Interactive and Automatic Segmentation of Tomographic Data

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What Is Segmentation?

- The process of isolating objects of interest from the rest of the scene (Castleman, 1979)
- The process of partitioning an image into non-intersecting regions such that each region is homogeneous and the union of no two adjacent region is homogeneous (Pal, 1993)
  - Subsequent *classification* is required to identify objects of interest

Tomographic Data and Segmentation

- Large number of anatomically distinct objects
- Variability of object shapes
- Variability of scanner parameter settings
- 3D nature of objects
- High demands on segmentation precision

Segmentation Techniques

- Image based / knowledge based
- Automatic / interactive
- 2D / 3D

Image Based / Knowledge Based

- Image-based, image properties
  - Discontinuity-oriented
    - Boundary detection, edge linking
  - Similarity-oriented
    - Thresholding, region-growing
- Knowledge-based
  - Algorithmic information encoding
    - Homogeneity, density range, shape
    - Distance (e.g., from the skull surface)
  - Rule based systems: *If(condition) then…*

Automatic / Interactive

- Automatic systems
  - Processing of numerous data sets
  - Specific tasks (brain from MRI data)
  - Needs special parameter settings
  - Often visual verification is necessary
- (Semi)interactive systems
  - Based on operator's knowledge & experience
  - High precision
  - Laborious
  - 2D (slice) and 3D approaches

2D / 3D

- 2D techniques
  - Manual labeling by paintbrush tools
  - Contour tracking or thresholding
  - Problems with 3D anatomy
- 3D techniques
  - Connected components in 3D
  - Problems with anatomically distinct objects

Geometric Features

- Use discontinuities in the image to isolate distinct elements:
  - Points
  - Lines
  - Edges

Point Detection

-1	-1	-1
-1	8	-1
-1	-1	-1

$$R = w_1 z_1 + w_2 z_2 + \cdots + w_9 z_9 = \sum_{i=1}^{9} w_i z_i$$

- A point is detected if |R| > T
  - T is a nonnegative threshold
- Adjust kernel to detect points of other sizes

Line Detection

- Use specific masks to detect lines of a particular slope

-1	-1	-1
2	2	2
-1	-1	-1

-1	-1	2
-1	2	-1
2	-1	-1

-1	2	-1
-1	2	-1
-1	2	-1

2	-1	-1
-1	2	-1
-1	-1	2

Hough transform

- Detection of general shapes (lines circles
- The idea: representation in dual space:
  - Line: $y=kx+q \rightarrow q=y-kx$
  - In the dual space, lines become points

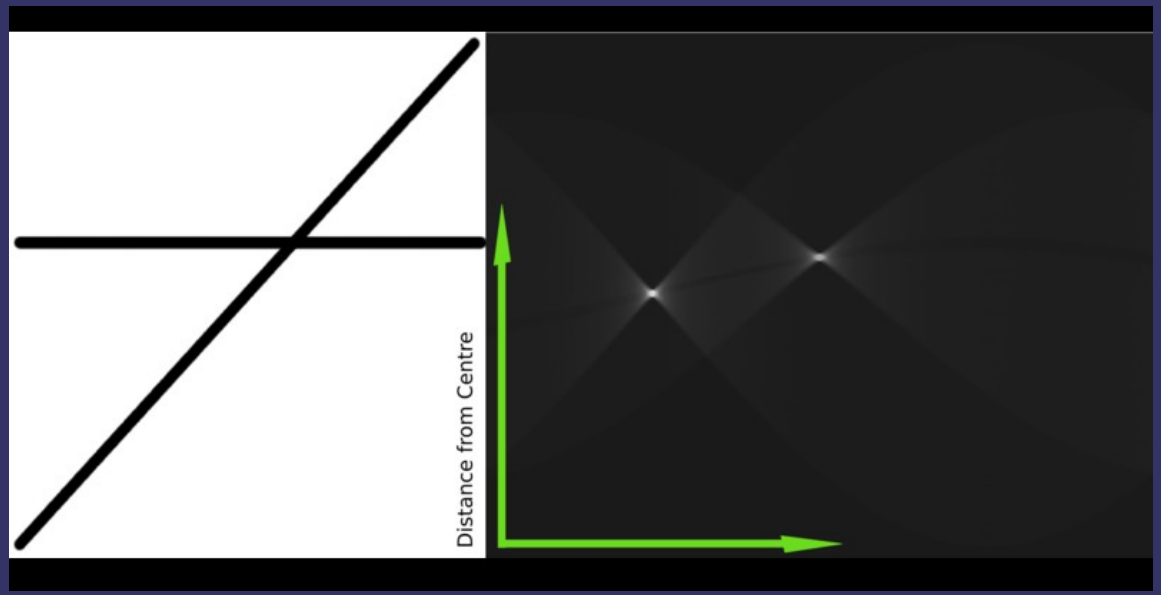


Image source: Wikipedia

Edge Detection

- An edge is the boundary between two regions with distinct gray level properties.
- Rely on derivative operators.
- The most common approach for detecting meaningful discontinuities.

Sobel Operators

- Used to compute the derivatives:

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

- In formulas:

$$G_x = \left(z_7 + 2z_8 + z_9\right) - \left(z_1 + 2z_2 + z_3\right)$$

$$G_y = \left(z_3 + 2z_6 + z_9\right) - \left(z_1 + 2z_4 + z_7\right)$$

$$G = \sqrt{G_x^2 + G_y^2}$$

Gradient Operators

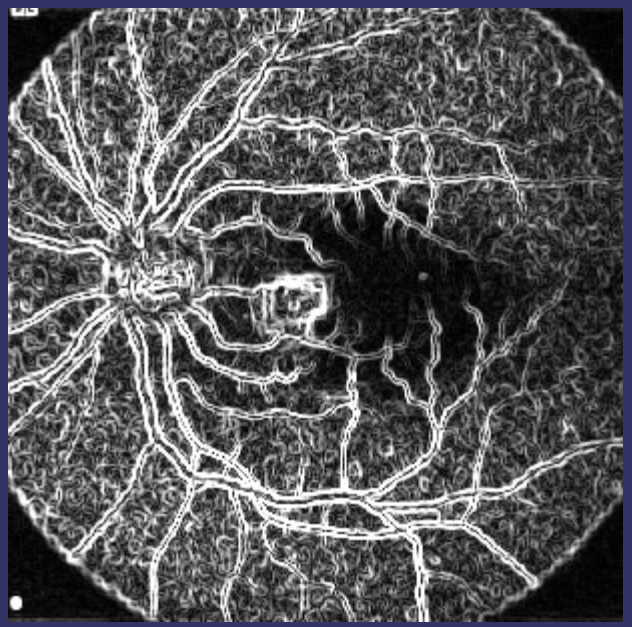
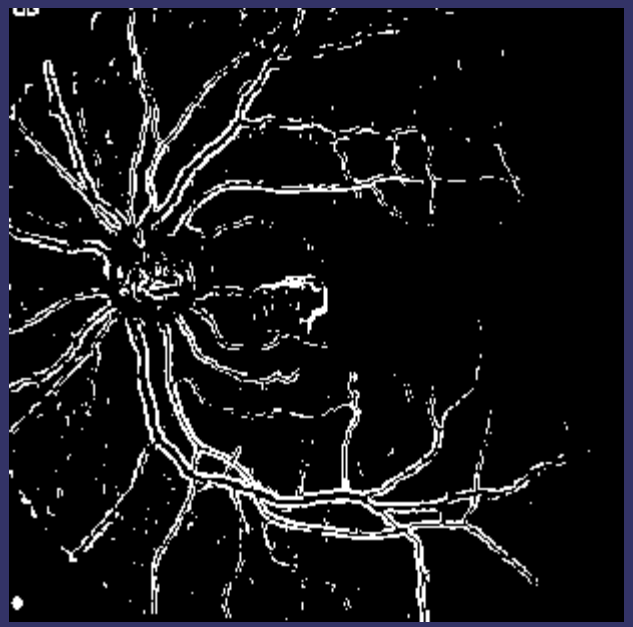
Sobel

Roberts

Prewitt

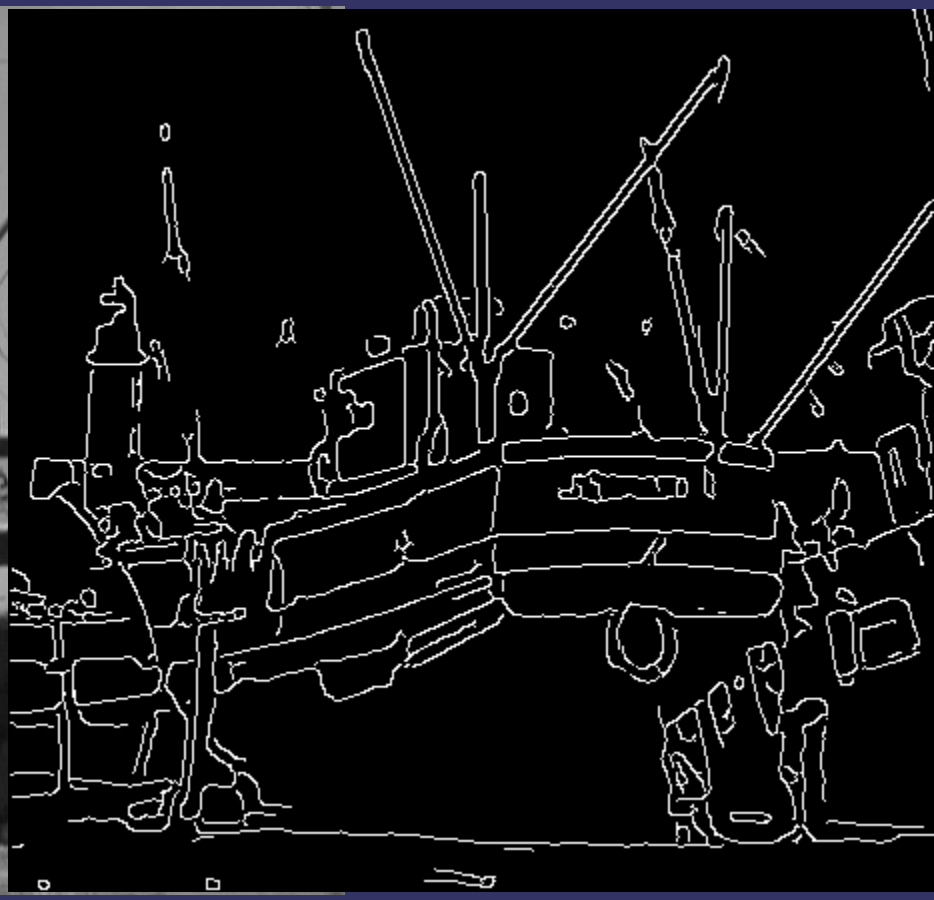
Edge detection from gradient image

- Compare gradient strength to threshold: $|\nabla f(x, y)| \geq T$

Canny edge detector

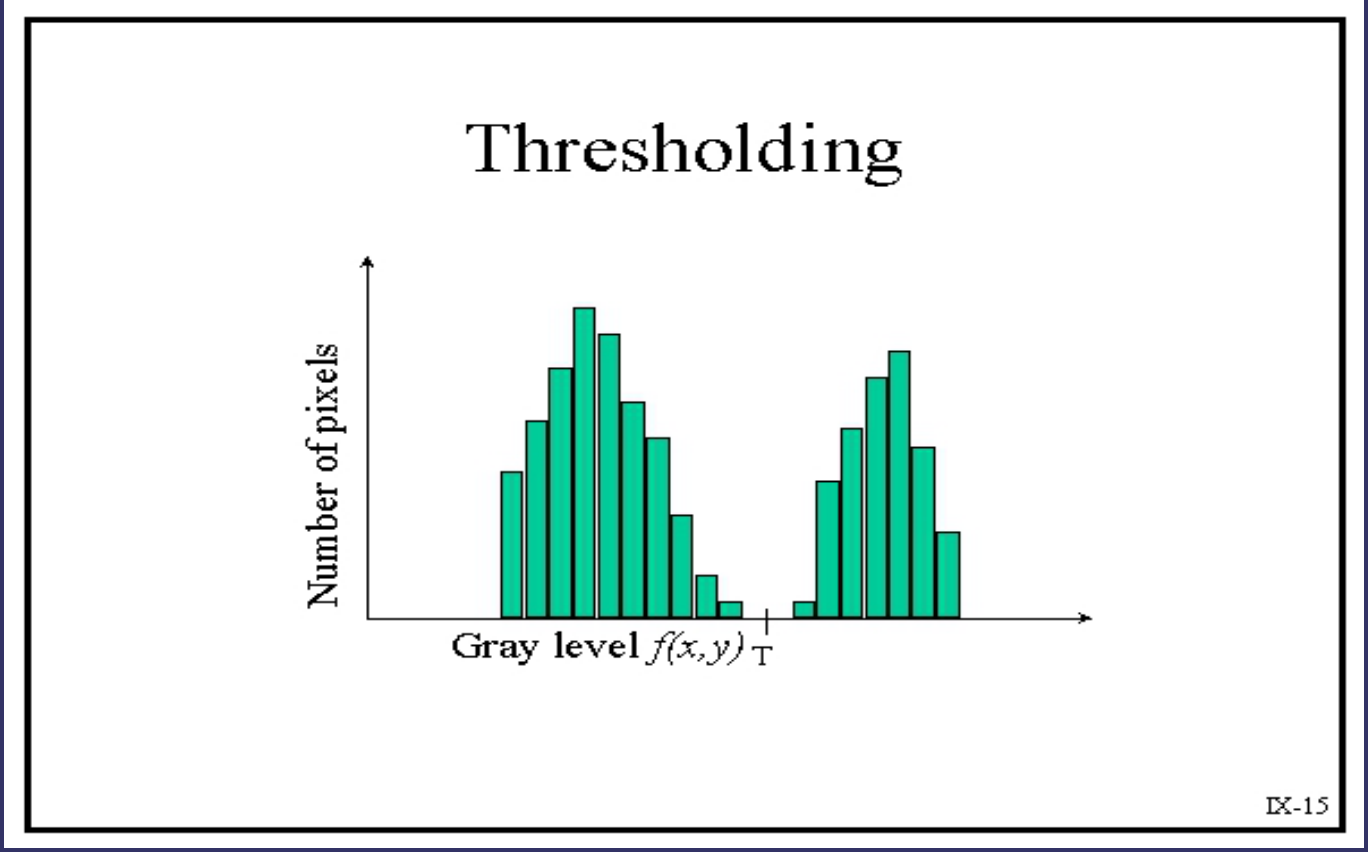
- „optimal“ edge detection
  - Edge strength, orientation, noise suppression



Thresholding

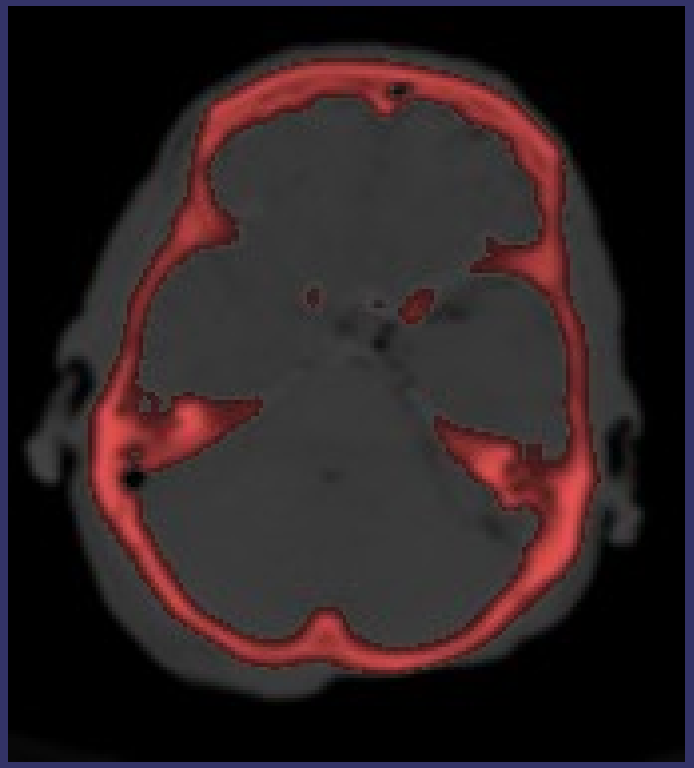
- Labeling operation on a gray scale image that distinguishes pixels of a higher intensity from pixels with a lower intensity value
- The output is usually a binary image.
- Works well when the image histogram is bi-modal.

