Algorithm :
  - Build a Template Surface
  - Perform Low-Level Processing
  - Initialize Template Surface in Image
  - Do :
    - Compute Internal and External Forces
    - Update Mesh Position
  - Until Convergence

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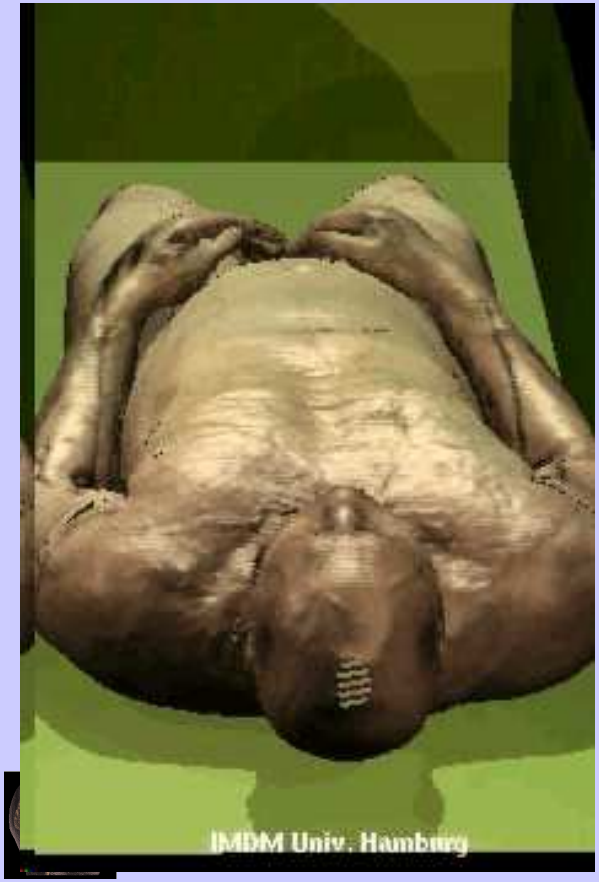
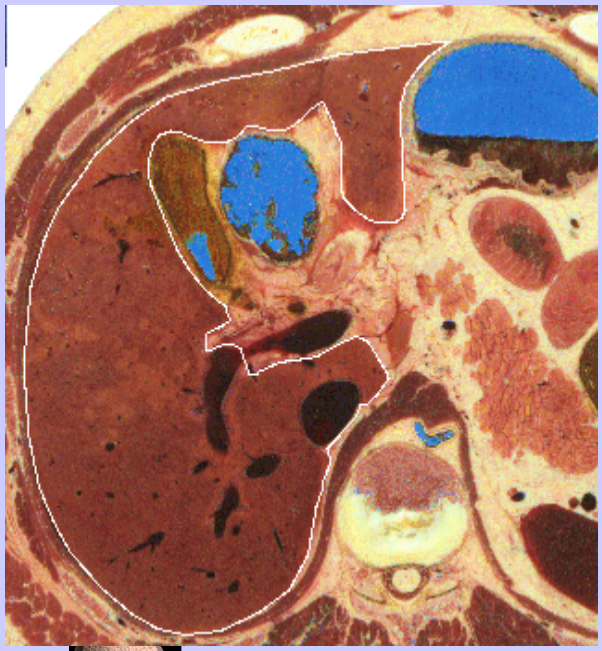
Segmentation of the Liver (7)

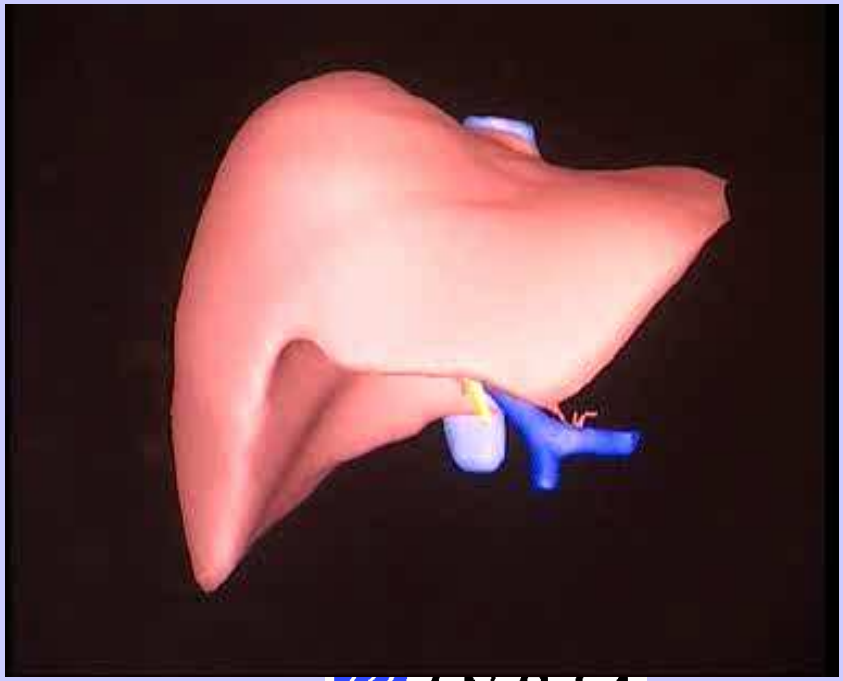
- Generic Template Surface : Visible Human



Segmentation of the Liver (8)

- Reconstruction of the Liver, Portal and Sus-Hepatic Veins, Hepatic Artery, ...





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Segmentation of the Liver (9)

- Initialization :
  - Automatic :
    - Segmentation of vertebra + ribs by thresholding
    - Rough Registration with a template rib cage image
    - Detection of the potential location of the liver
  - Manual :
    - ROI drawn by the user

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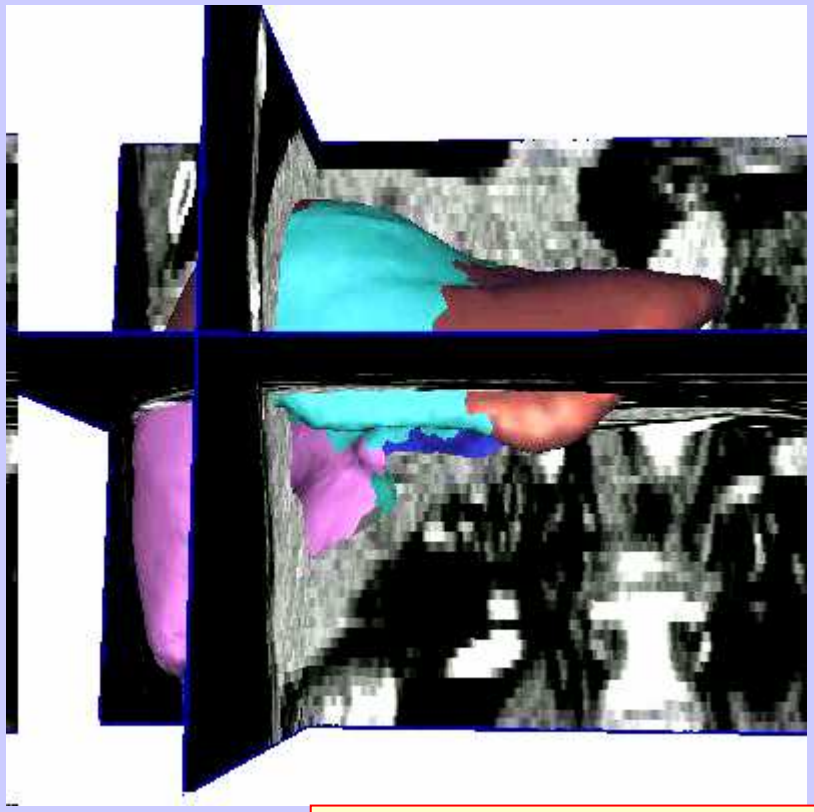
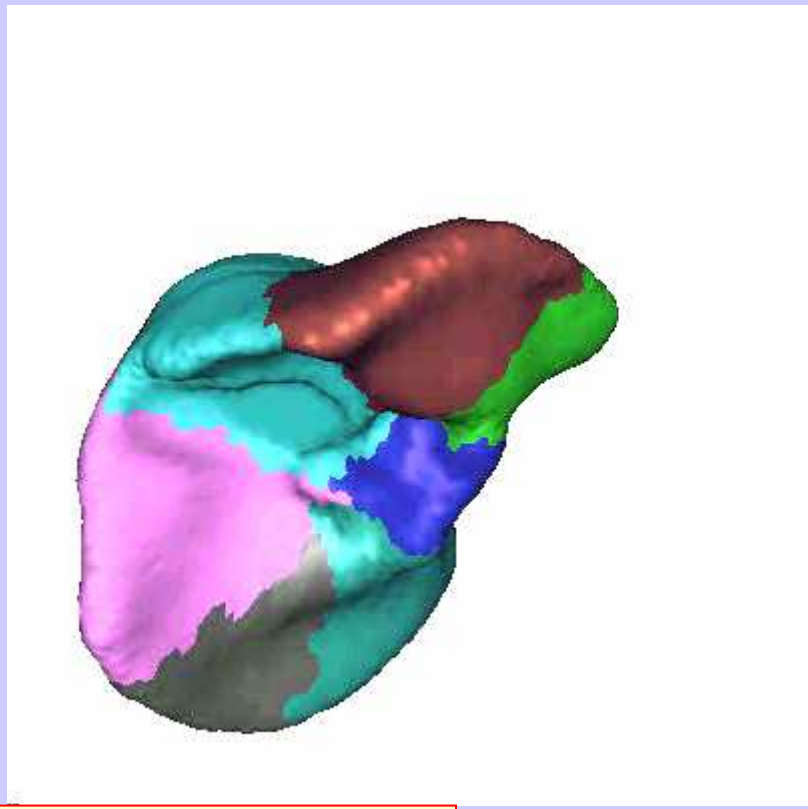
Segmentation of the Liver (10)

- Deformation of the template surface





Computation Time : 2mn 50 s

Segmentation of the Liver (11)

Trace of deformed model

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Segmentation of the Liver (11)

- Validation study on 3 images :
  - Manual Delineation of each image requires 10h for a radiologist

Image	Sensitivity	Spécificity	Similarity	Overlap	Correlation
1	76%	95%	84%	73%	98%
2	90%	95%	93%	87%	99%
3	93%	96%	95%	91%	99%

Image	Interslice Distance	Mean Distance	Standard Deviation	Median Distance
1	4 mm	2,5 mm	3,1 mm	2,6 mm
2	1,66 mm	1,3 mm	1,8 mm	1,66 mm
3	2 mm	1,1 mm	1,6 mm	1,3 mm

Segmentation of the Liver (12)

- Robustness of the approach :
  - Could cope with the segmentation of roughly 70% of the database provided (45 cases) to us by hospitals
  - Problems with already resected livers
  - Problems often near stomach
  - Possibility to interactively modify the segmentation

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Additional Work

- Since 1999, segmentation techniques have been much improved :
  - Initialization based on non-rigid registration (Brain)
  - Better Low-Level Detection (Brain)
  - Use of Statistical Shape Model (Liver)
  - Cooperation between Deformable Models (Brain)

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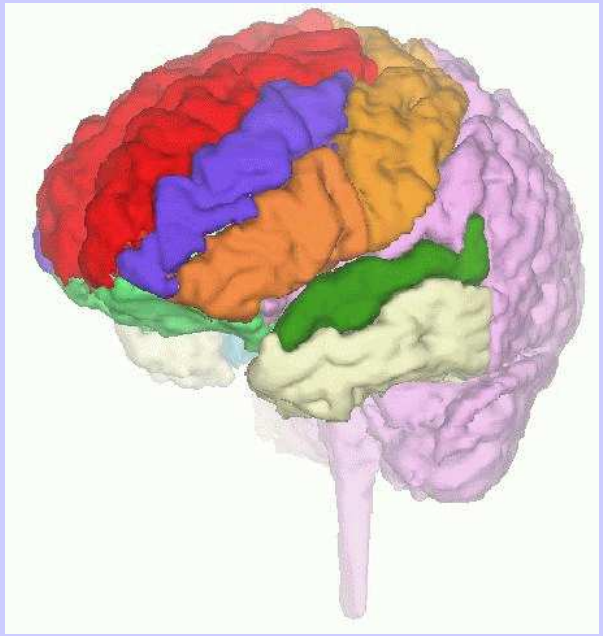
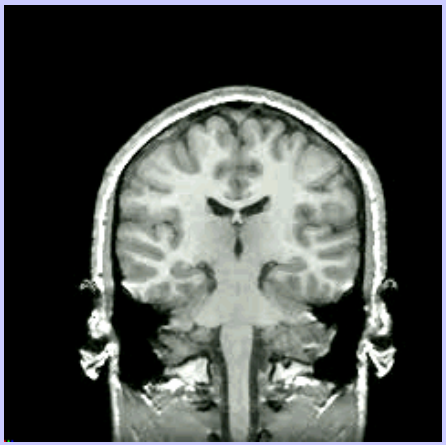
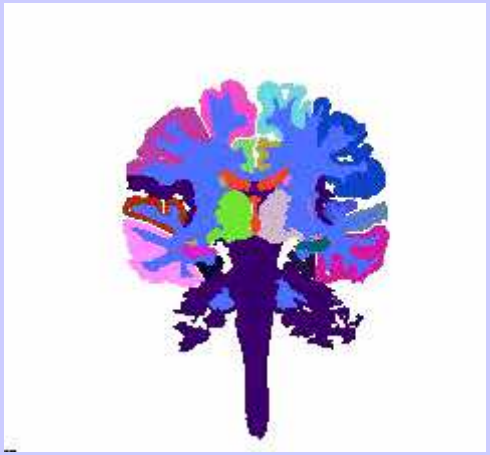
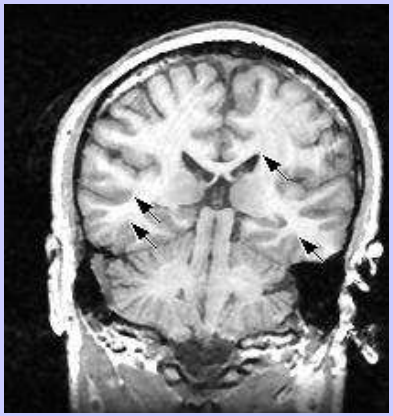
Initialization

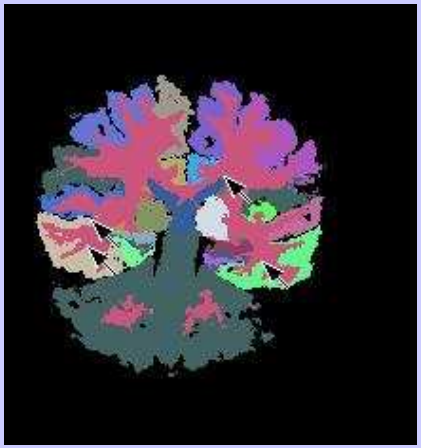
- Use of a brain atlas to initialize deformable model