Thresholding

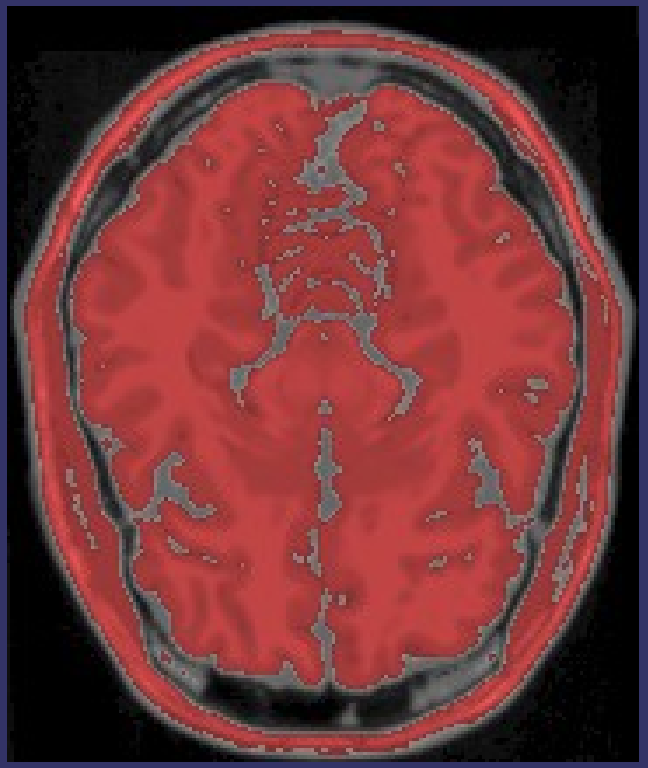


A bimodal histogram

Thresholding



CT data



MRI data

Interactive Segmenation (ISEG)

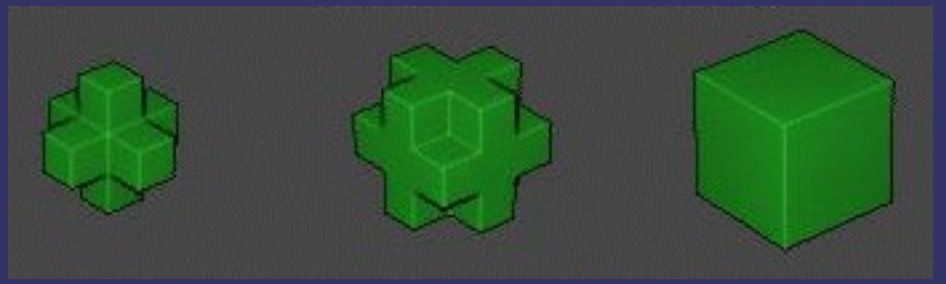
- Anatomic organs are connected and homogeneous:
  - Objects identification by
    - Thresholding (classification)
    - Connected component analysis (CCA)
- Objects are sometimes interconnected
  - Objects separation by morphological operations

Morphologic Operations

- Erosion $O \otimes S$
  - Peeling the outer layer off
- Dilation $O \oplus S$
  - Thickening by adding a layer
- Erosion + Dilation $\neq$ Original !!

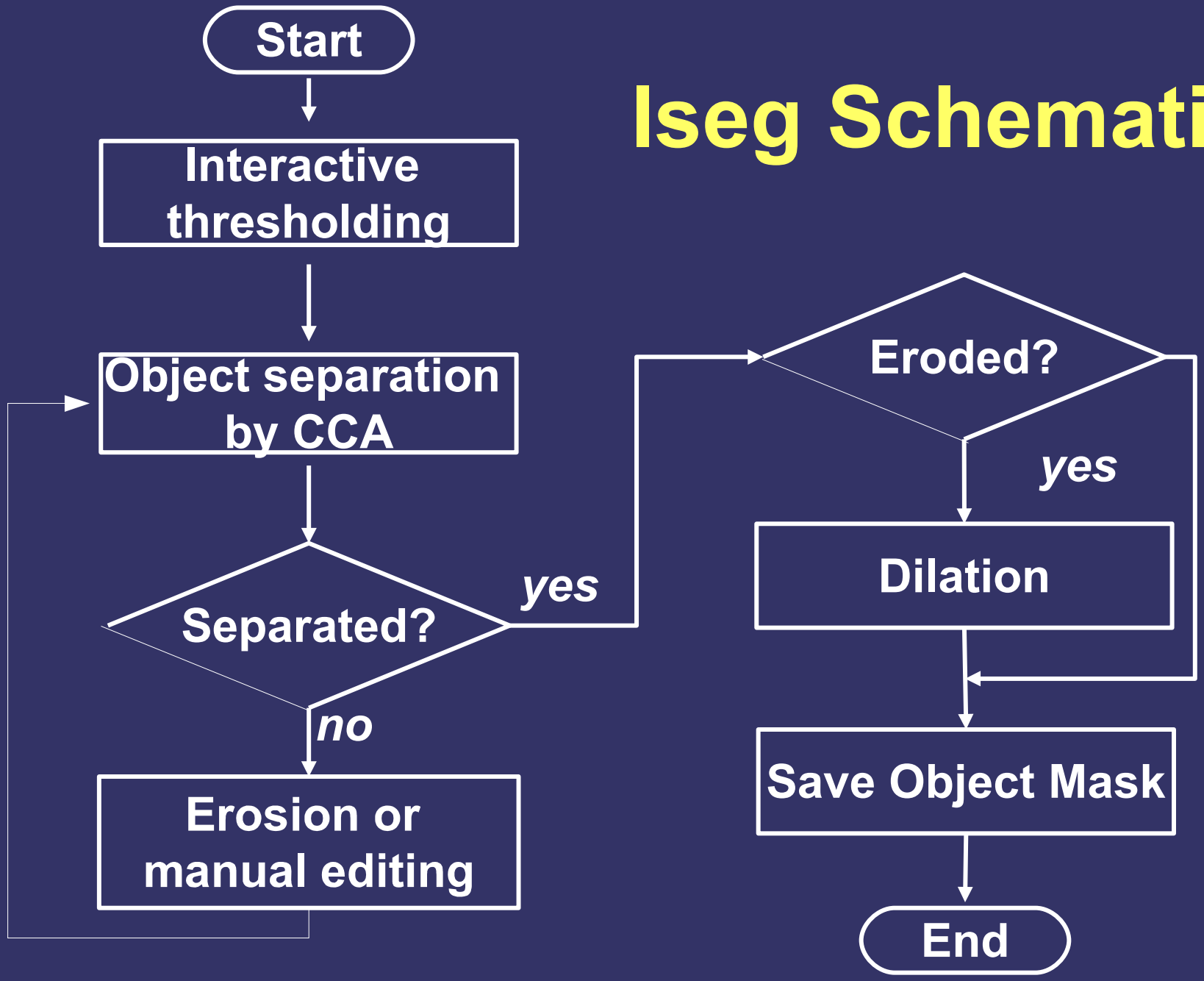
$O \otimes S$

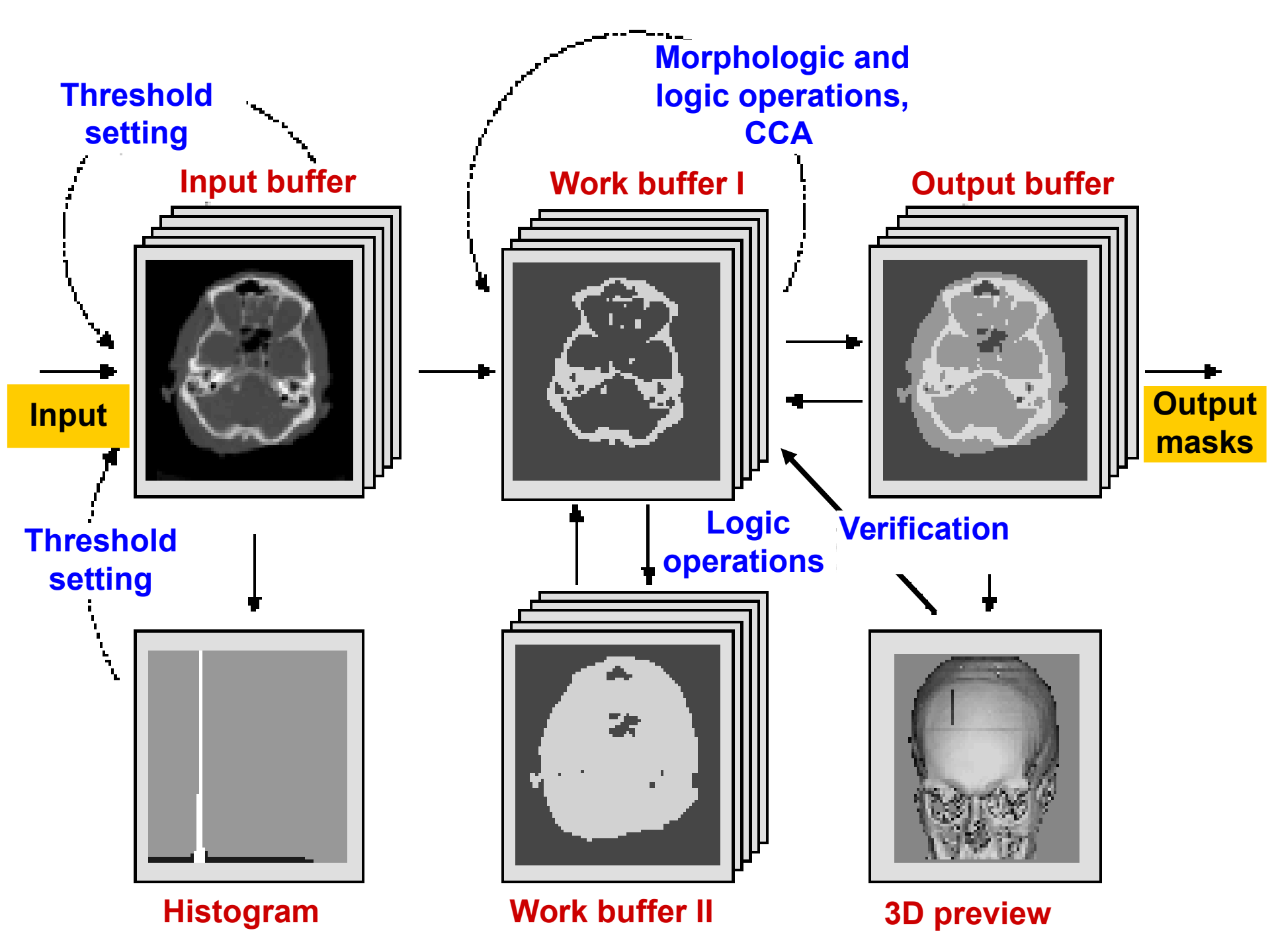
$O \oplus S$



Structuring elements

Iseg Schematic




Threshold setting
Morphologic and logic operations, CCA
Input buffer
Work buffer I
Output buffer
Input
Output masks
Threshold setting
Logic operations
Verification
Histogram
Work buffer II
3D preview

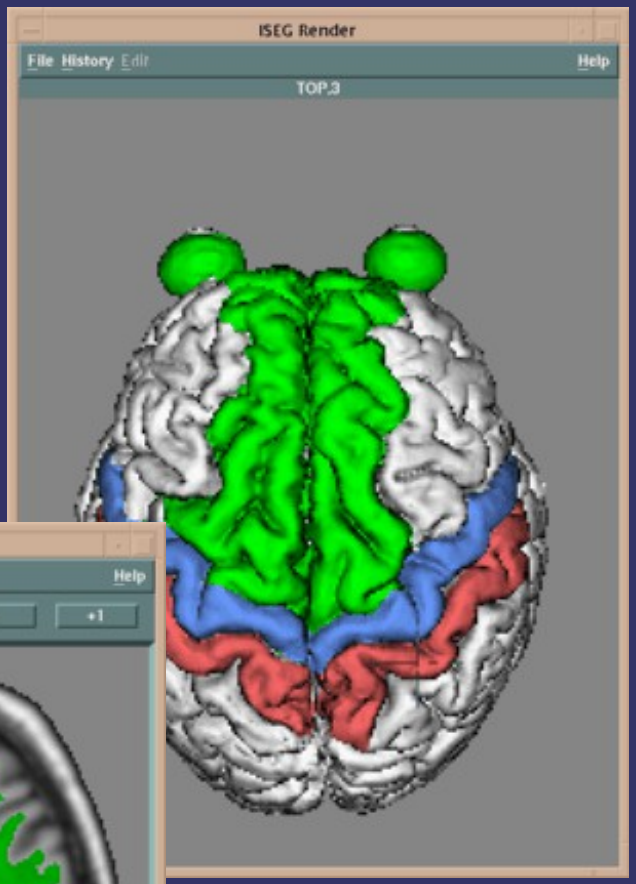
Iseg Data Structures

- Input buffer
  - gray level data
  - Histogram & thresholding
- Work buffer I & II
  - Morphologic, logic (AND, OR, XOR) operations
  - Manual editing of masks
- Output buffer
  - Up to 256 objects
  - Preview (6 orthographic views)