Low-Level Detection

- Texture classification :
  - Off-line Computation :
    - Gather a set of images representative of inter-patient variability
    - Compute a set of texture descriptors for each image (statistical, model-based, signal processing)
    - Train classifier (linear, SVM, Neural-Nets)
  - On-line Computation :
    - Compute texture descriptors
    - Apply classifier

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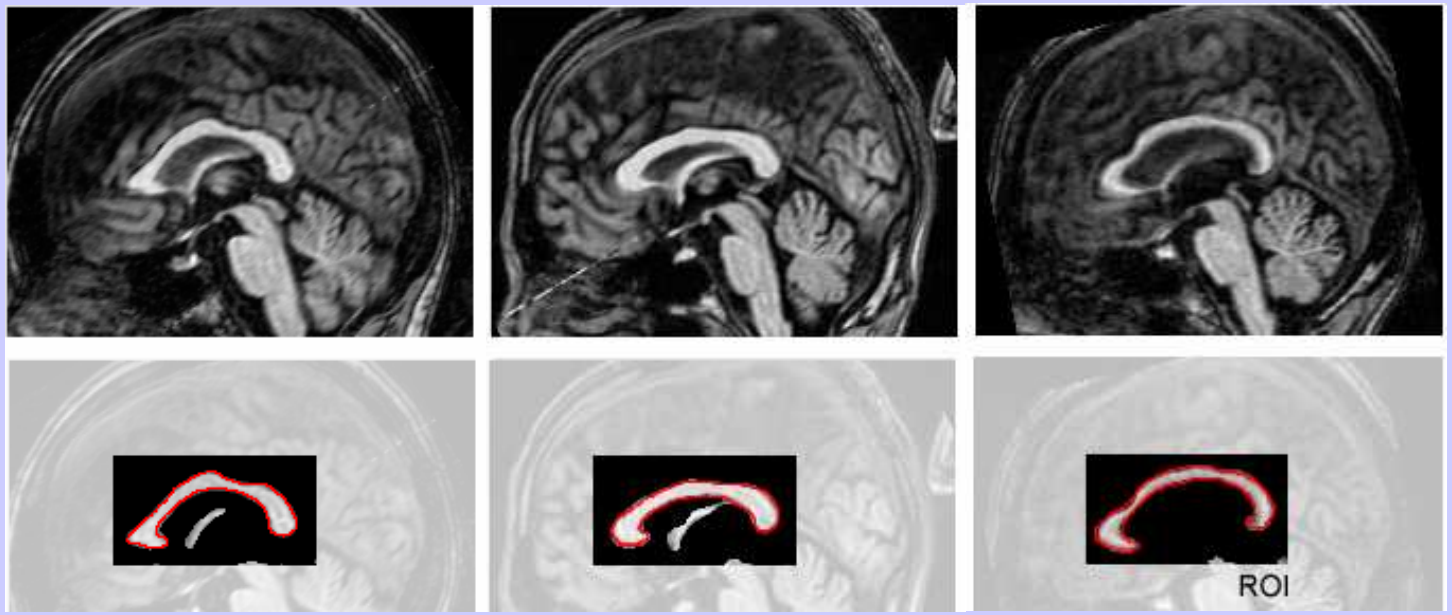
Low-Level Detection (2)

- Example for Corpus Callosum with SVM



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Statistical Shape Model

- Use Statistical Prior to guide the segmentation :
  - Build a representative set of Liver Surfaces
  - Find Correspondences between Points
  - Compute the Mean Liver Shape
  - Compute the Covariance Matrix
  - Keep main modes of variation from the mean shape (Principal Component Analysis and Independent Component Analysis)

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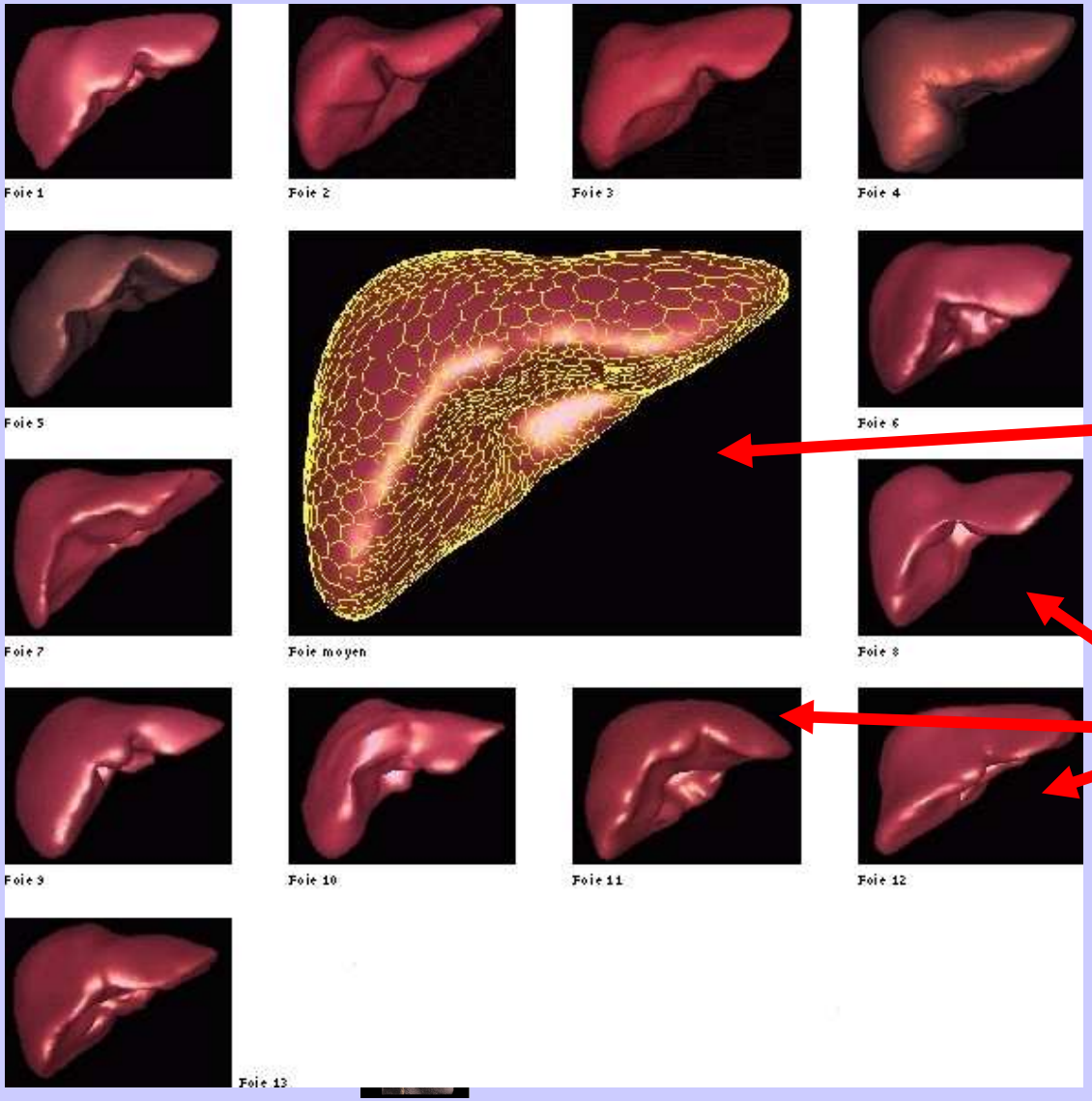
Statistical Shape Model (2)



Mean Liver Model

Training Set of 13 Liver Models

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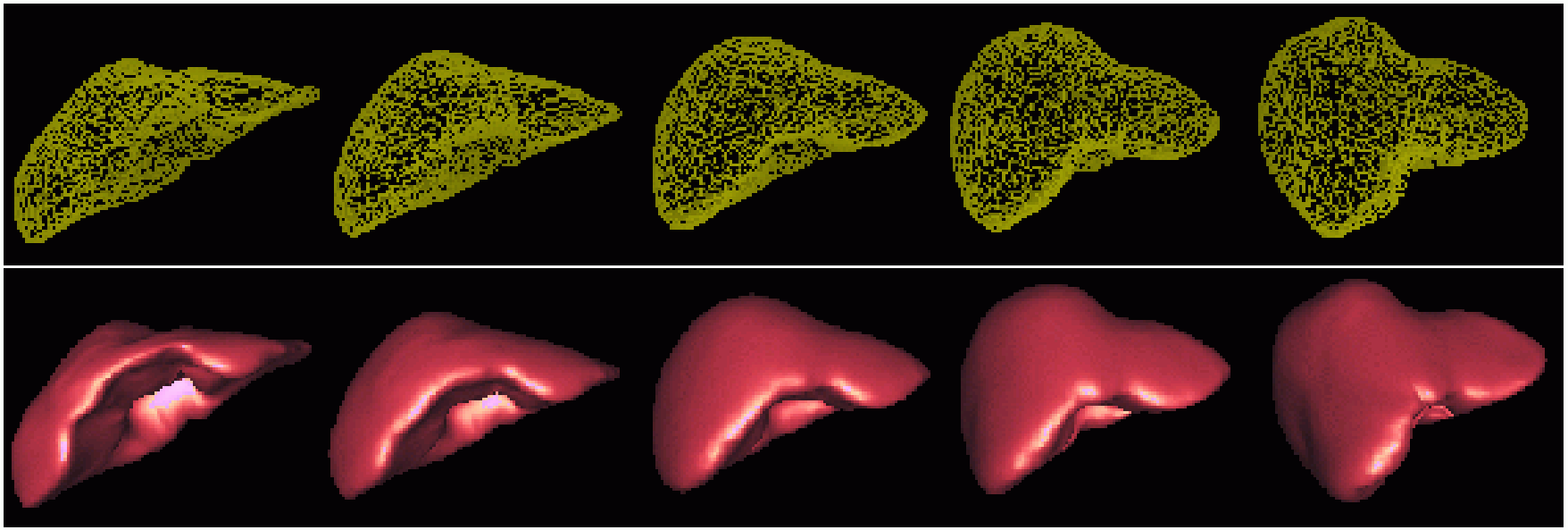
Statistical Shape Model (3)

- Modes Of Variation



First Mode of Variation

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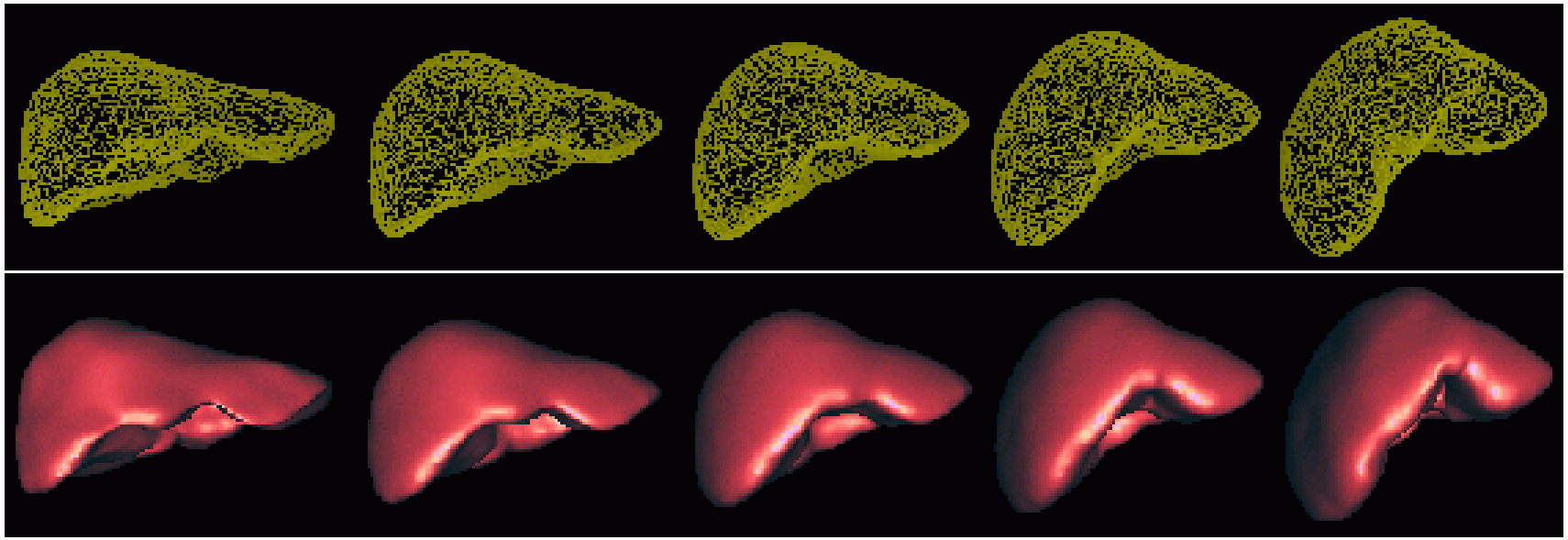
Statistical Shape Model (4)

- Modes Of Variation



Second Mode of Variation

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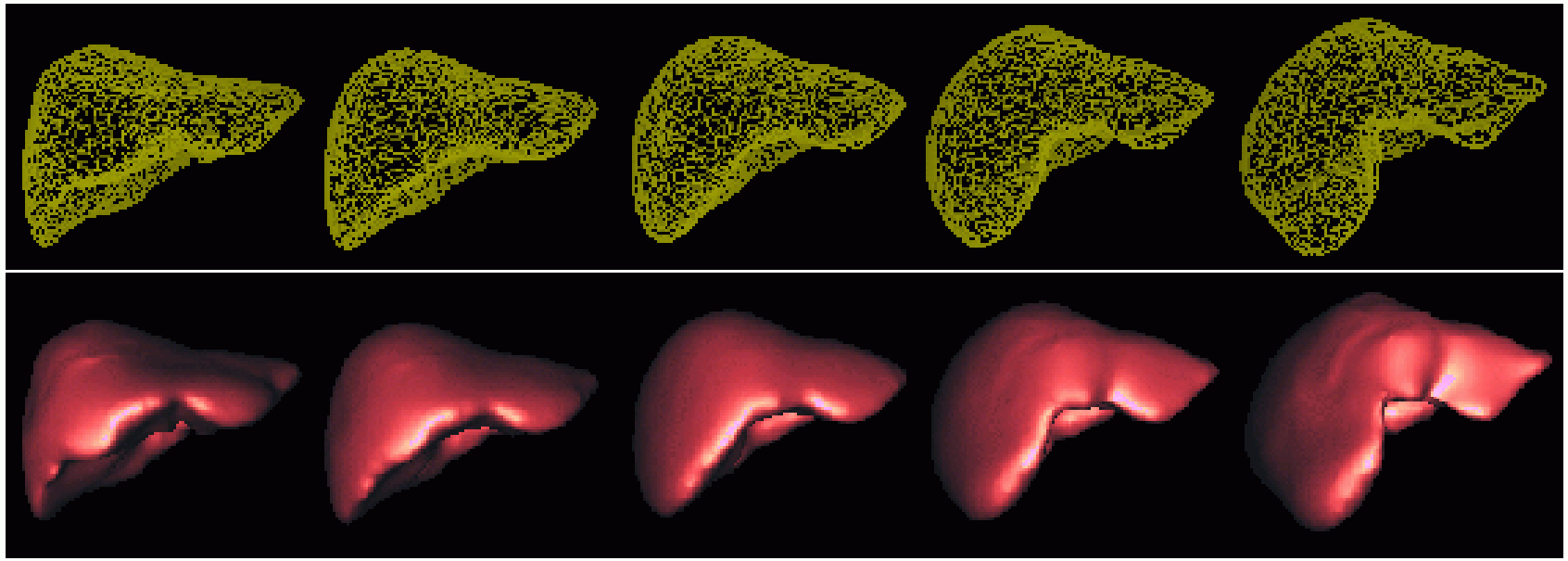
Statistical Shape Model (5)

- Modes Of Variation



Third Mode of Variation

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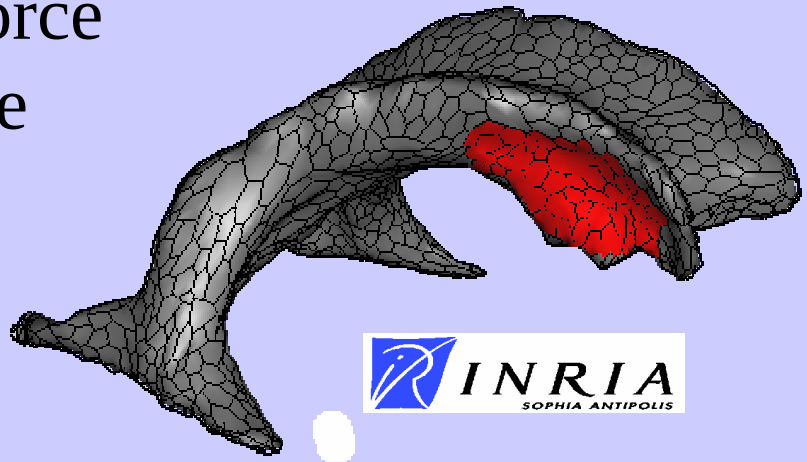
Cooperation Between Models

- Simultaneous segmentation with a family of models
  - Use a Hierarchy of Segmentations
  - Use Distance constraints to prevent intersection or to enforce anatomical knowledge



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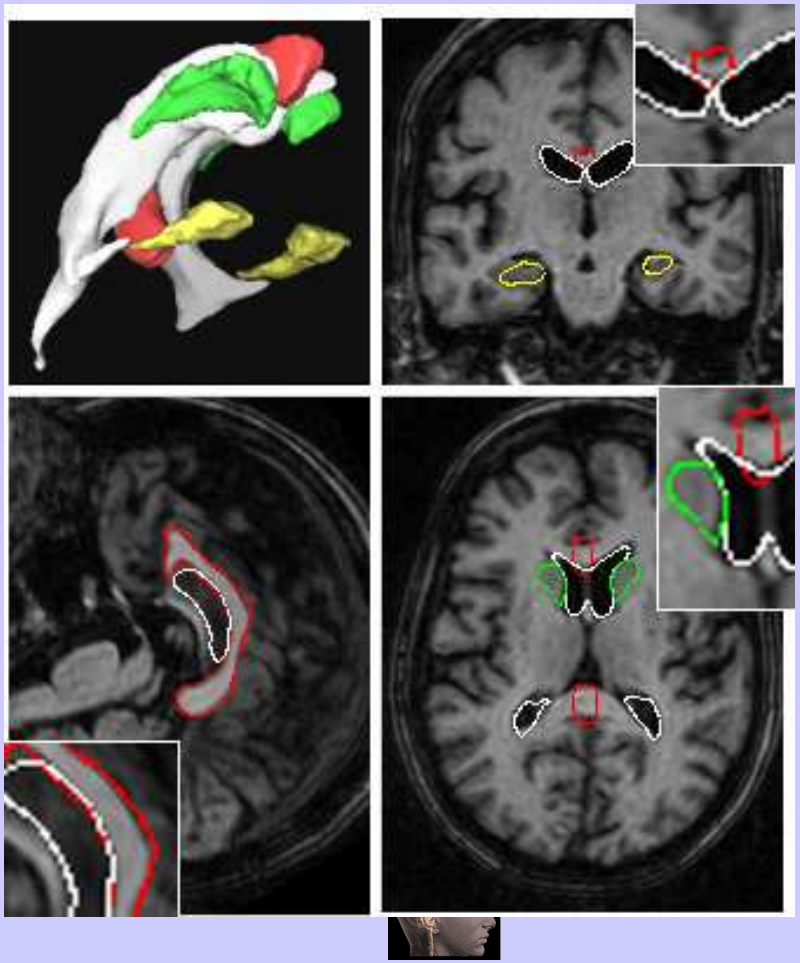
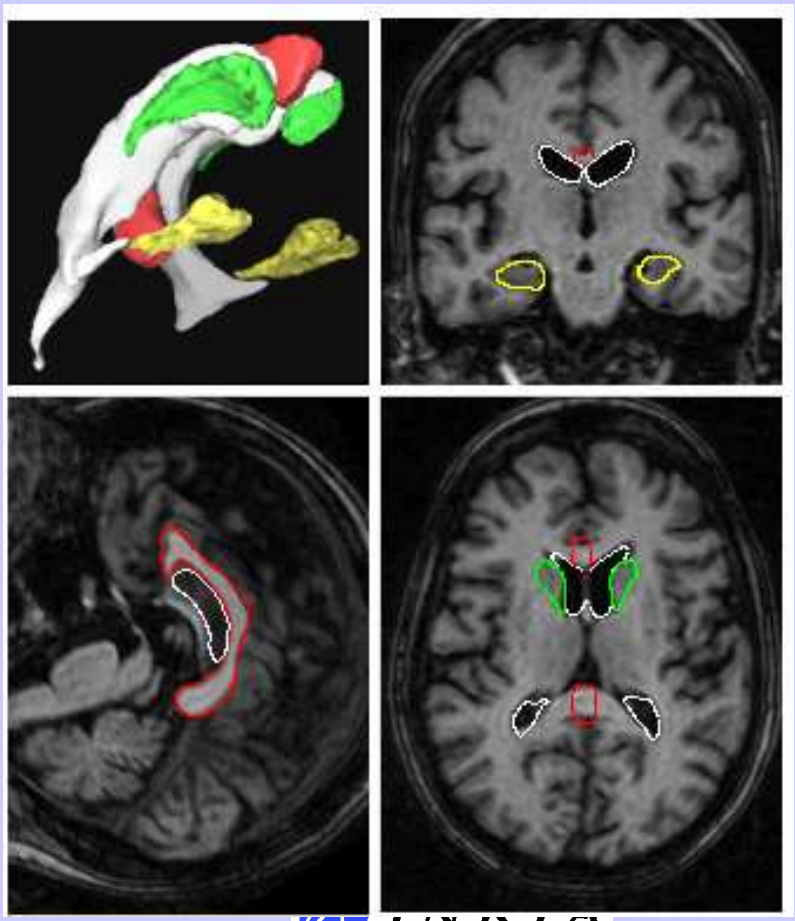
Cooperation Between Models

Without Distance Constraints



With Distance Constraints



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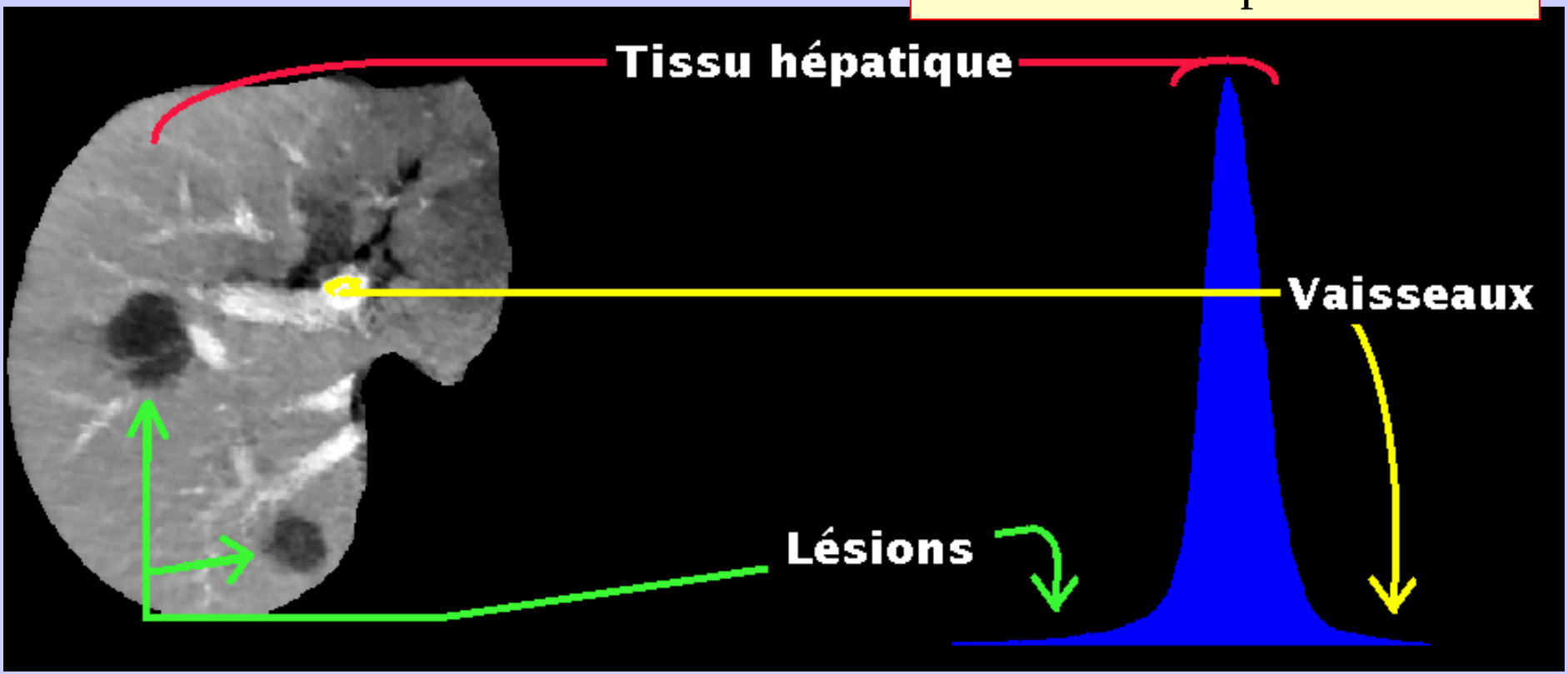
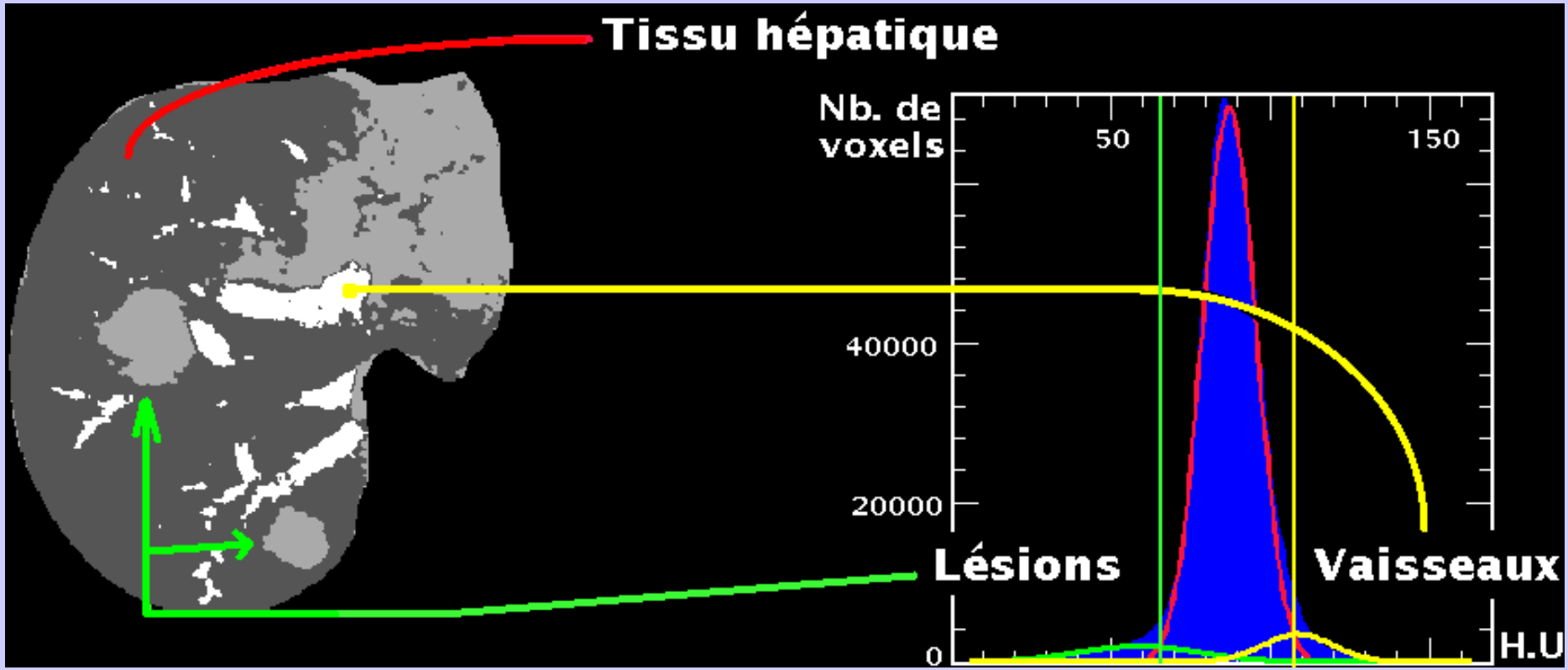
Histogram Analysis