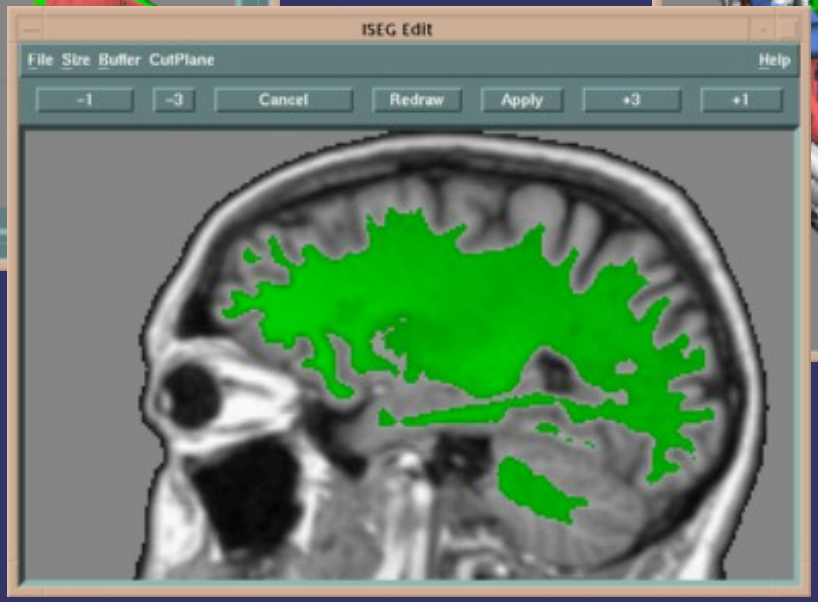
Iseg Implementation

Main window

Histogram



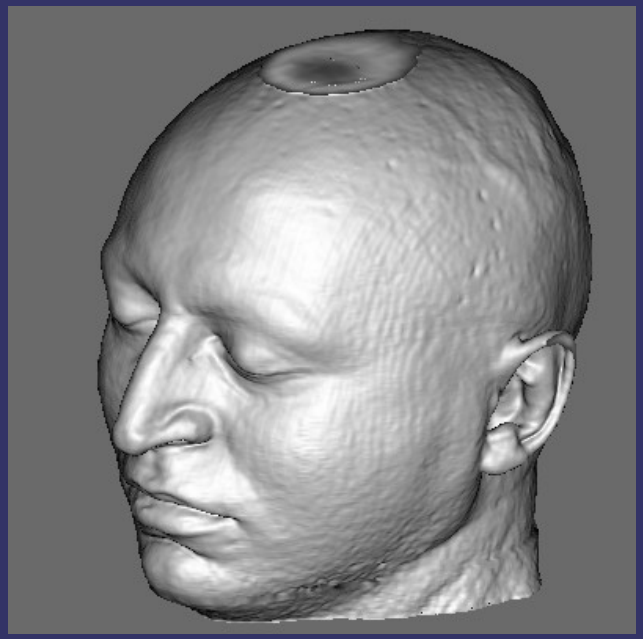
Preview



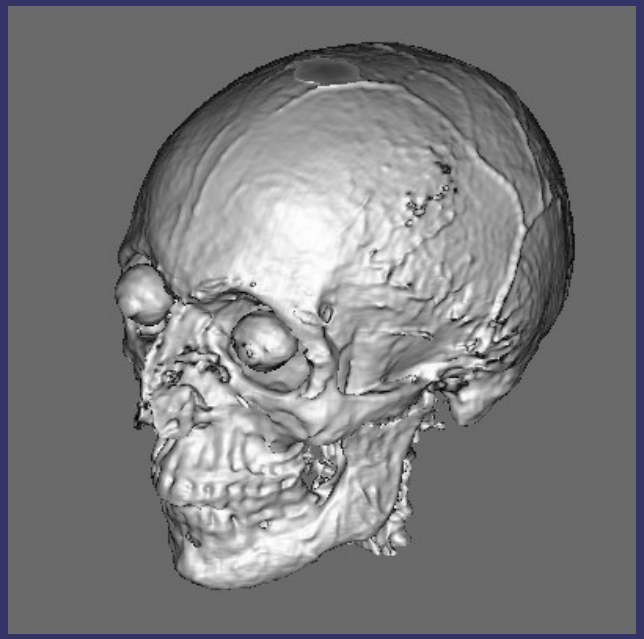
Edit

Iseg Results

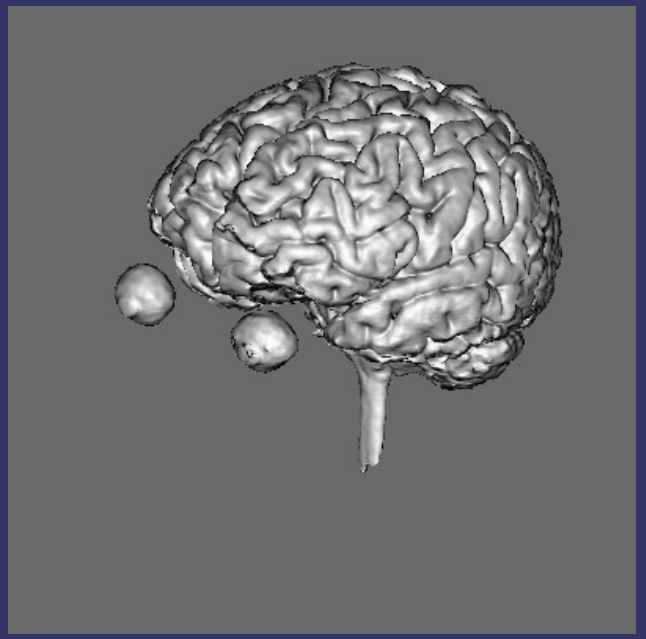
MRI head data segmented in 15 tissues and objects



Head



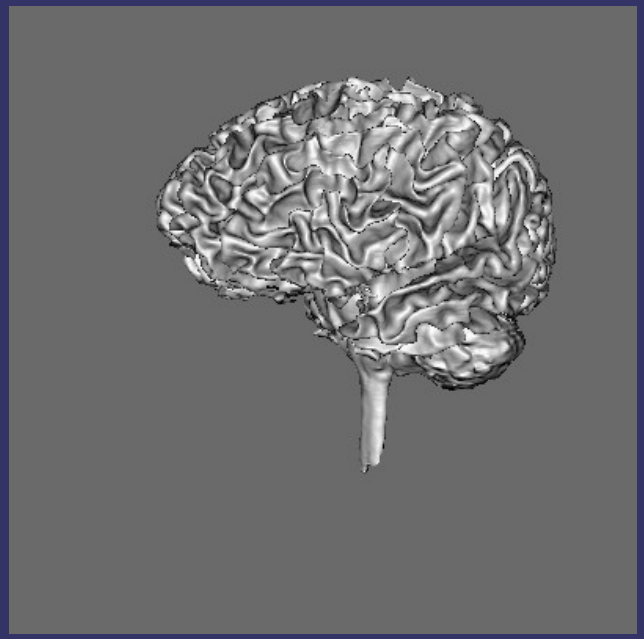
Skull



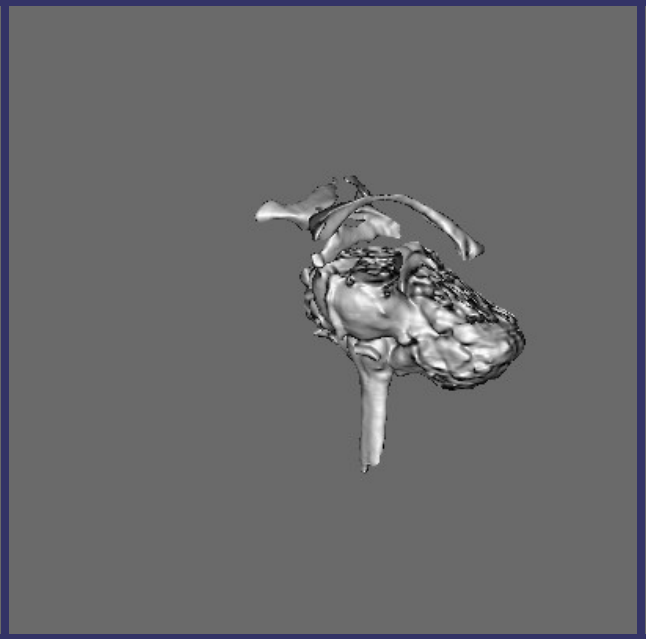
Brain & eyes

Iseg Results

MRI head data segmented in 15 tissues and objects



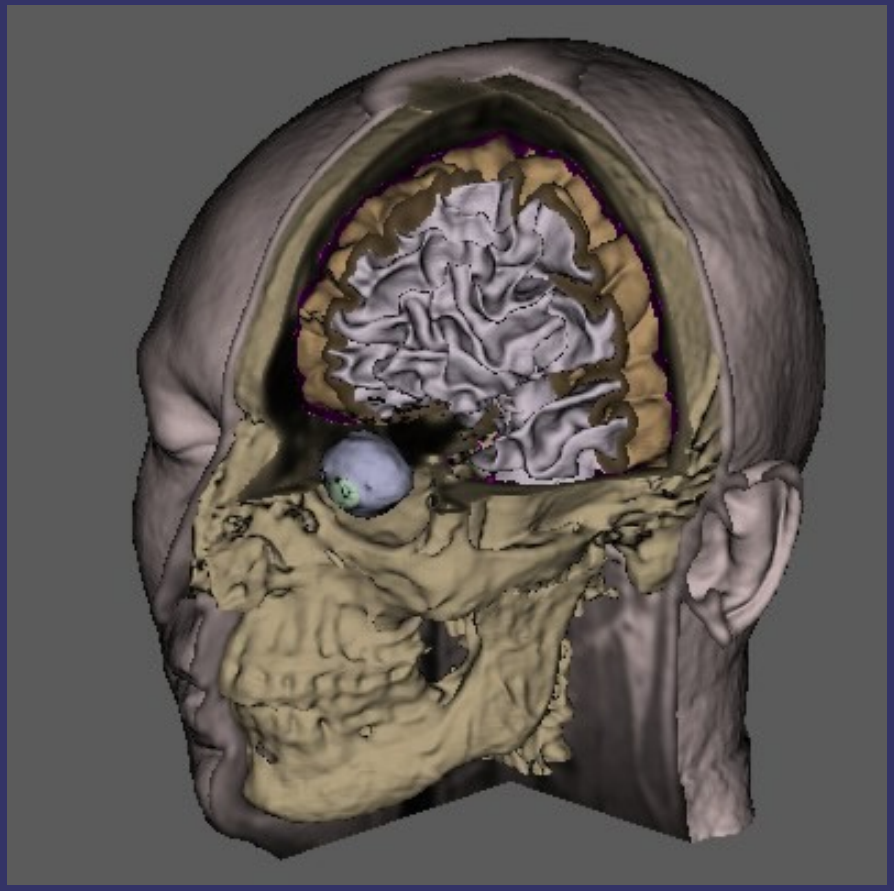
White matter



Cerebellum

Ventricles

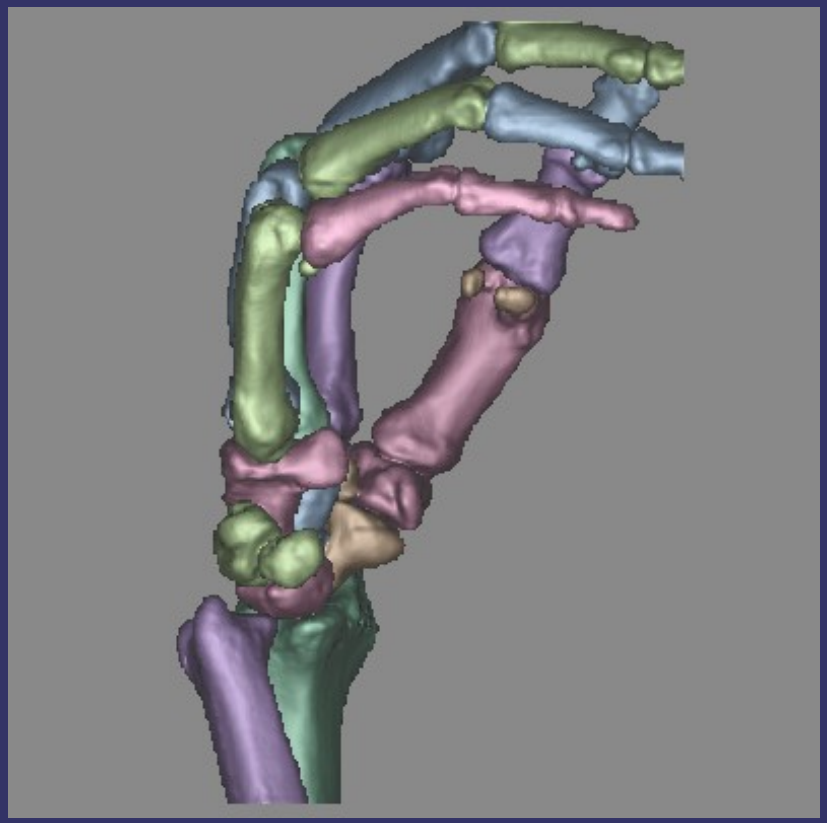
Iseg Results

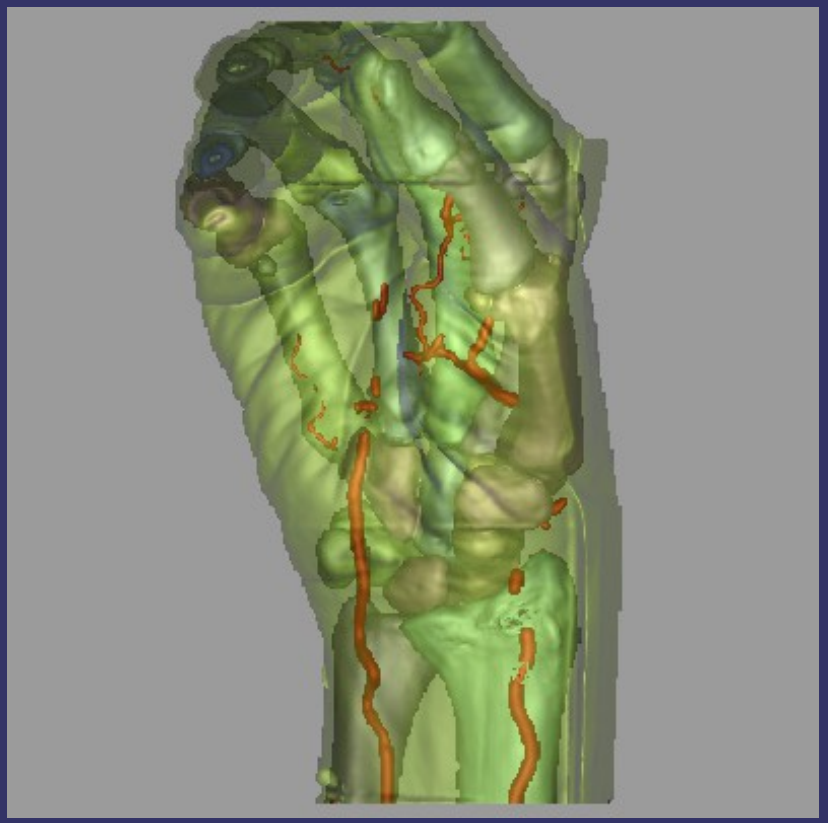


MRI head data

Iseg Results

CT hand data





Iseg Summary

- Segmentation of arbitrary objects
- Data and parameter independent
- Quite fast
- Feeling of result fidelity

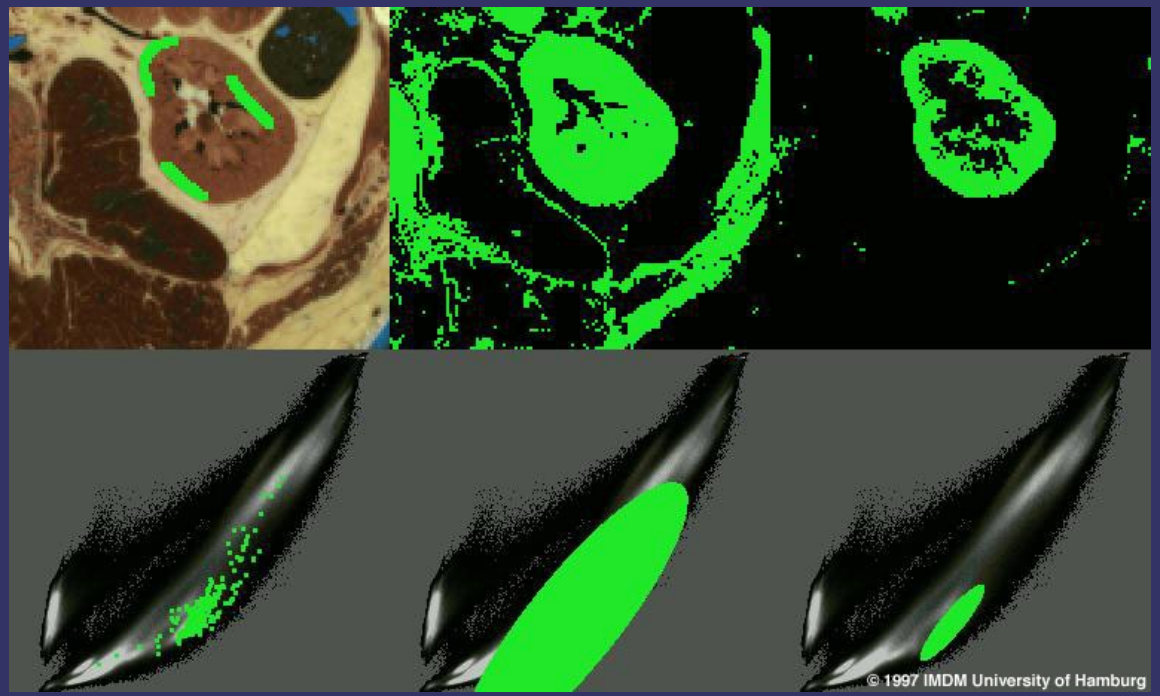
- Alternatives of thresholding:
  - Any segmentation technique

Demos

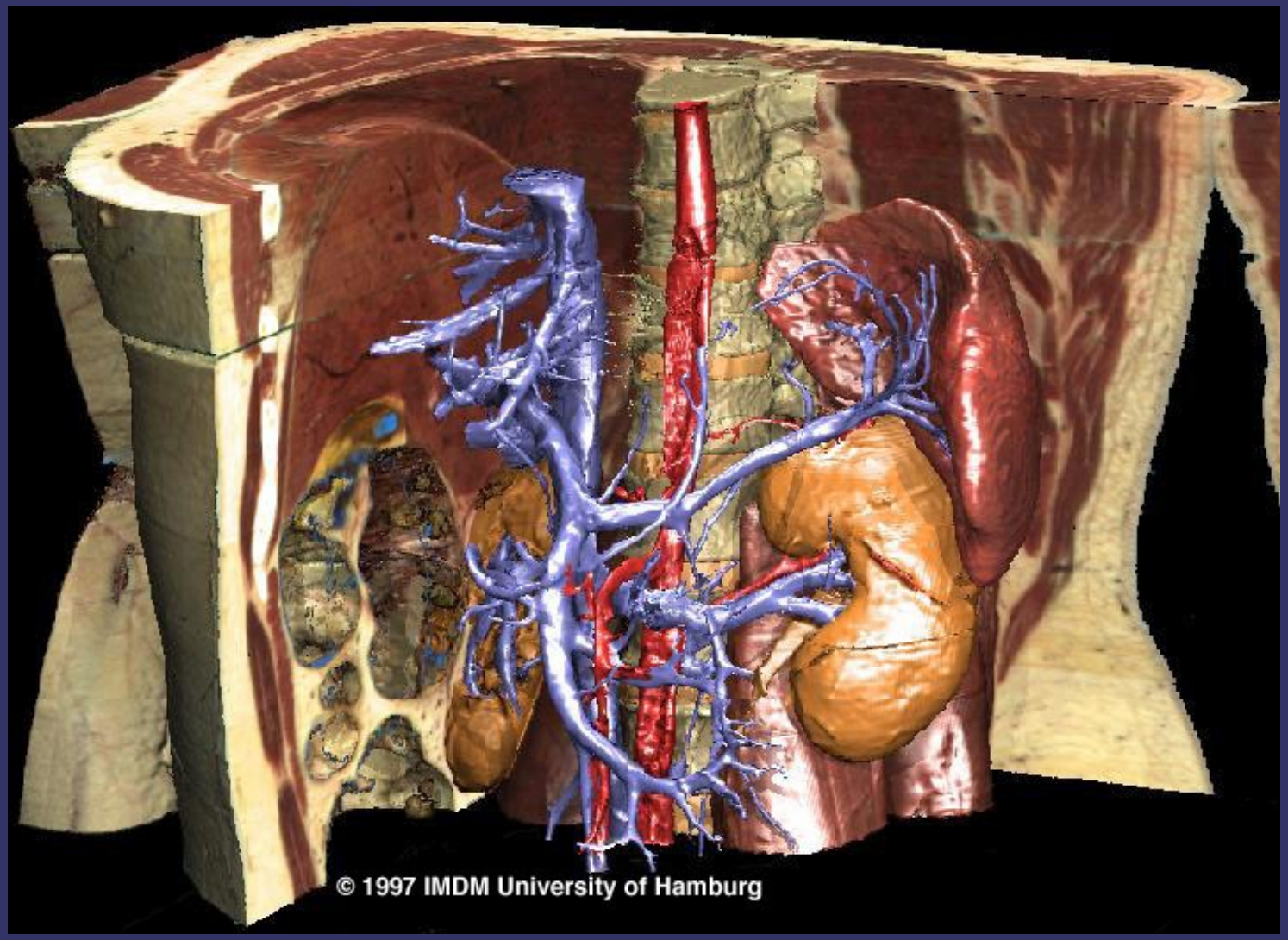
- iseg tot2.f3d
- iseg tot2.f3d tot2_obj.f3d
- mplayer m304.mpg
- mplayer animation07_high.mpg

Interactive Segmentation of RGB Data

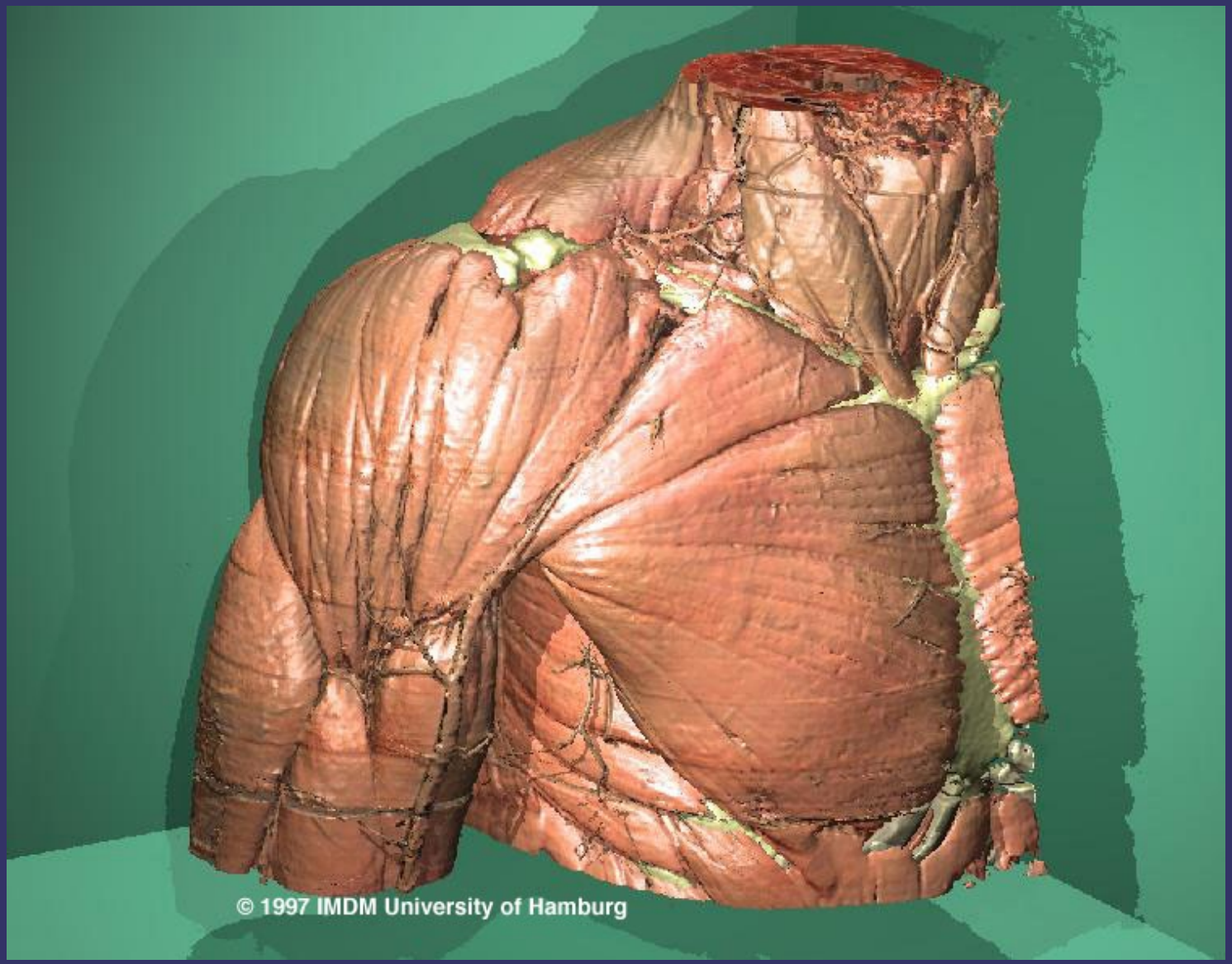
- The Visual Human Project
  - Physical slices(photographs)
  - CT & MRI data
- Thresholding replaced by data classification
  - 3D scatter plot analysis



Interactive Segmentation of RGB Data



Interactive Segmentation of RGB Data



The Watershed Concept (1)

Štrbské pleso, Slovakia

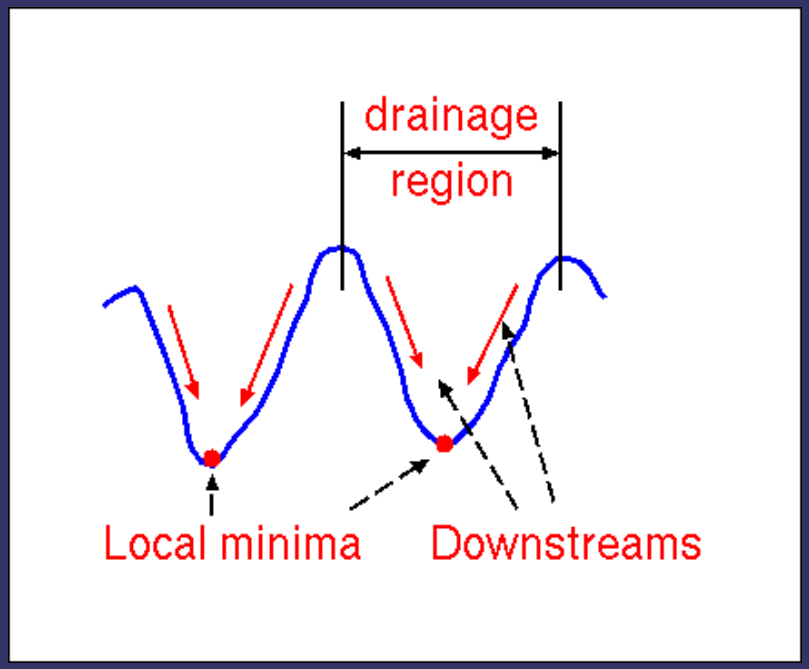
The Watershed Concept (1)