- The liver includes 3 main structures : parenchyma, vessels and lesions



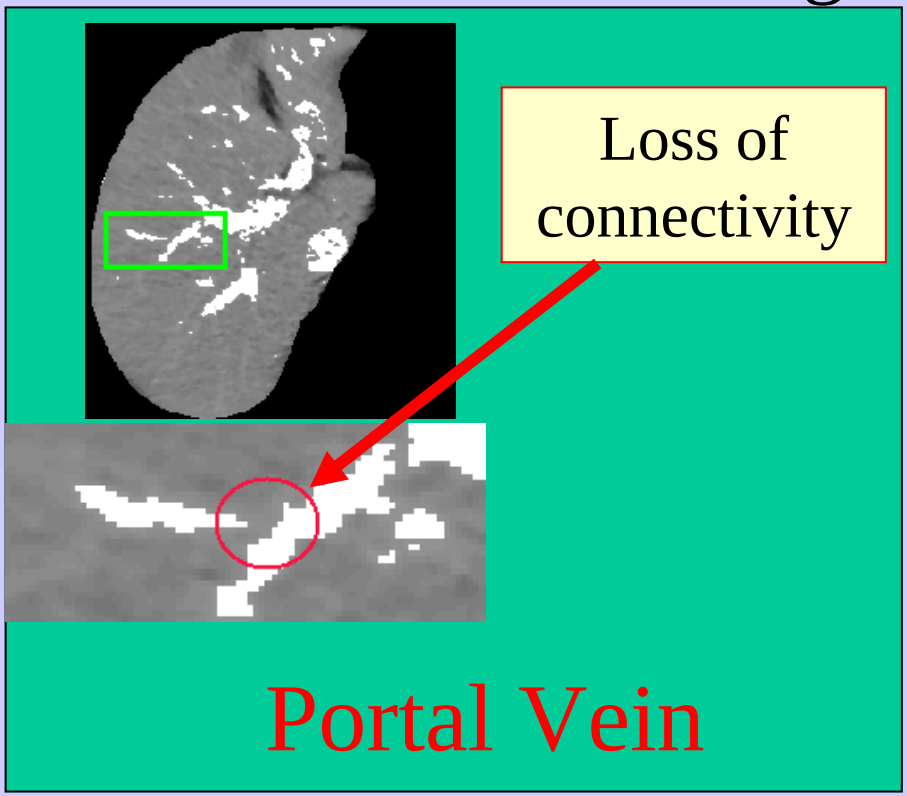
Lesions and Vessel Segmentation

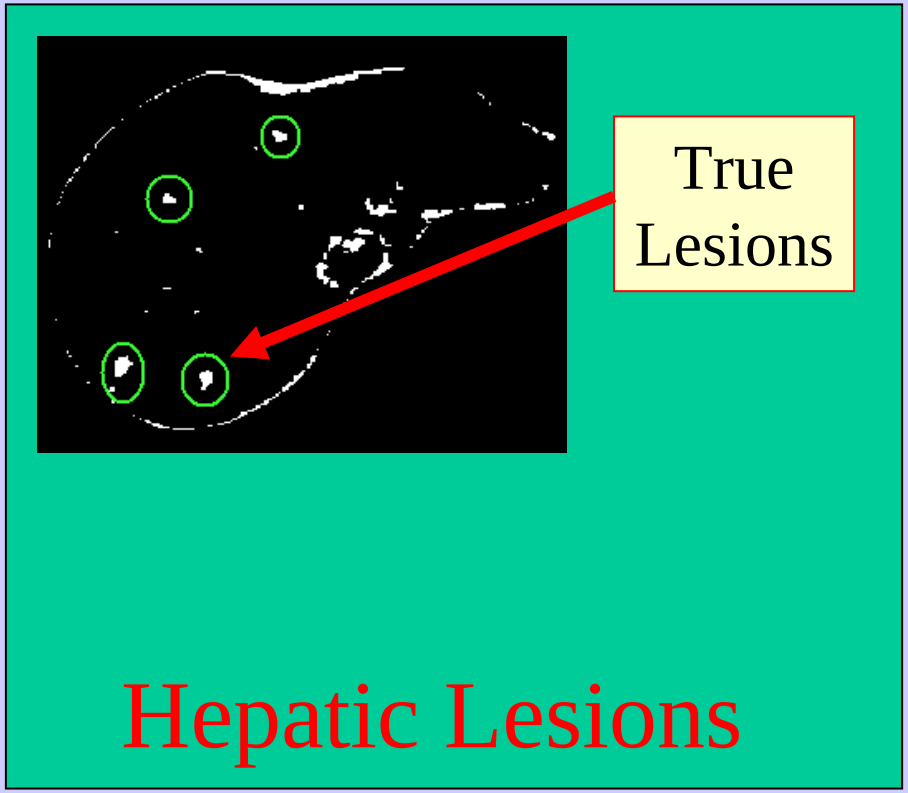
- Automatic Threshold Computation based on Gaussian Distribution



Lesions and Vessel Segmentation (2)

- This is a crude segmentation :





Post-Processing to improve segmentation based on Prior Knowledge

Lesion Post-Processing

- Assumes 2 types of Hepatic Lesions :

Shape : Nodular
Location : internal or subcapsular

Shape : Flat but min depth
Location : peripheral

Haemangioma cavernous,
Carcinoma

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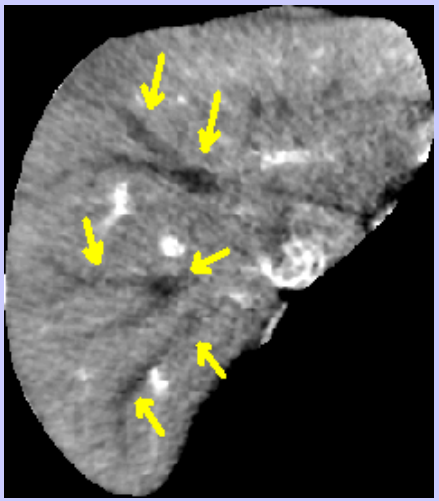
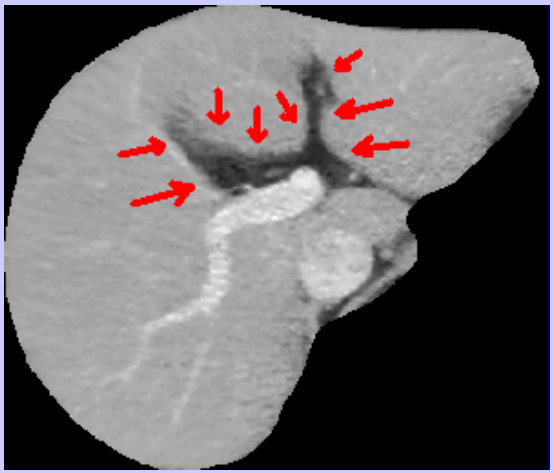
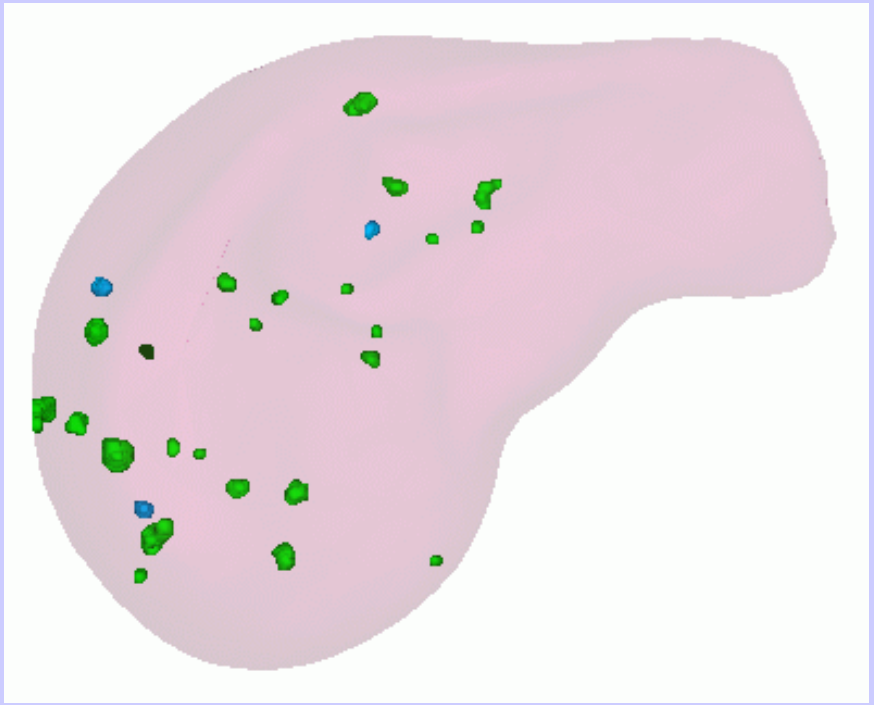
Lesion Post-Processing (2)

- Process outcome of rough segmentation :
  - 1) Detect Distance from Capsule
  - 2) Analyze Shape
- Remove False Positive

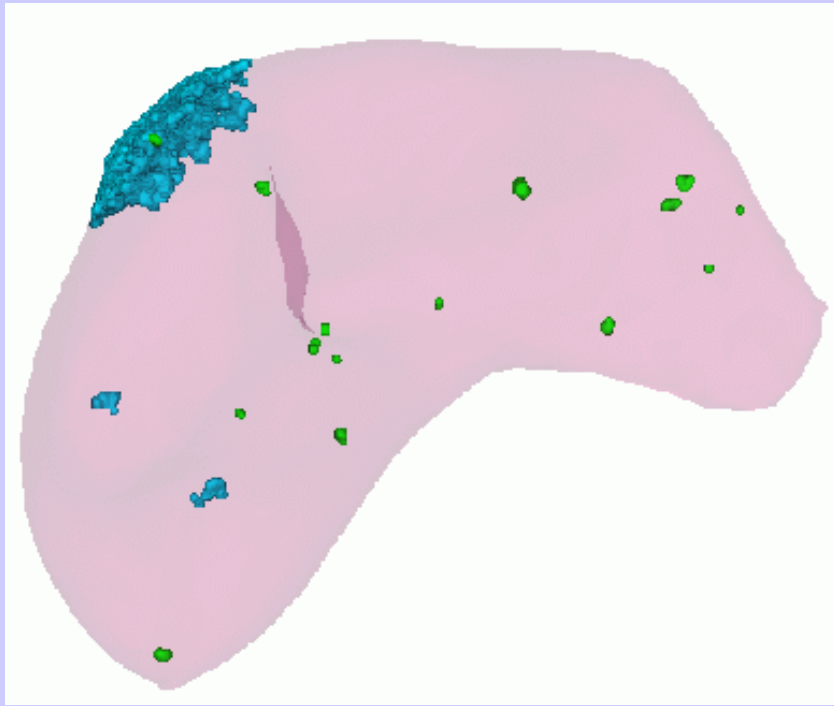




Lesion Final Segmentation



Nodular Lesions



Peripheral Lesions

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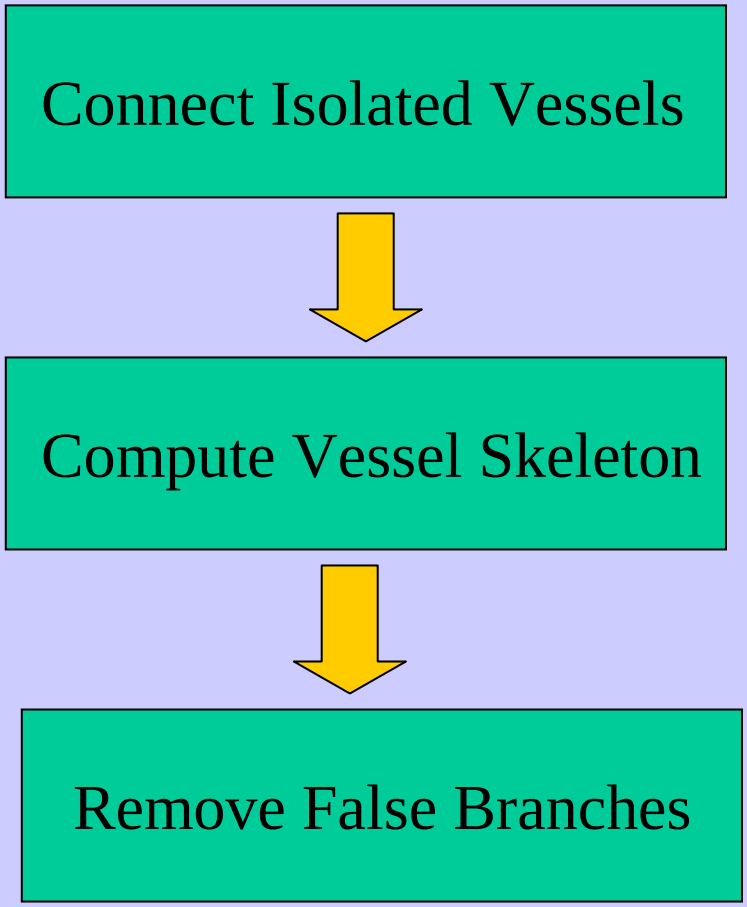
Portal Vein Segmentation



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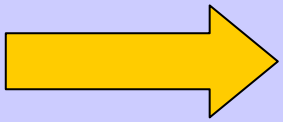
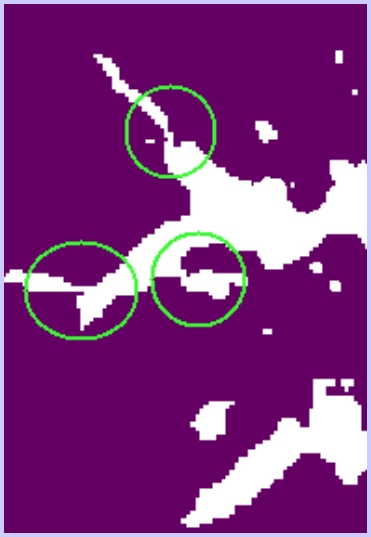
Connect Isolated Vessels