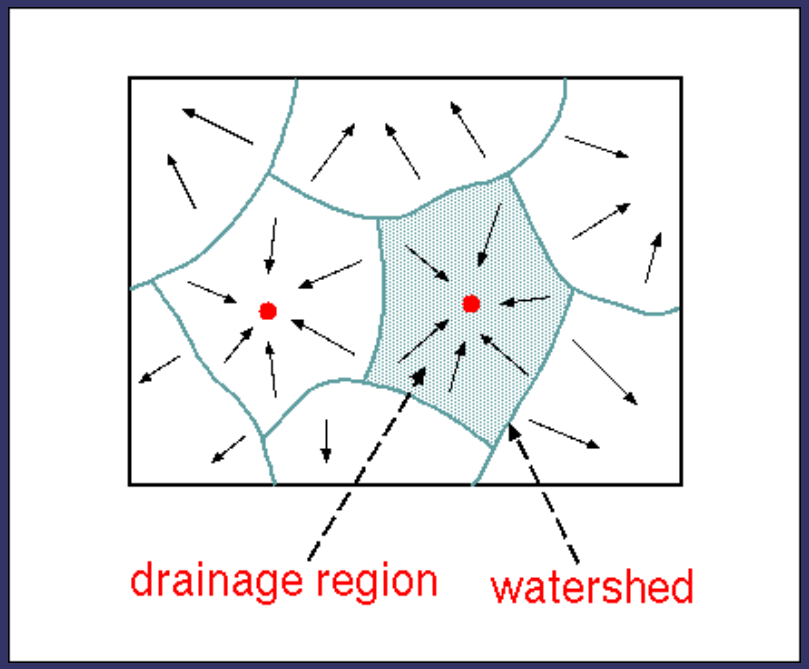
Main European watershed (Black/Baltic sea)

Štrbské pleso, Slovakia

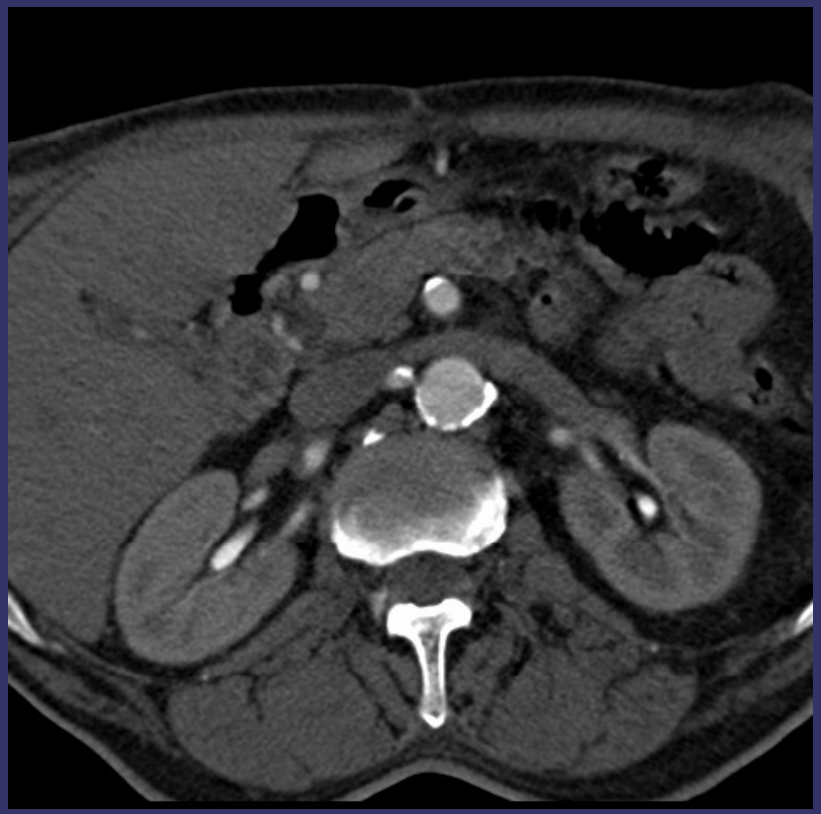
The Watershed Concept (2)

- Waterflow simulation on gradient images:
  - Catchment basins & watershed lines



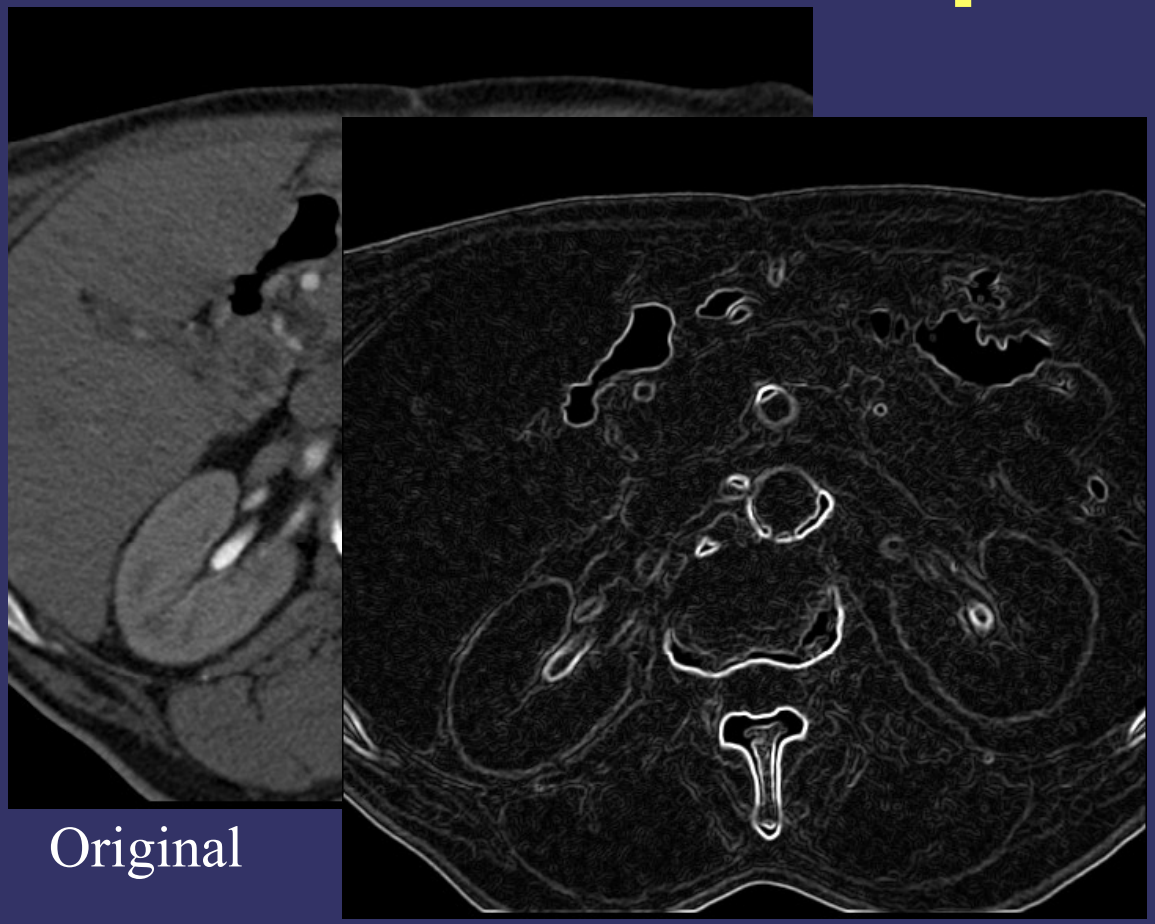


Watershed Implementation



Original

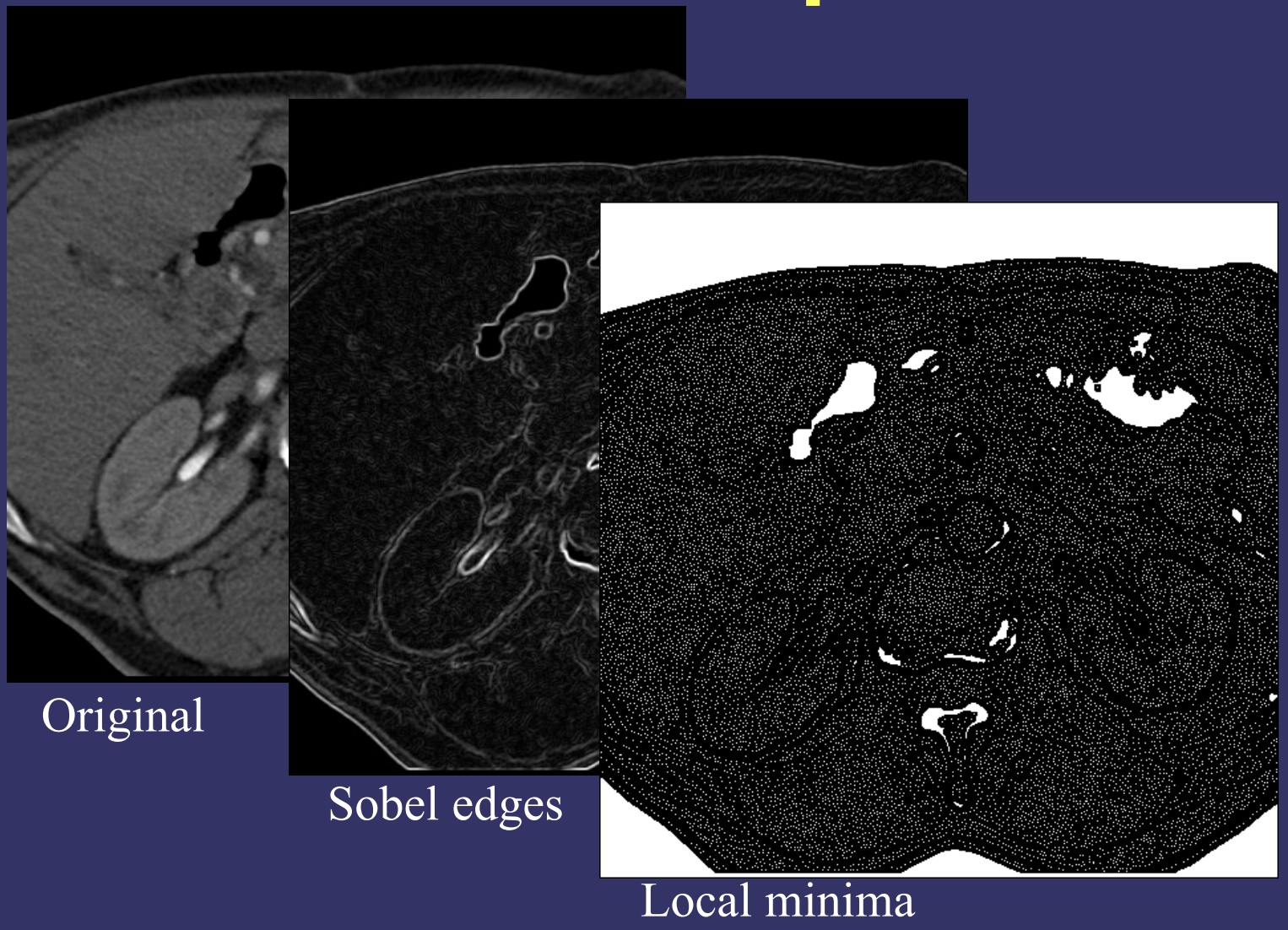
Watershed Implementation



Original

Sobel edges

Watershed Implementation

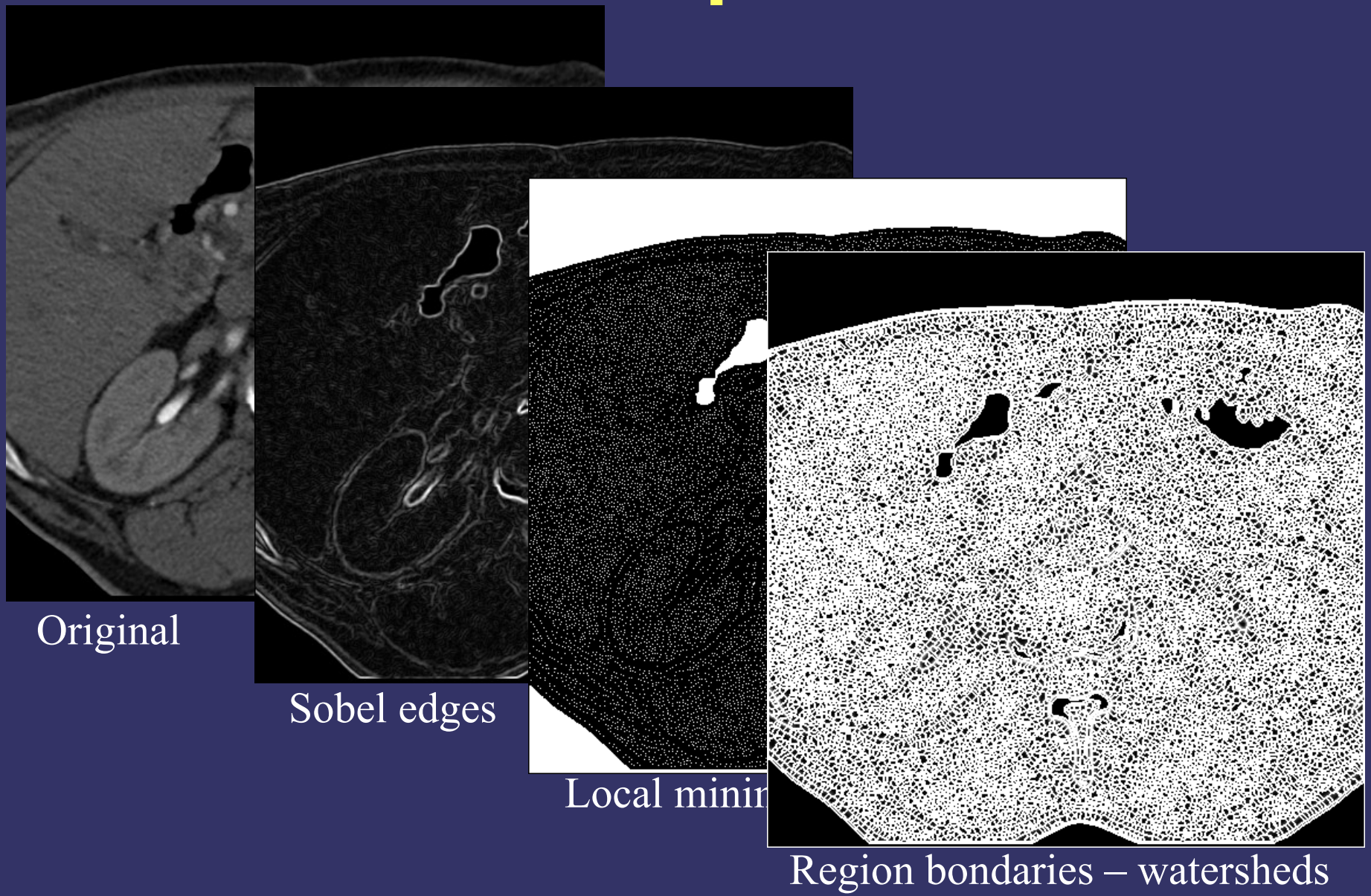


Original

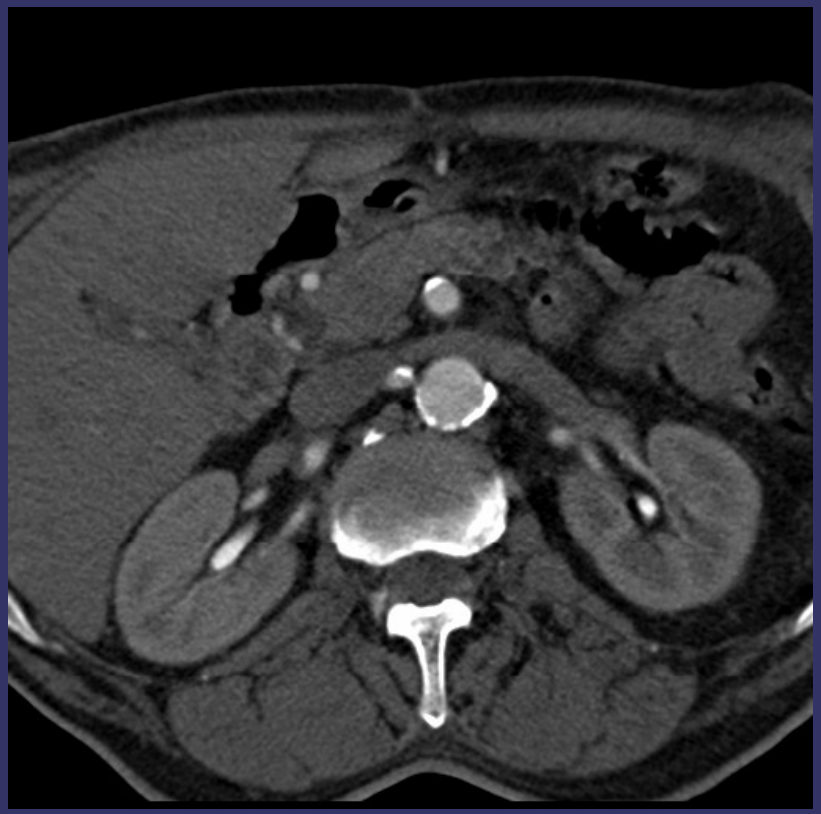
Sobel edges

Local minima

Watershed Implementation

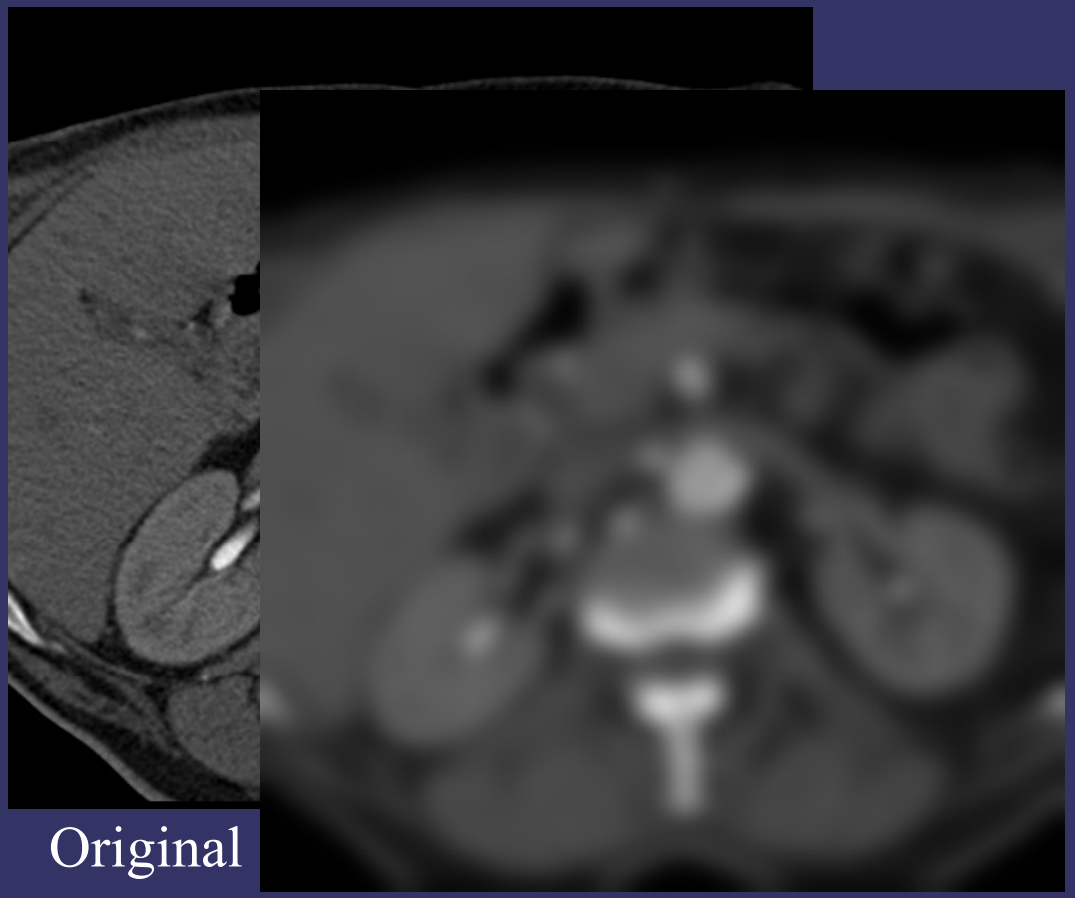


Large Regions by Gaussian Smoothing



Original

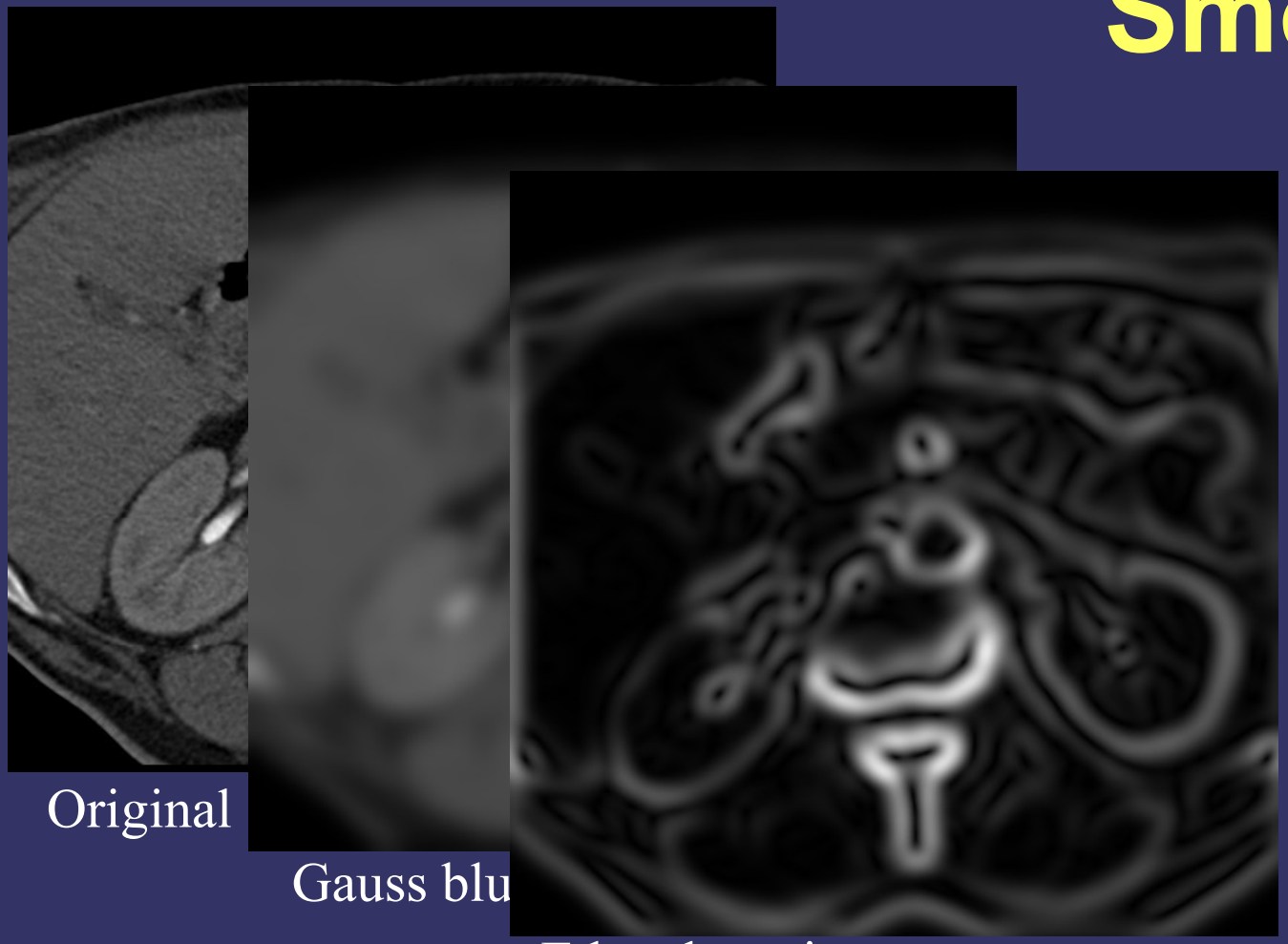
Large Regions by Gaussian Smoothing



Original

Gauss bluring, σ=8.0

Large Regions by Gaussian Smoothing

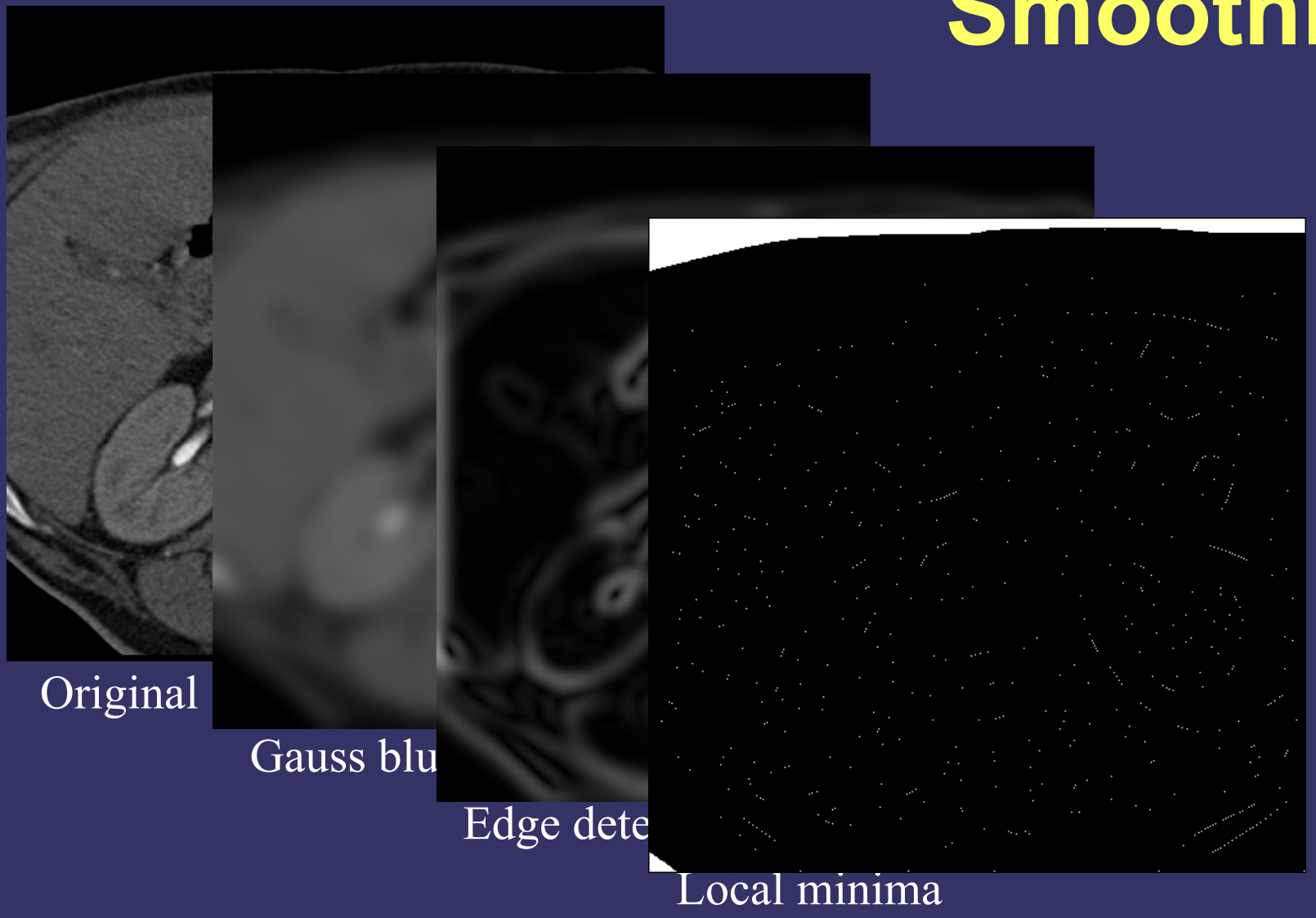


Original

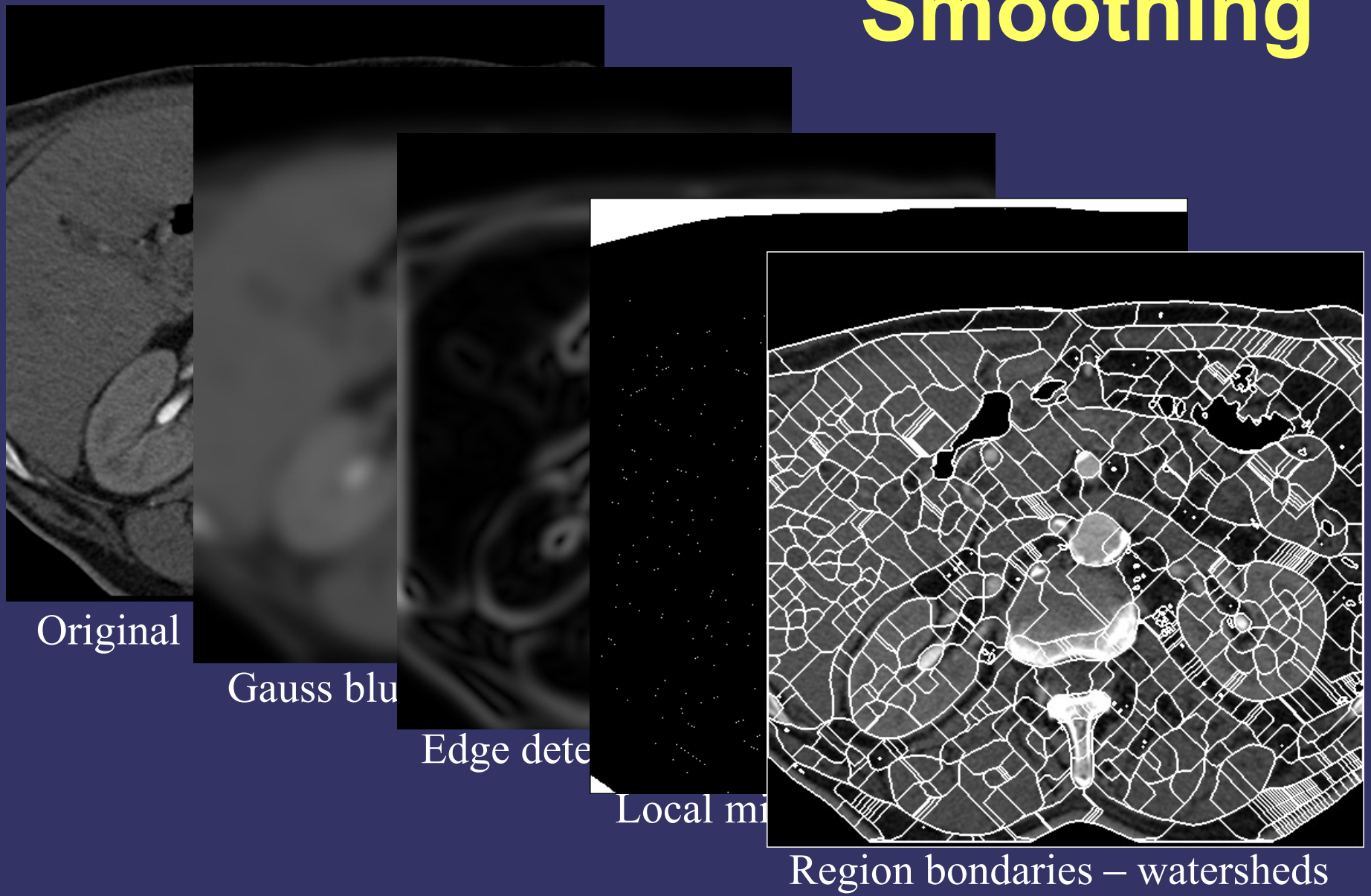
Gauss blu

Edge detection

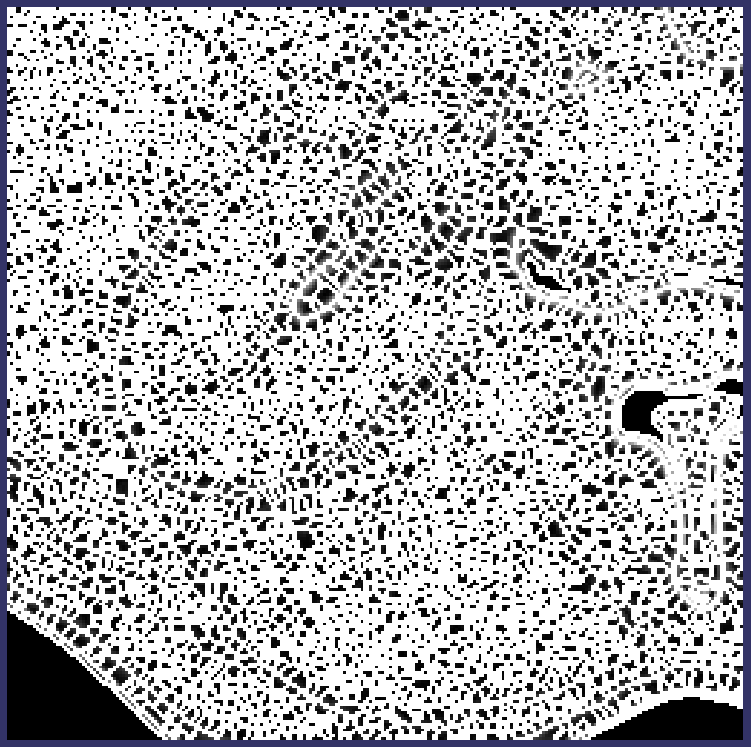
Large Regions by Gaussian Smoothing



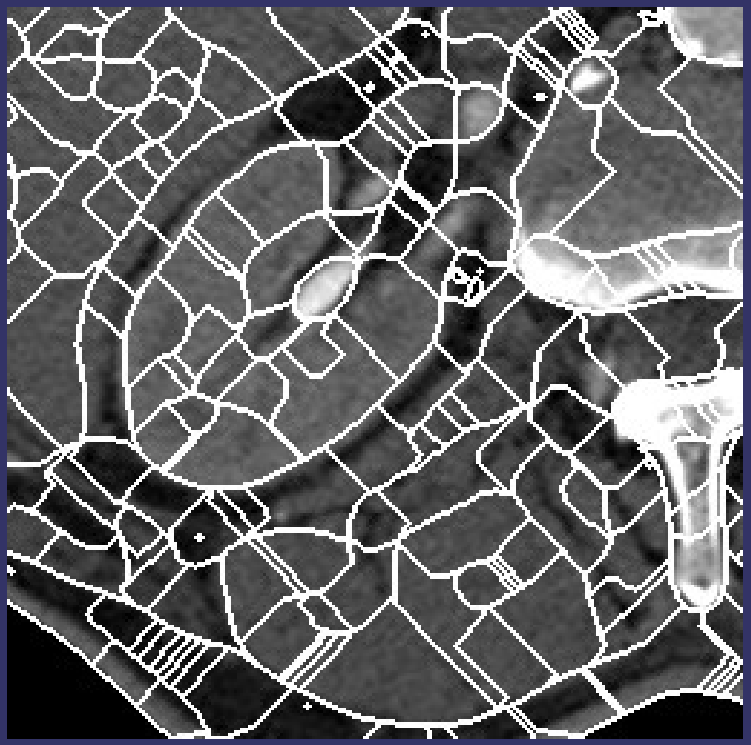
Large Regions by Gaussian Smoothing