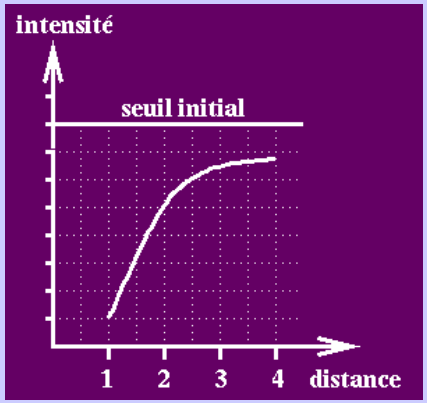
Input Image





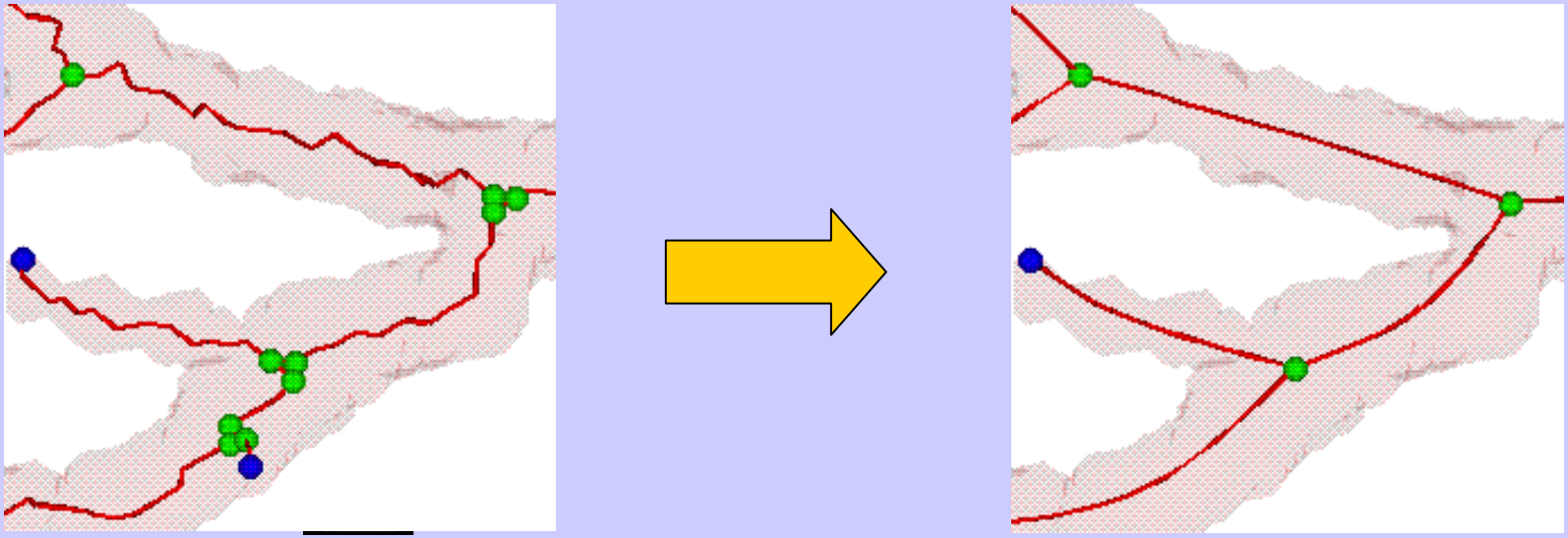
Output Image

Combines Thresholding and Topological Closure



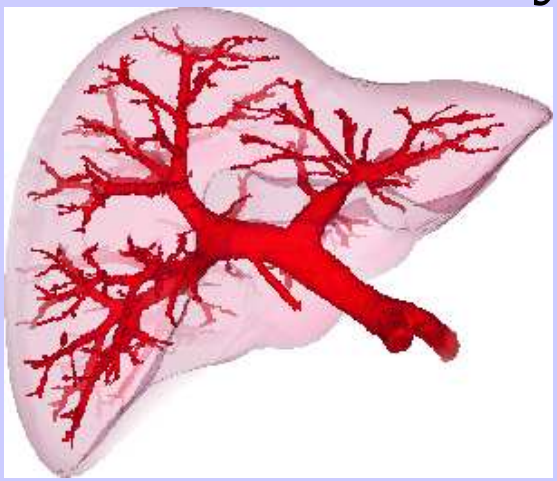
Skeleton Computation

- Use algorithm of Bertrand-Malandain
  - Fuse Junctions,
  - Remove Small Branches
  - Smooth center line



Remove False Branches

- Makes 3 hypothesis



Tree Structure

Next to Arterial Tree

Next to Hepatic Vein

Remove Loops

Remove Tangent Network

Remove Crossing Network

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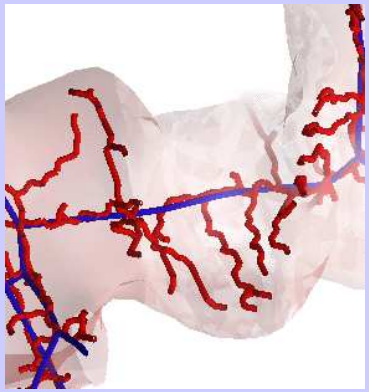
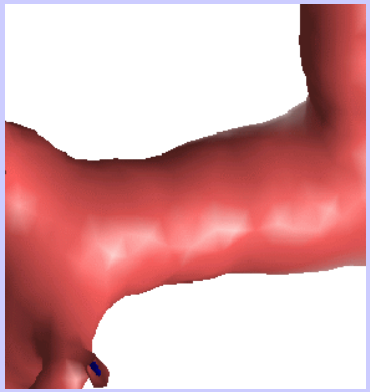
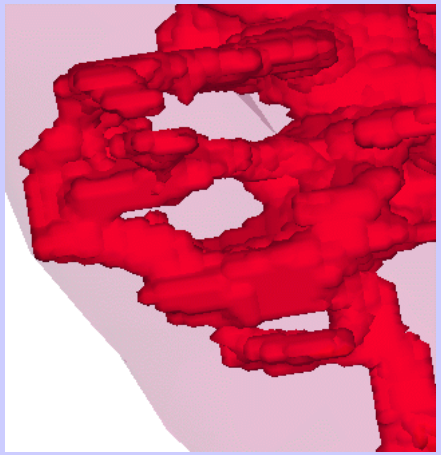
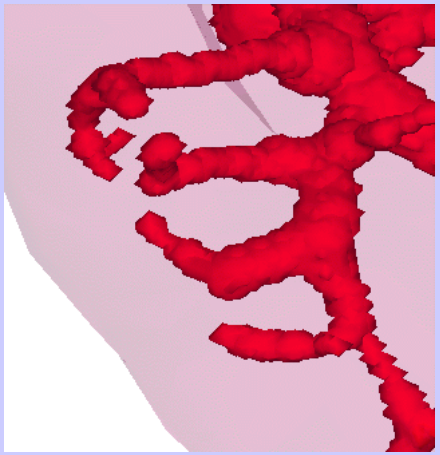
Remove False Branches (2)

- Removing arterial connexion

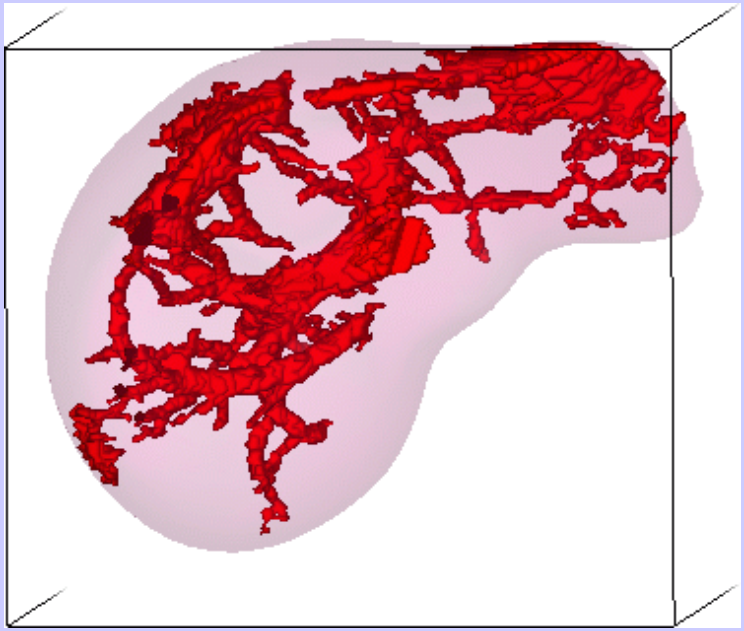




- Removing Loops

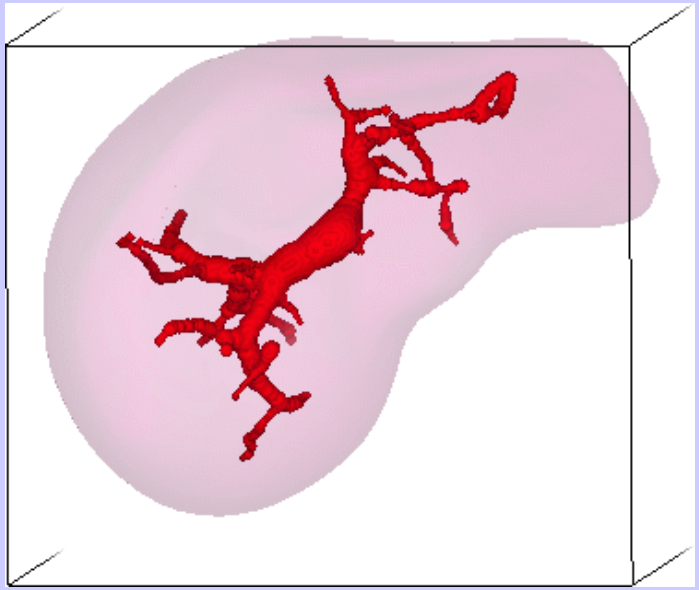



Remove False Branches (3)

- Final Result



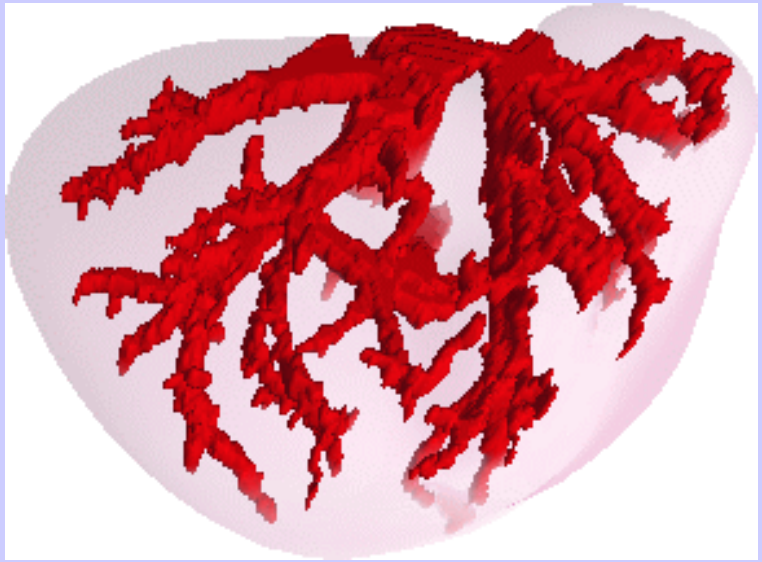
Before Processing Branches

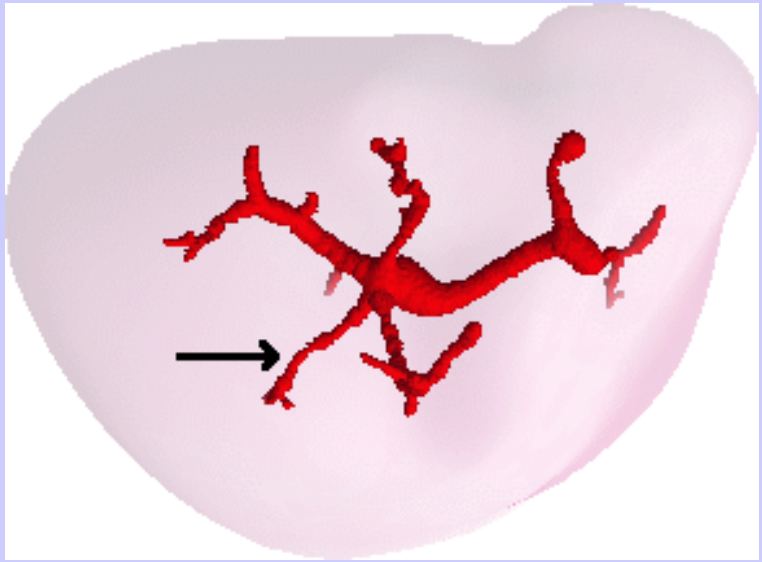


After Processing Branches

Remove False Branches (4)

- Final Result





Before Processing Branches

After Processing Branches

Overview

- Introduction
- Liver Segmentation
- Lesion and Vessel Segmentation
- Functional Segment Computation
- Applications based on Liver Reconstruction
- Conclusion

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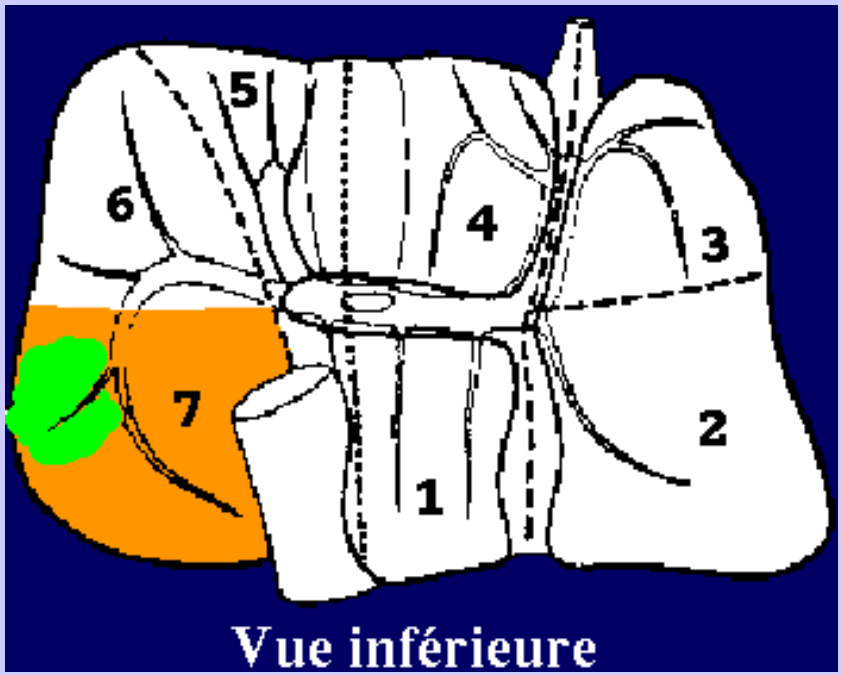
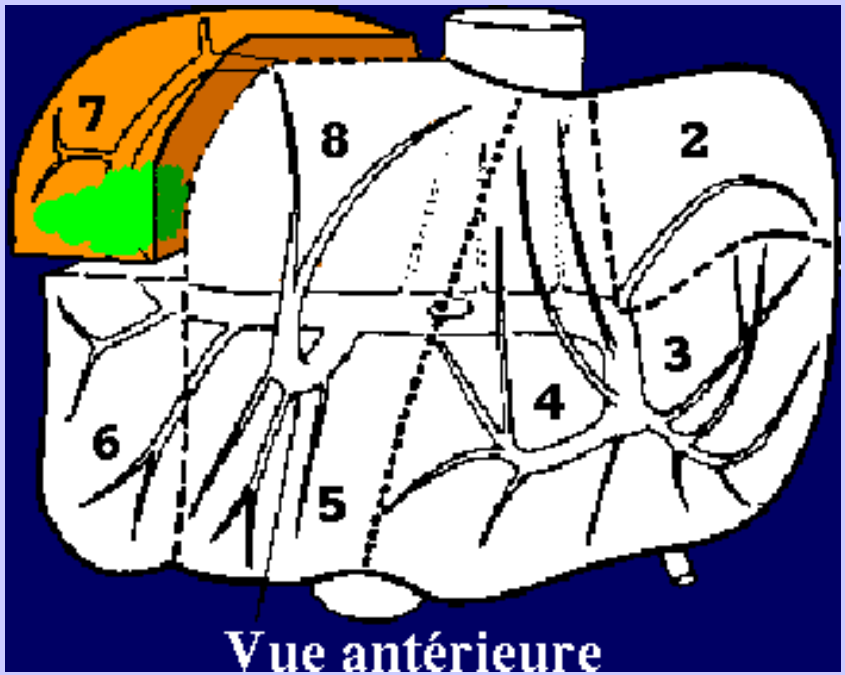
Functional Segments of the Liver