Watersheds



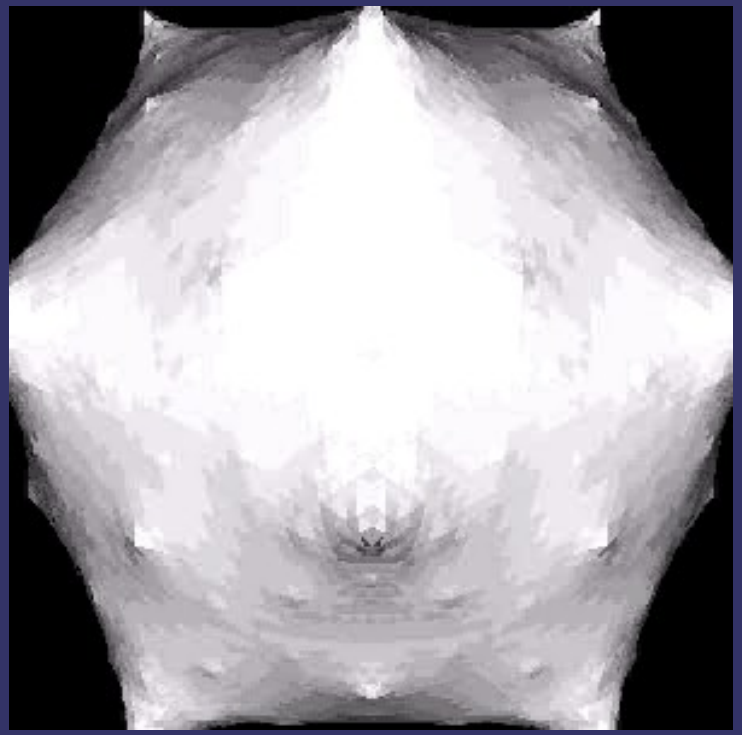
No smoothing: numerous small regions



Smoothing: fewer regions but imprecise contours

Segmentation by Deformable Models

- Parametric form
  - 2D snakes & 3D baloons
  - Model and image forces govern the model to solution
- Implicit form
  - Embedding in $\Re^{n+1}$ space
  - Level-set methods
- Mesh form
  - Mass-spring models



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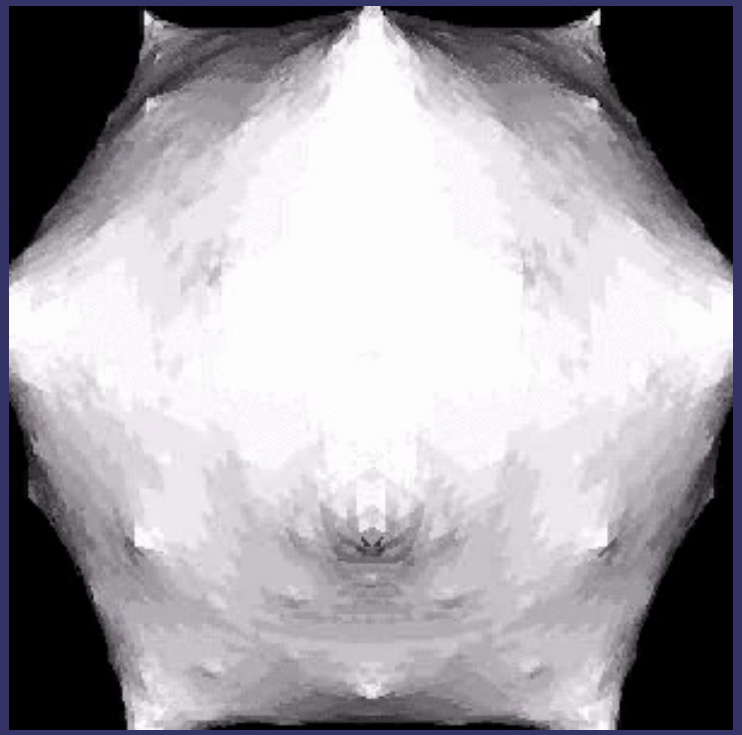
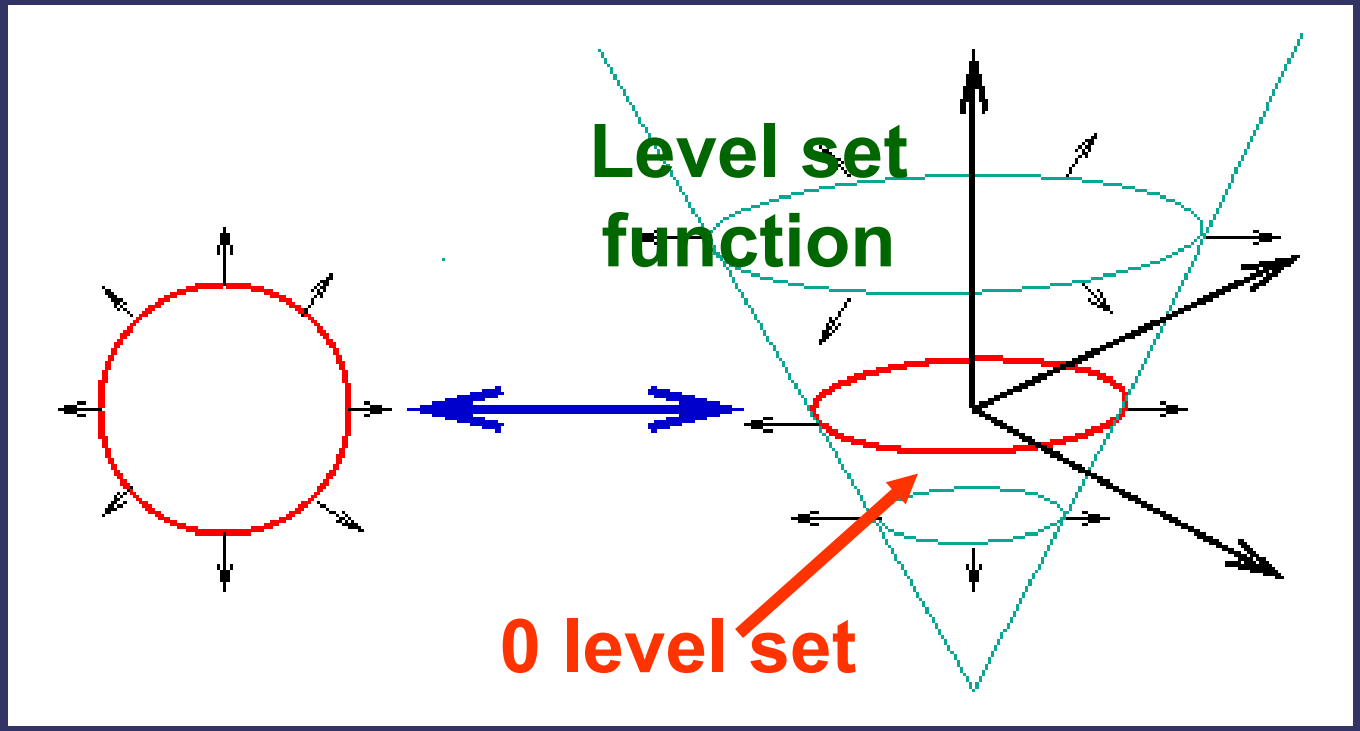


Level Set Methods

- General idea:
  - Instead of following the interface (curve), a cone shaped surface (Level set function - LSF) is built



LSF Definition

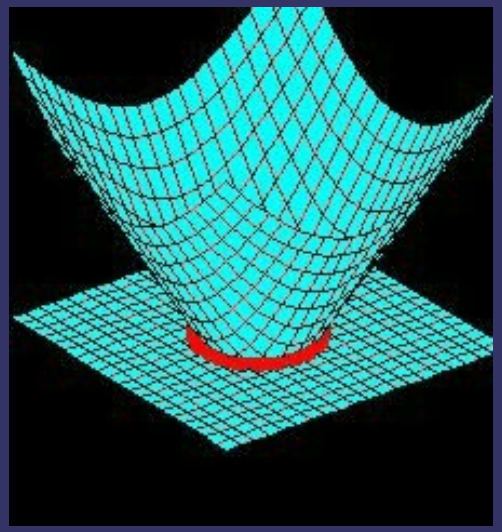
- Initialization
  - Signed distance to the initial zero level set
    Level set function Φ evolution
- Solution:

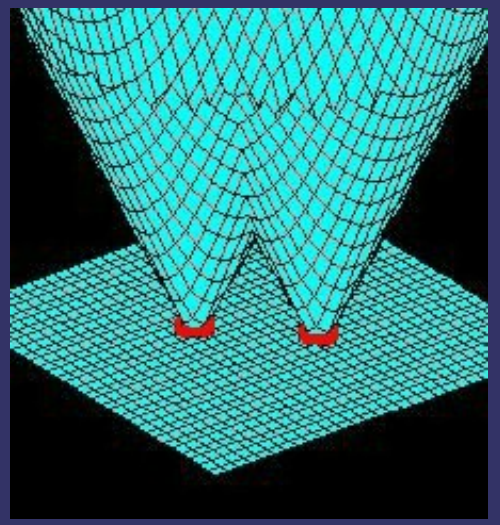
$$\frac{\partial \Phi}{\partial t} = -F|\nabla \Phi|$$

  - F - speed of the interface (depends on the problem)

LSF Evolution

- Tracking the interface:
  - Moving the function instead of the front
  - Level function is well-behaved but topology of the front can change





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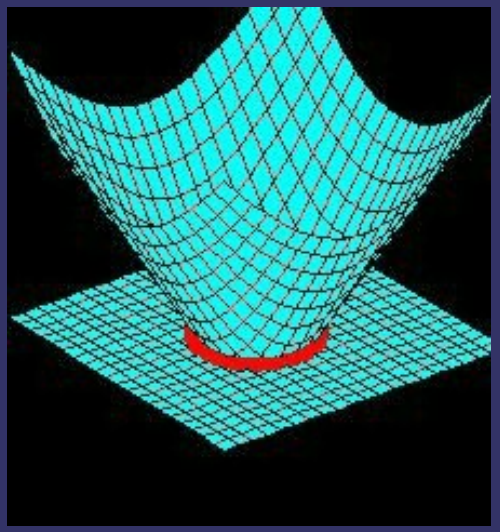

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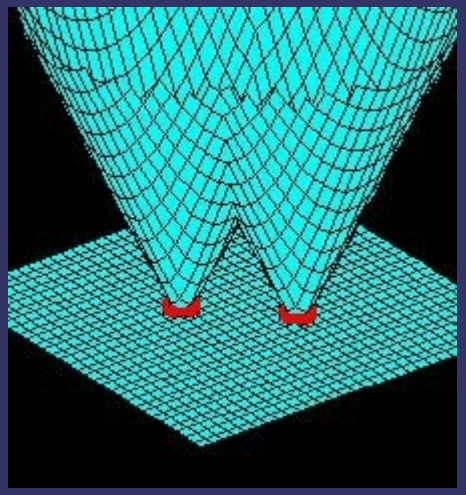
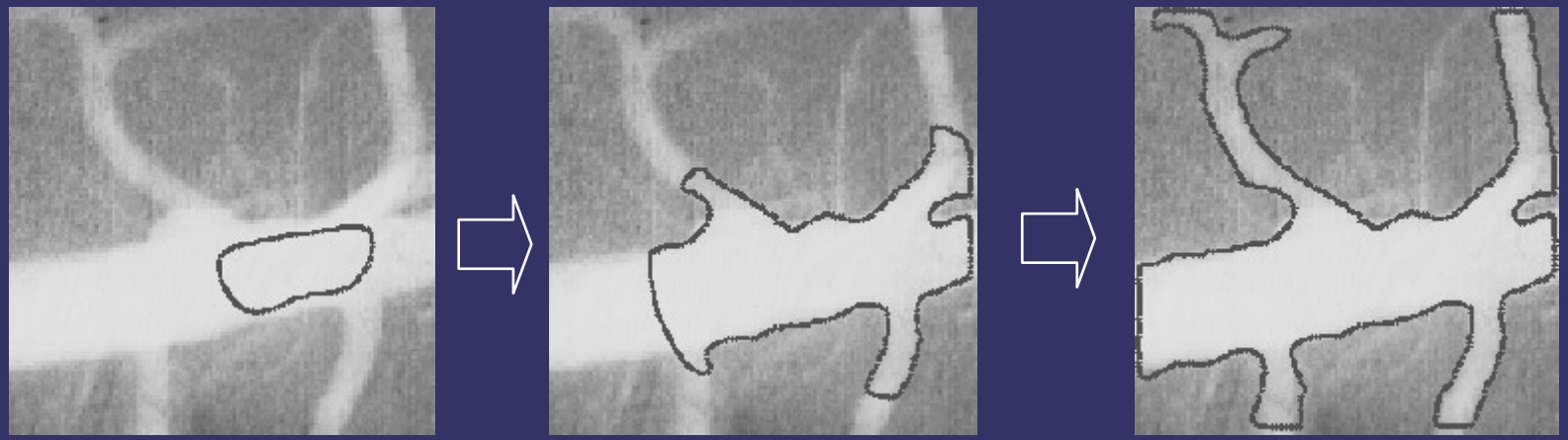


LSF Example

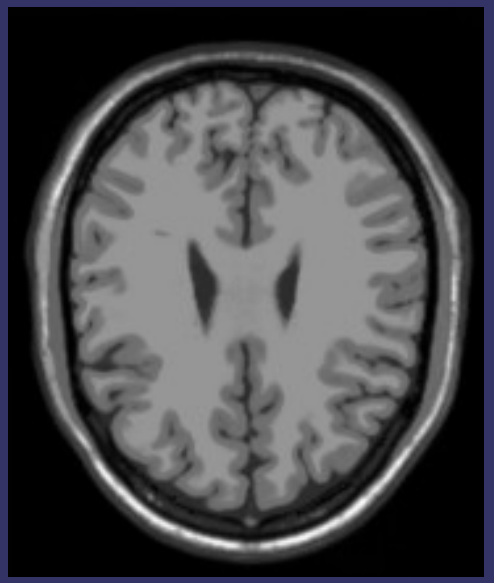
- Segmentation of a ventricle from Digital Subtraction Angiogram (DSA)
- Speed depends on gradient magnitude



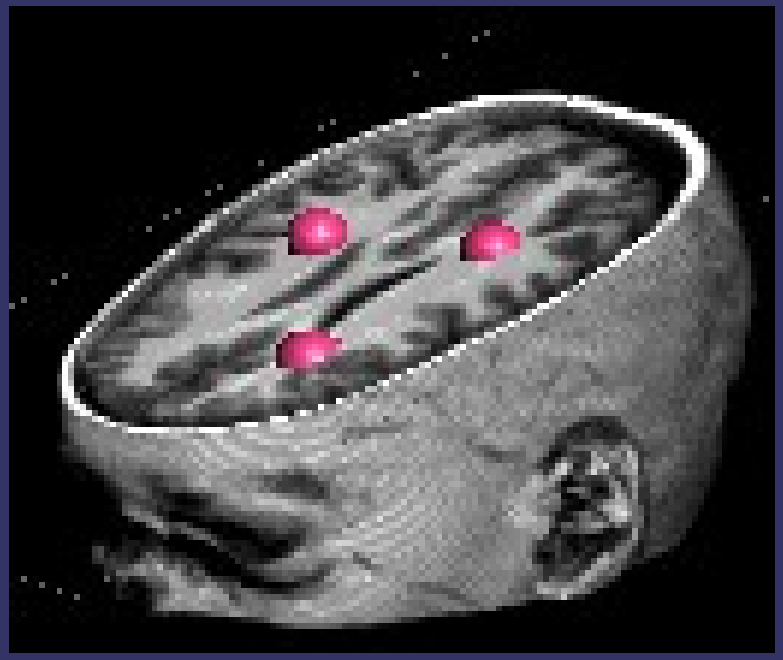
Initialization

LSF Application - Coupled Surfaces Propagation

- Brain cortex is bounded by two surfaces:
  - white - gray - CSF
  - Gradient at surface
  - Homogeneous in between
- Cortex thickness - about 3mm
- Automatic & robust technique
  - Problems at one boundary (unsharp edge) can be solved by the second boundary



Coupled Surfaces



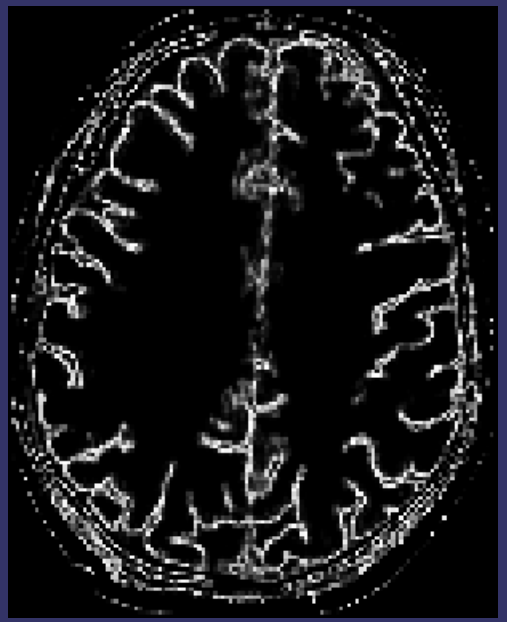
- Initialization
- Interface speed:
  - Interface White-Gray (W/G)
    - W/G presence probability
    - Distance to G/CSF interface
  - Interface Gray/CSF (G/CSF)
    - G/CSF presence probability
    - Distance to W/G interface

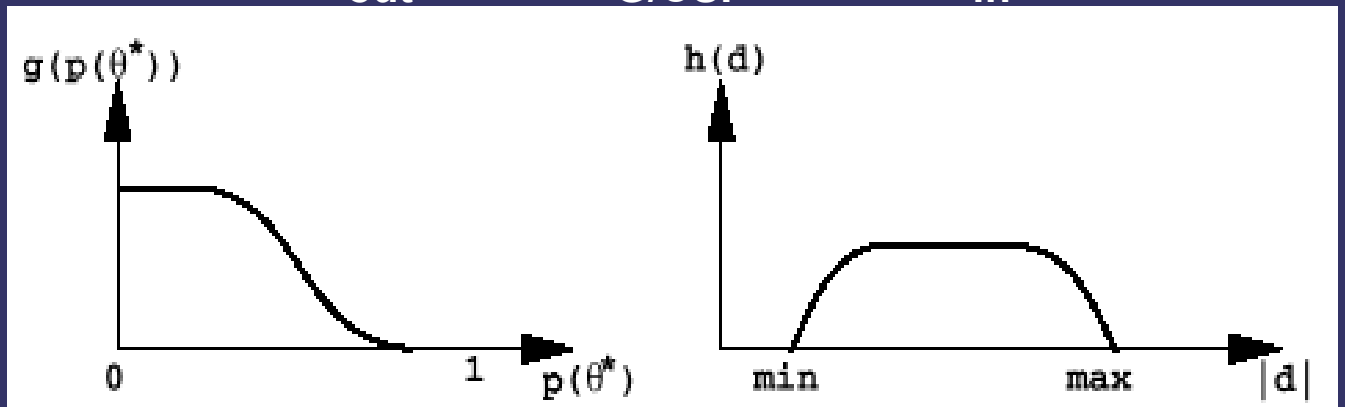
Interface speed

- Interface W/G
  - $F_{in} = g(p_{W/G}) * h(\Phi_{out})$
- Interface G/CSF
  - $F_{out} = g(p_{G/CSF}) * h(\Phi_{in})$

$p_{w/G}$

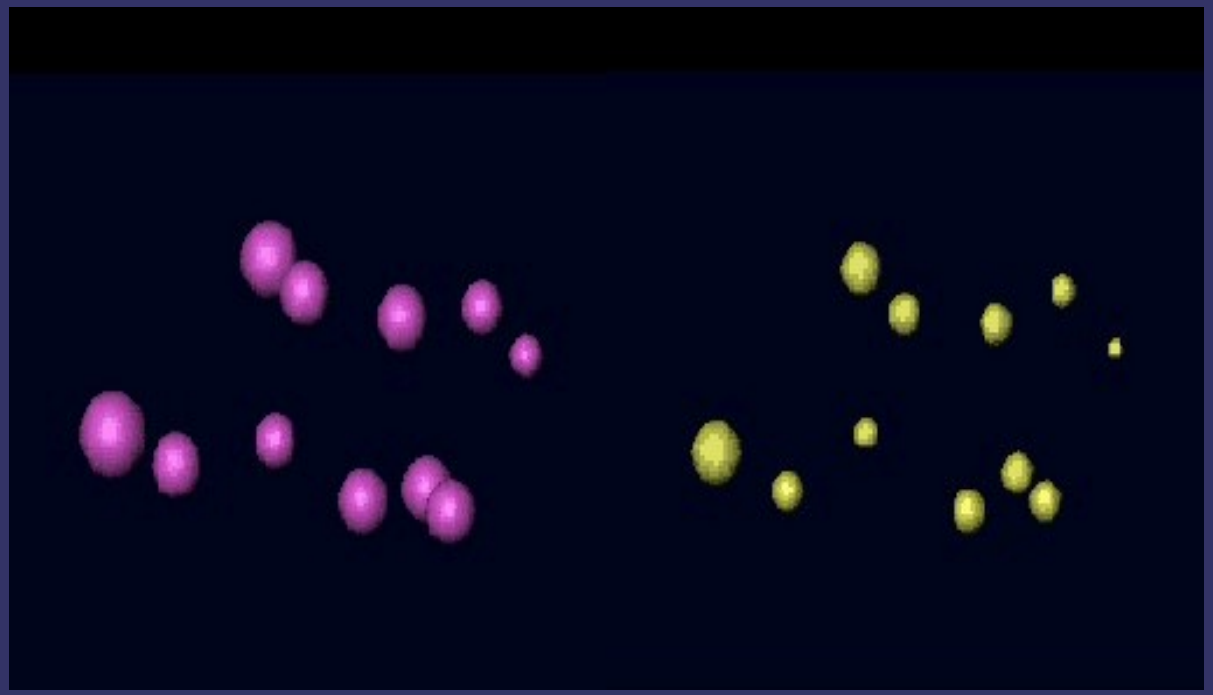
$p_{G/CSF}$





d: distance between the two bounding surfaces
|d|: absolute value of the distance
min: minimal distance allowed
max: maximal distance allowed

Interface Evolution and Results



Interface Evolution and Results