- Defined as a “quasi-autonomous” territory of the liver
- Basis for surgery planning

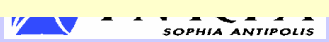




Functional Segments of the Liver

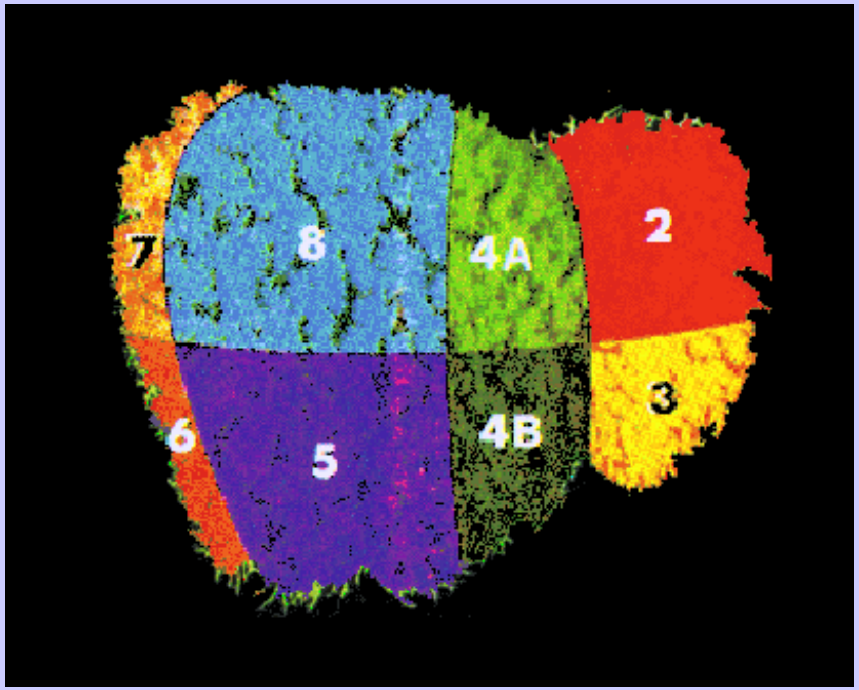
- Different Definitions of Functional Segments:
  - Couinaud with 8 segments (portal and suprahepatic veins)
  - North American (arteriobiliary systems)
  - Healey and Schroy (arteriobiliary systems)
  - Surgical (external landmarks)
- Still Active Debate

Liver Anatomy: Portal (and Suprahepatic) or Biliary Segmentation, C. Couinaud, Digestive Surgery, 1999;No 6, 16:459-467

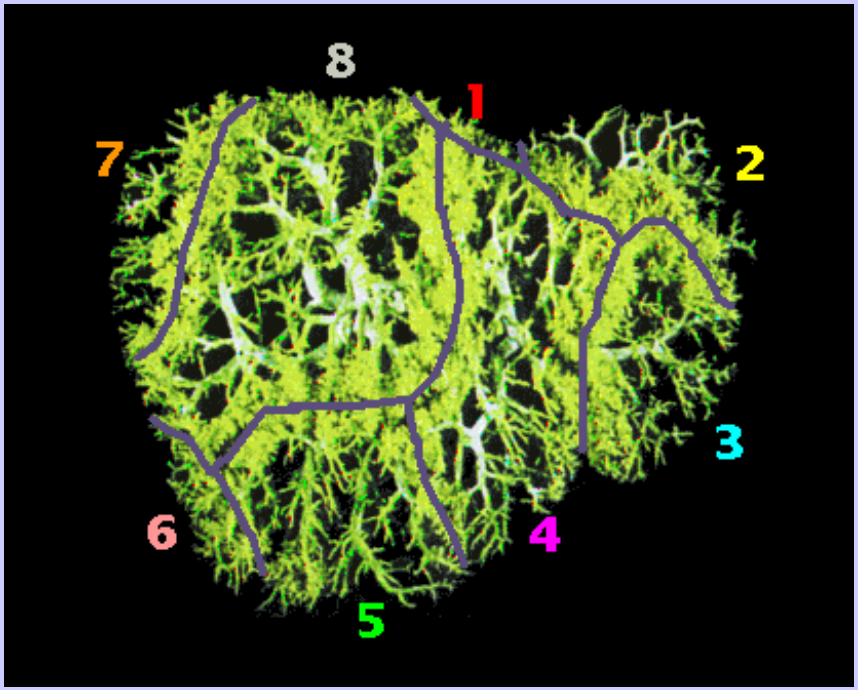


Functional Segments of the Liver

Surgical Functional Segmentation of the liver based on planes



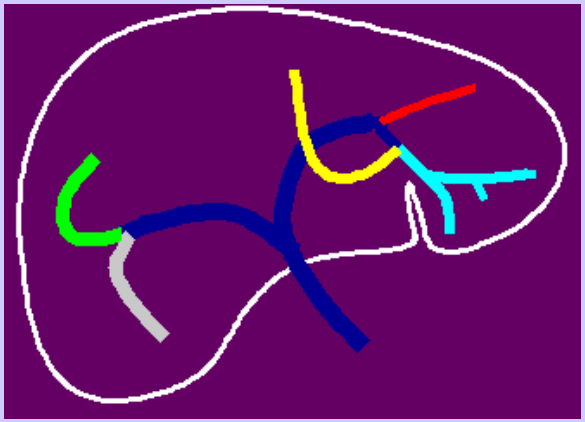
Portal-based Functional Segmentation of the liver



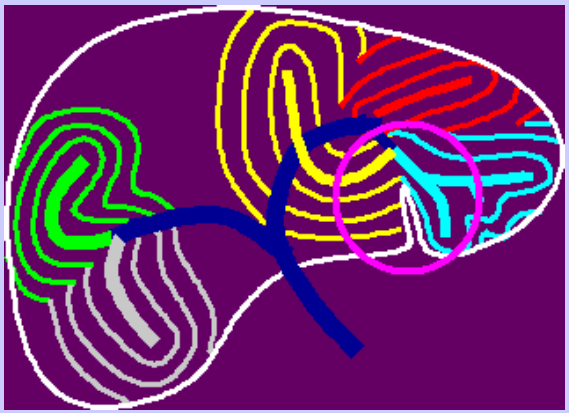
J. Fasel, D. Selle, and C. Evertsz et al. Segmental anatomy of the liver: Poor correlation with ct. *Radiology*, 206:151–156, 1998.

Automatic Functional Segmentation

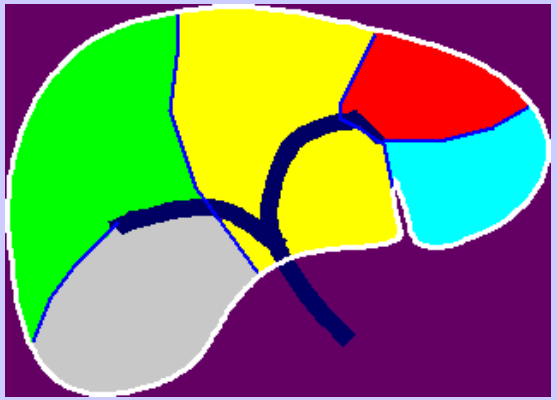
- Solely based on the Portal Vein
- Segments are regions surrounding given part of the portal vein



Labeling the portal Vein



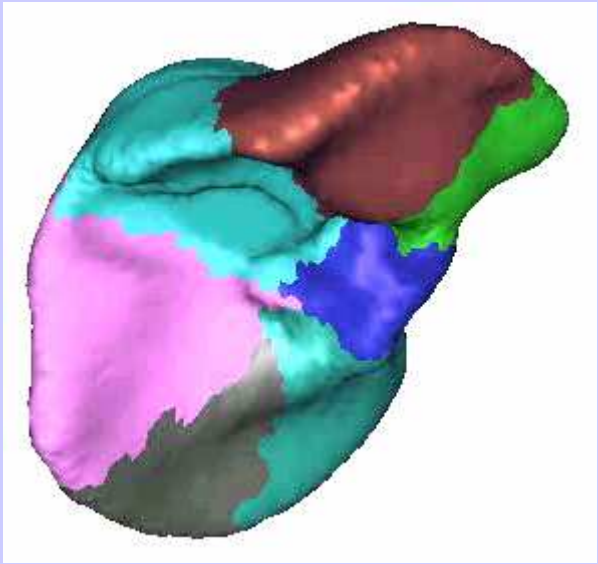
Dilation in a non convex region



Building Segment Surfaces

Labeling of the Portal Vein

- Can be done manually
- Automatic labeling
  - Use liver segmentation to define prior knowledge of segment location
  - Use hierarchical approach : coarse to fine



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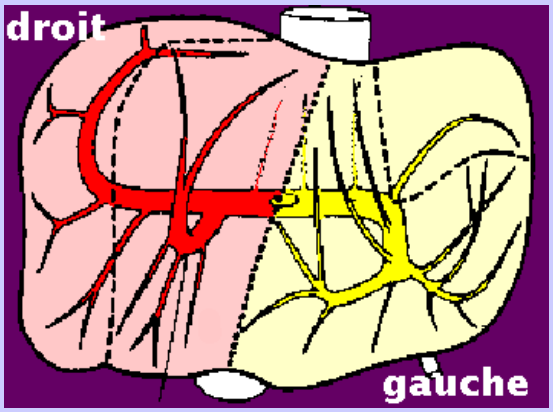
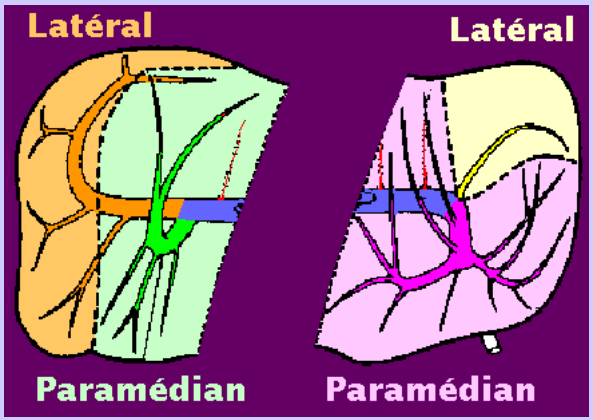
Labeling of the Portal Vein (2)

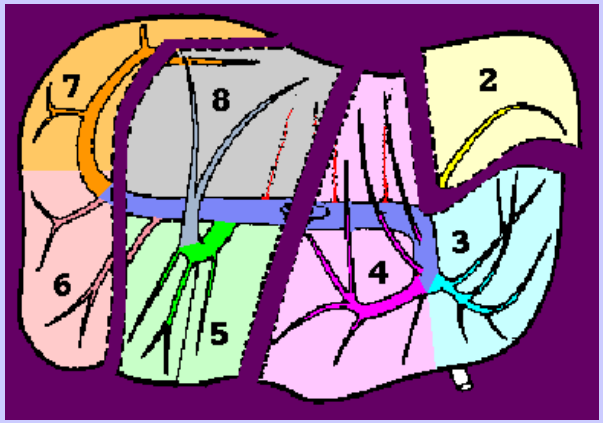
- Hierarchy:



Right and Left Lobes



Two Sectors for each lobe



Two Segments per sector

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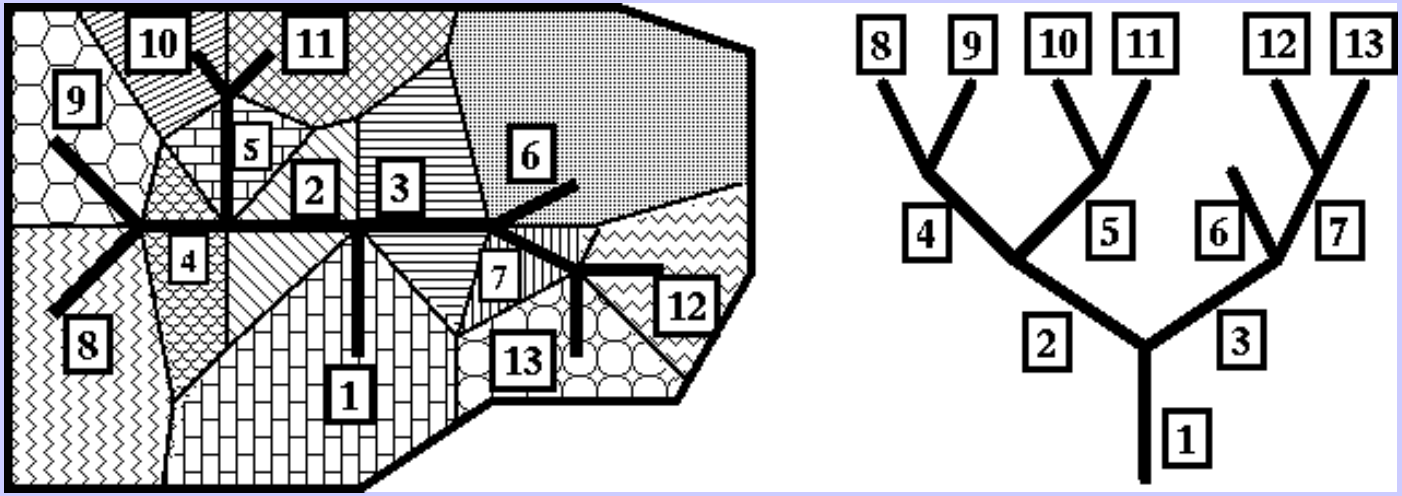
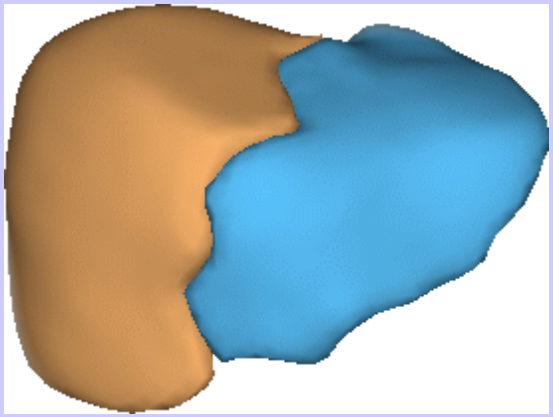
Labeling of the Portal Vein (3)

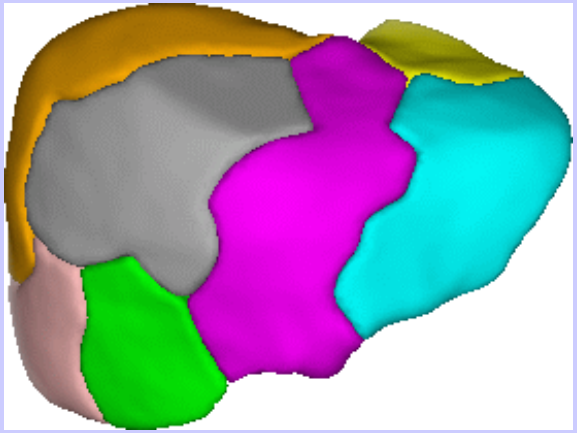
- Start labeling the leaves then progress towards the root
- Solve conflicts by taking into account :
  - prior knowledge on segment volume
  - prior knowledge on segment location



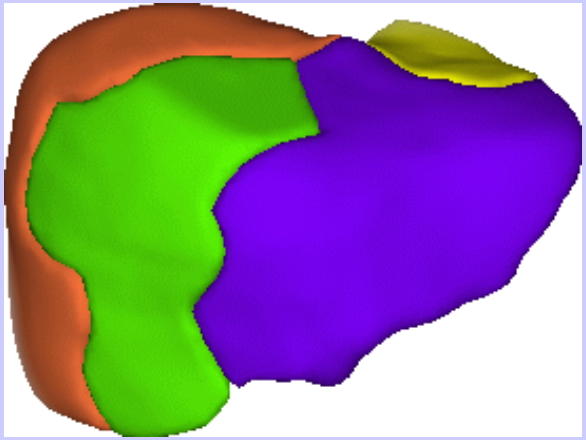
Liver Functional Segmentation



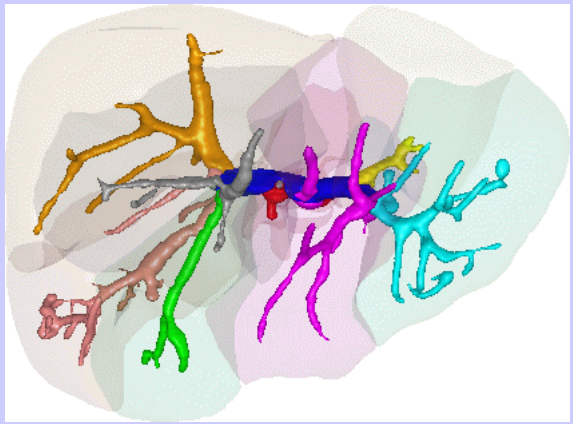
Right and Left Lobes

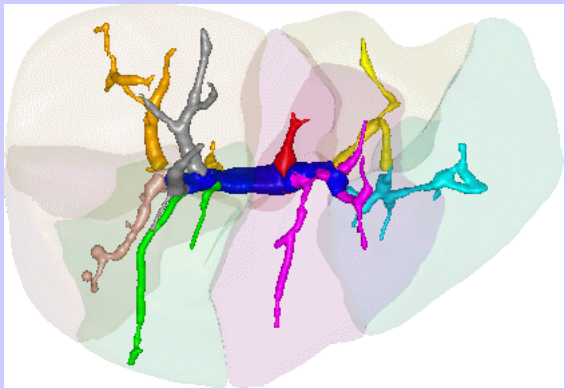


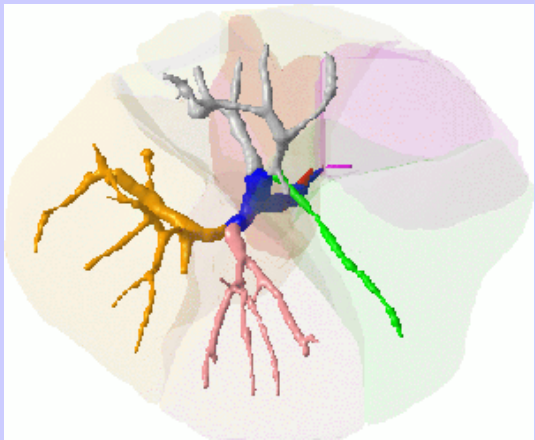
Two Sectors for each lobe



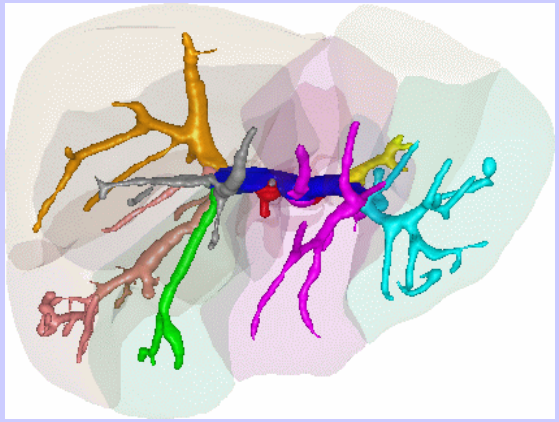
Two Segments per sector

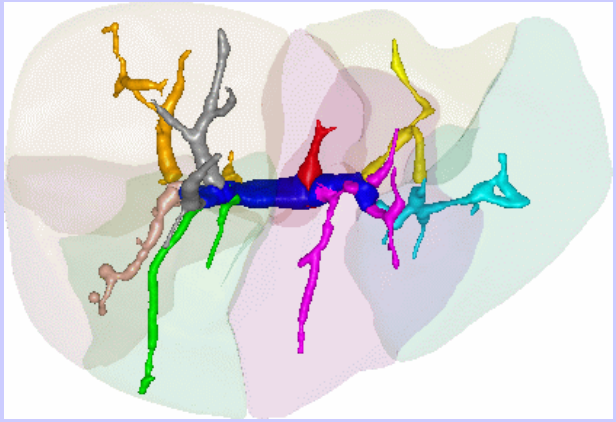


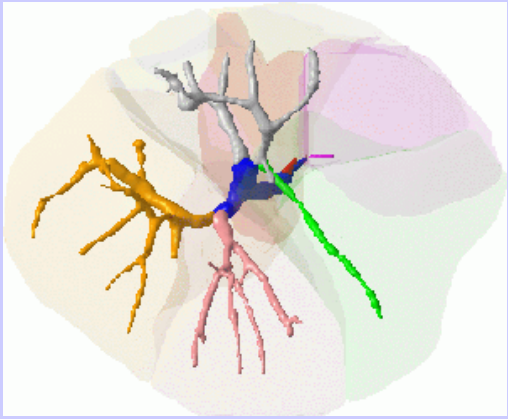


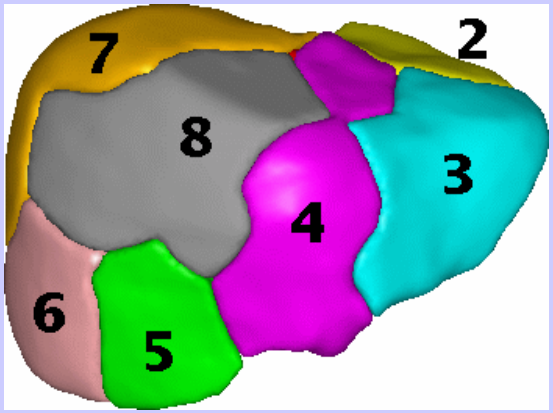


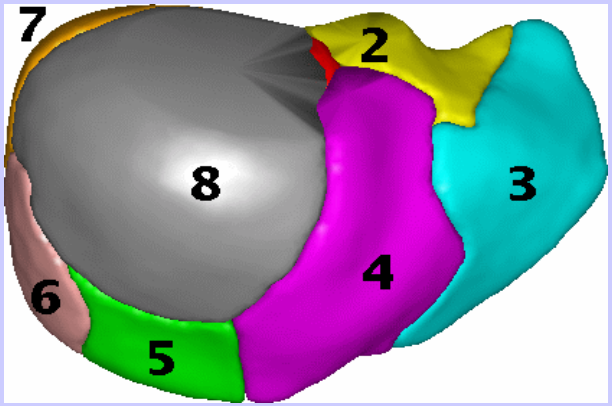
Liver Functional Segmentation (2)

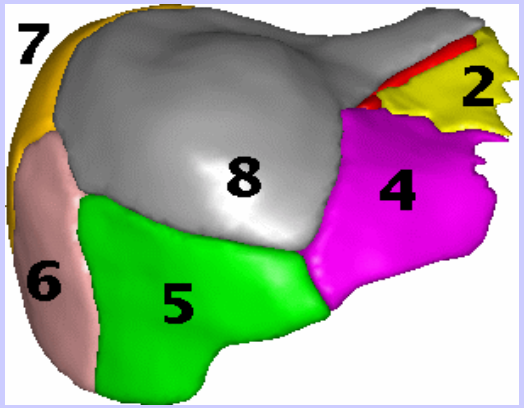












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Overview

- Introduction
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  - Surgery Simulation
- Conclusion

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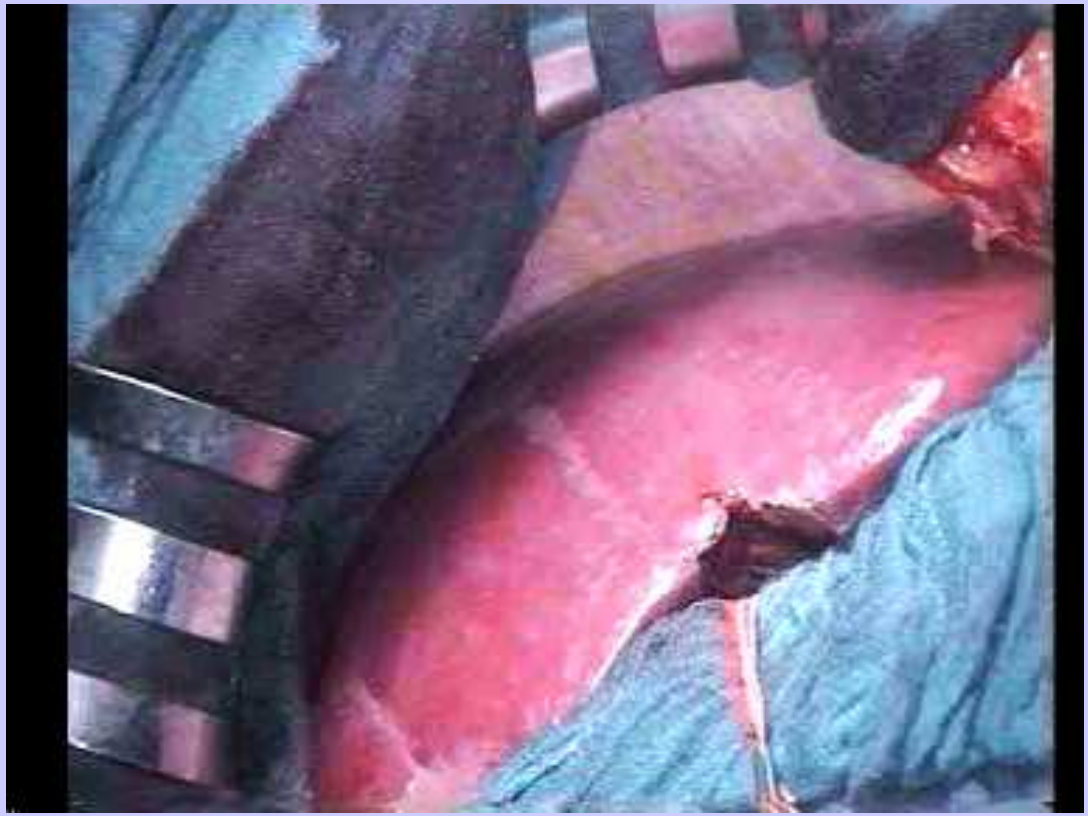
Augmented Reality

- Fusion between pre-operative imaging and video images



Manual Registration
Ongoing Research

Joint Work with IRCAD

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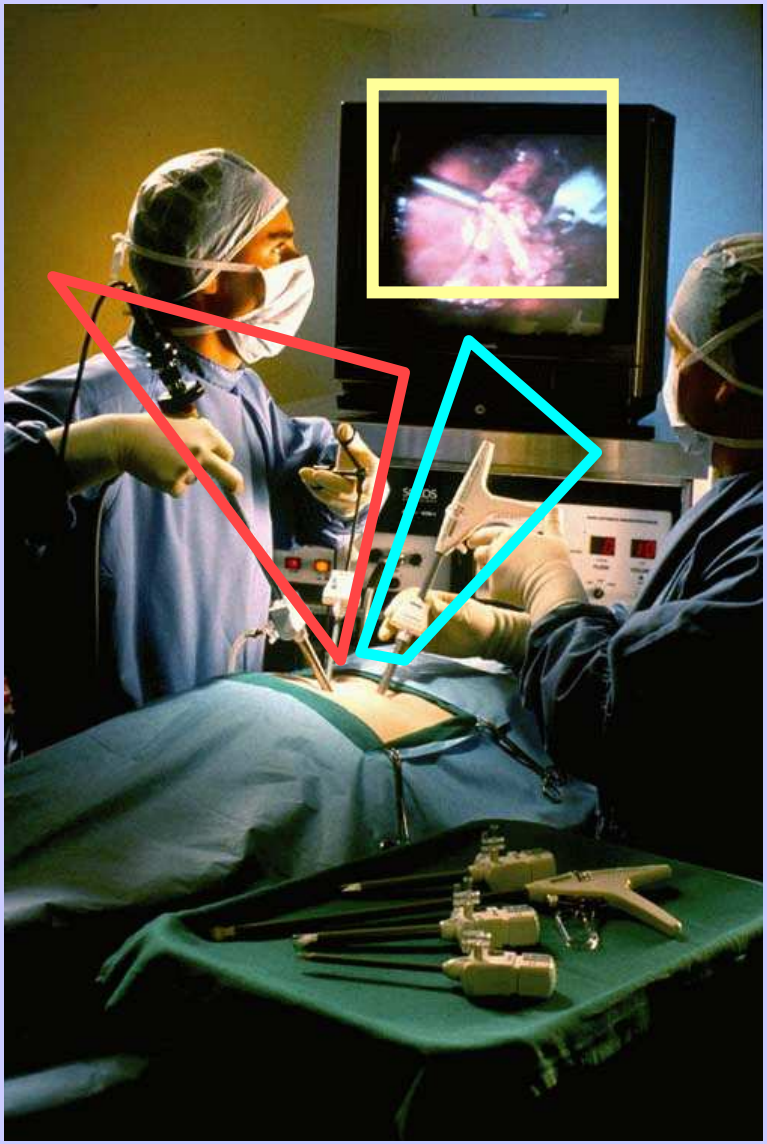
Need for Training



- Hand-eye Synchronisation
- Camera being manipulated by an assistant
- Long instruments going through a fixed point in the abdomen

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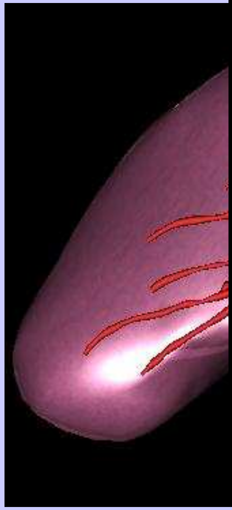
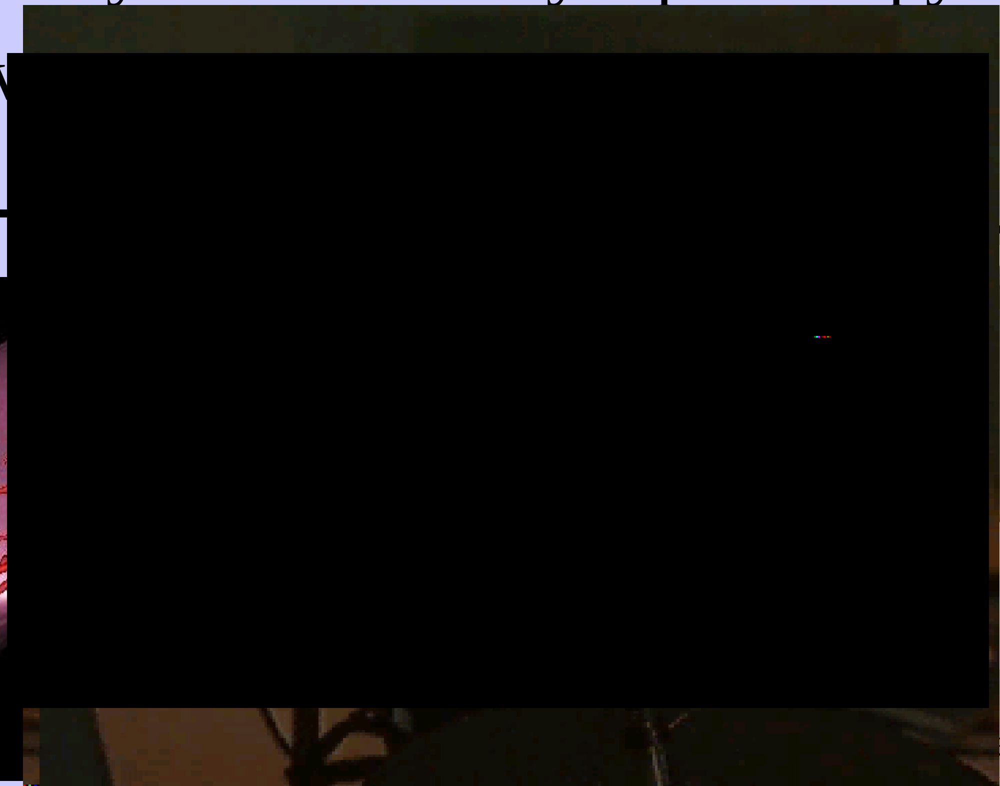
EPIDAURE SIMULATION

[Cotin, 1997] [Picinbono, 2001] [Forest 2003]

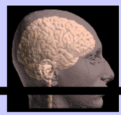
- Hepatectomy Simulation by laparoscopy
- Include v





egments

, 1998])



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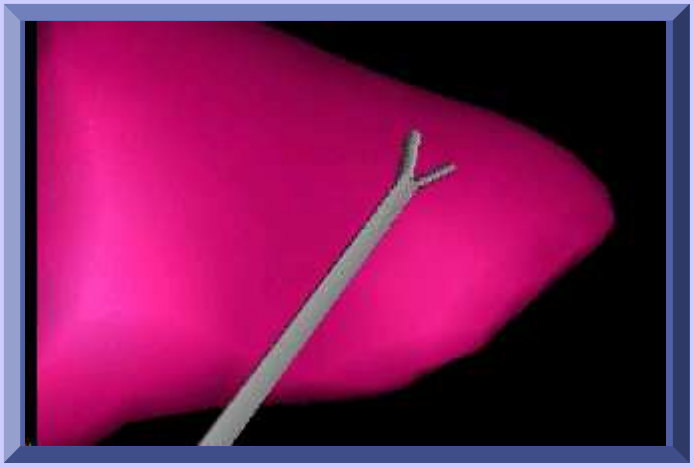
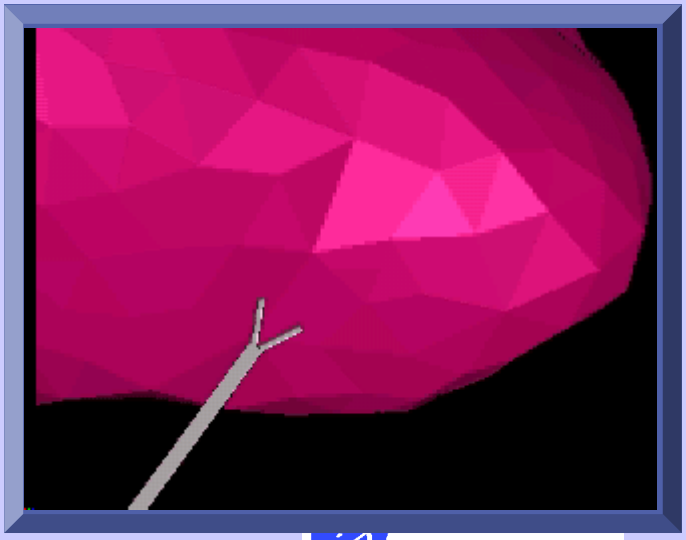
Modeling basic surgical gesture

Gliding



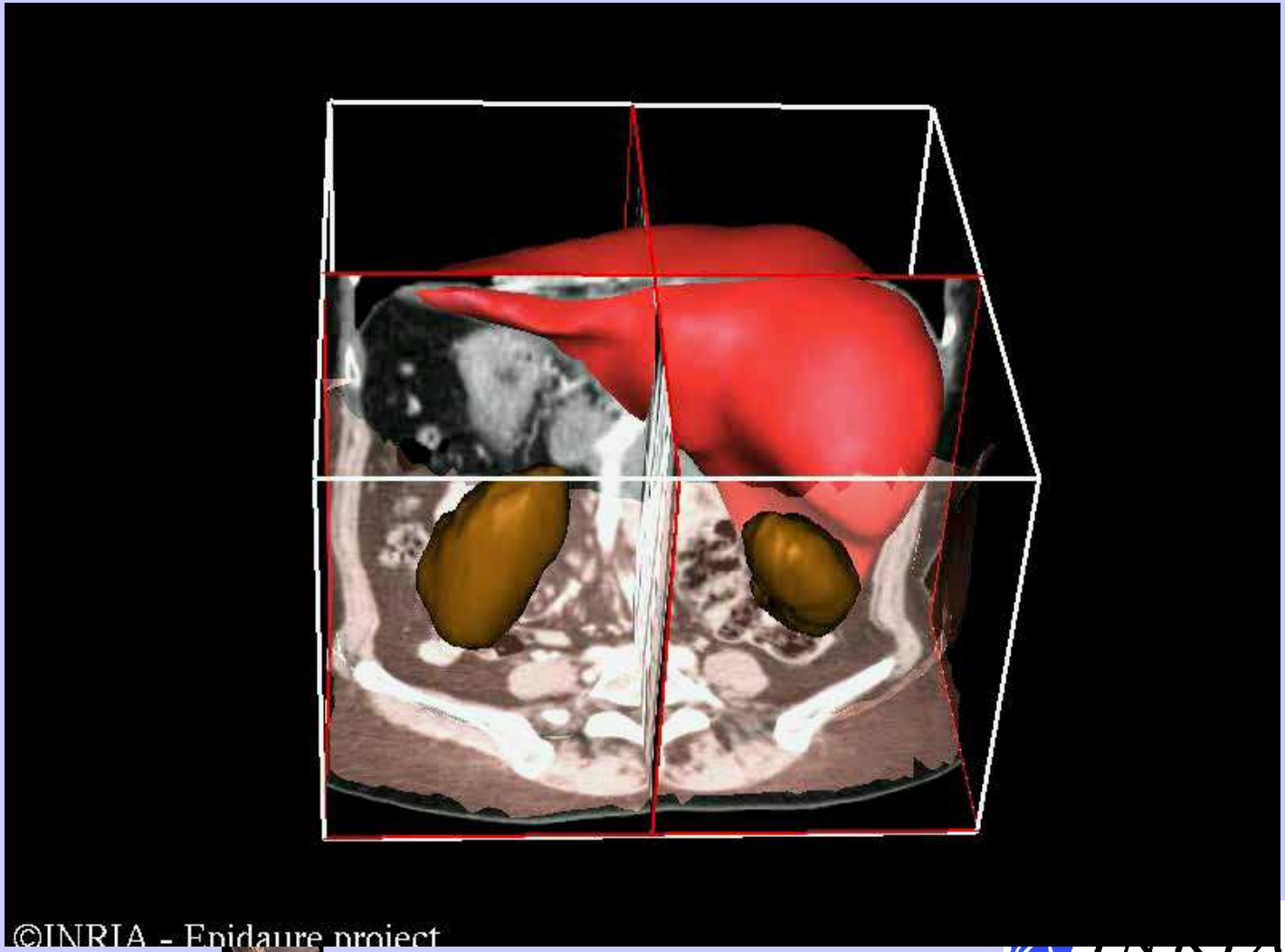
Gripping

Cutting (pliers)



Cutting (US)

Complete Simulation



Conclusion (1)

- Liver Segmentation :
  - Use of Deformable Models to make the segmentation more robust
  - Interactive correction of segmentation is possible
  - New CT imaging
    - No breathing artifacts
    - Less Texture
    - More Slices

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Conclusion (2)

- Lesion Segmentation :
  - Used as Second Reading in a CAD system
  - Follow-up of tumor volumetry for oncological studies (registration problems)
- Functional Segmentation :
  - Still an ill-posed and open problem
  - Relies on good segmentation of the portal vein
- Need for more robust algorithms and more validation

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L. Soler, G. Malandain, and H. Delingette. Segmentation automatique : application aux angioscanners 3D du foie. Traitement du signal, 15(5):411-431, 1998

J. Montagnat and H. Delingette. Globally constrained deformable models for 3D object reconstruction. Signal Processing, 71(2):173--186, 1998

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L. Soler, J.-M. Clément, C. Koehl, H. Delingette, G. Malandain, N. Ayache, O. Dourthe, and J. Marescaux. An Automatic Virtual Patient Reconstruction from CT-Scans for Hepatic Surgical Planning. In Medicine Meets Virtual Reality (MMVR'2000), Studies in Health Technology and Informatic, Los Angeles, January 2000

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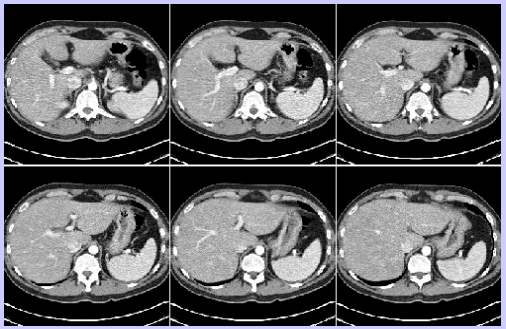

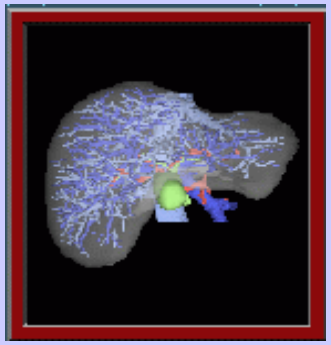

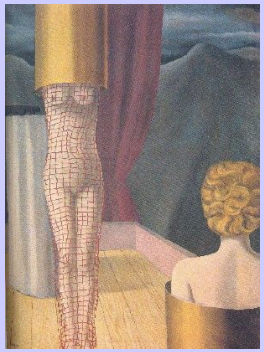

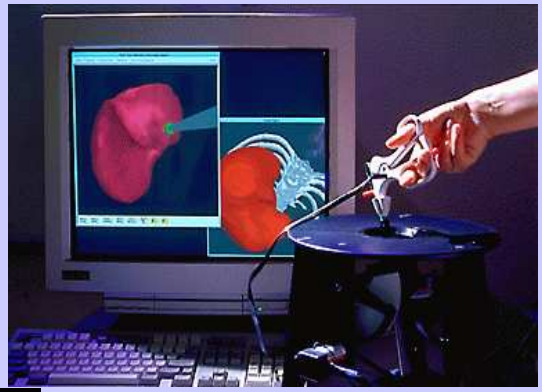

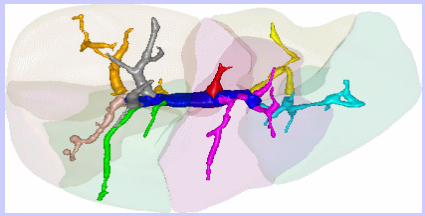

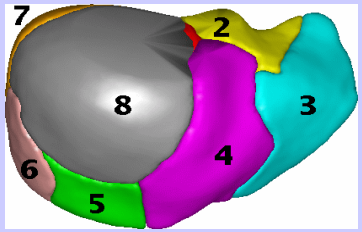

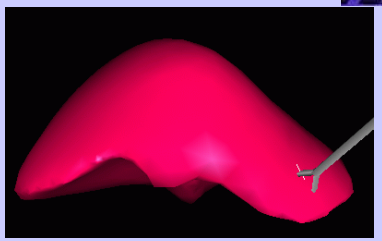

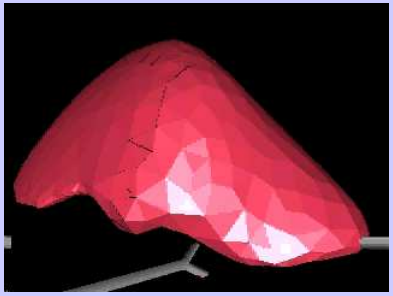

On line references and reports
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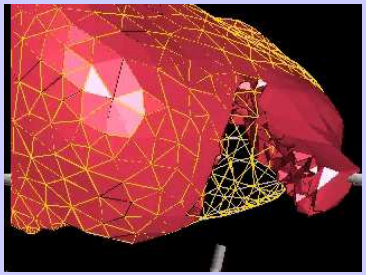

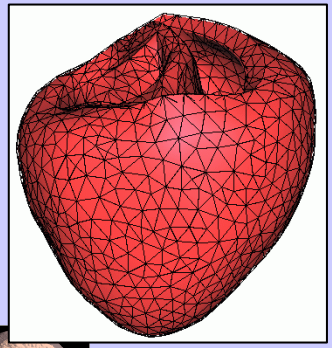

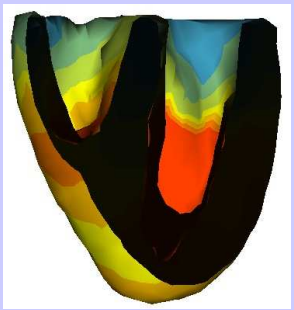

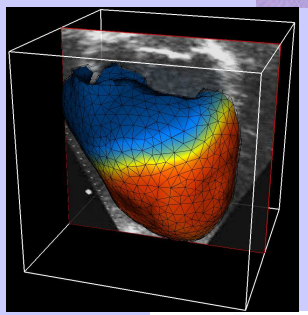

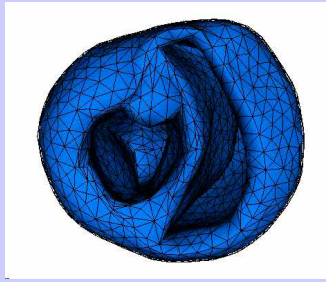

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