# Visualisierung Medizinischer Daten 2
# 3. Vorlesung
# Segmentation

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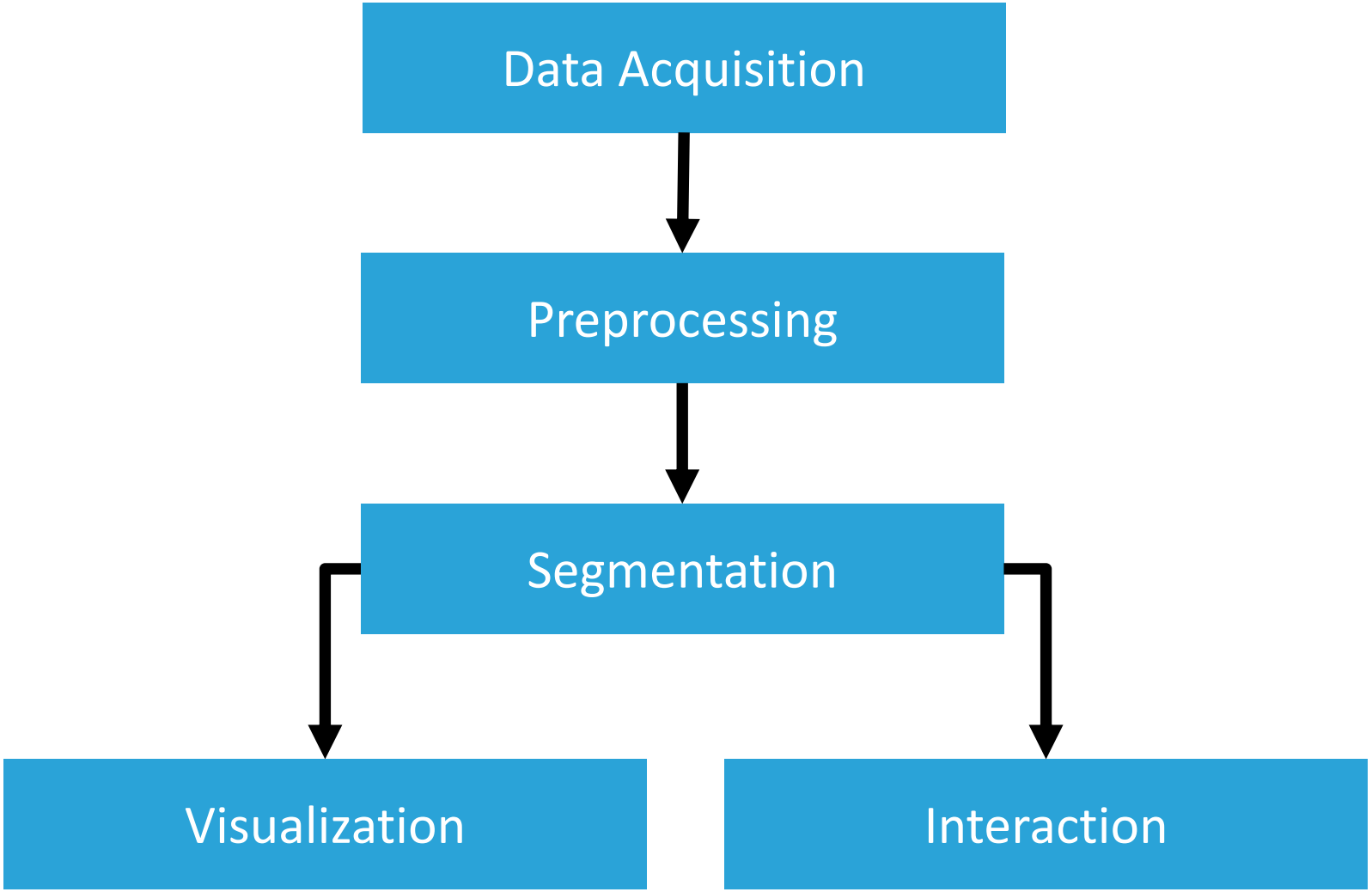
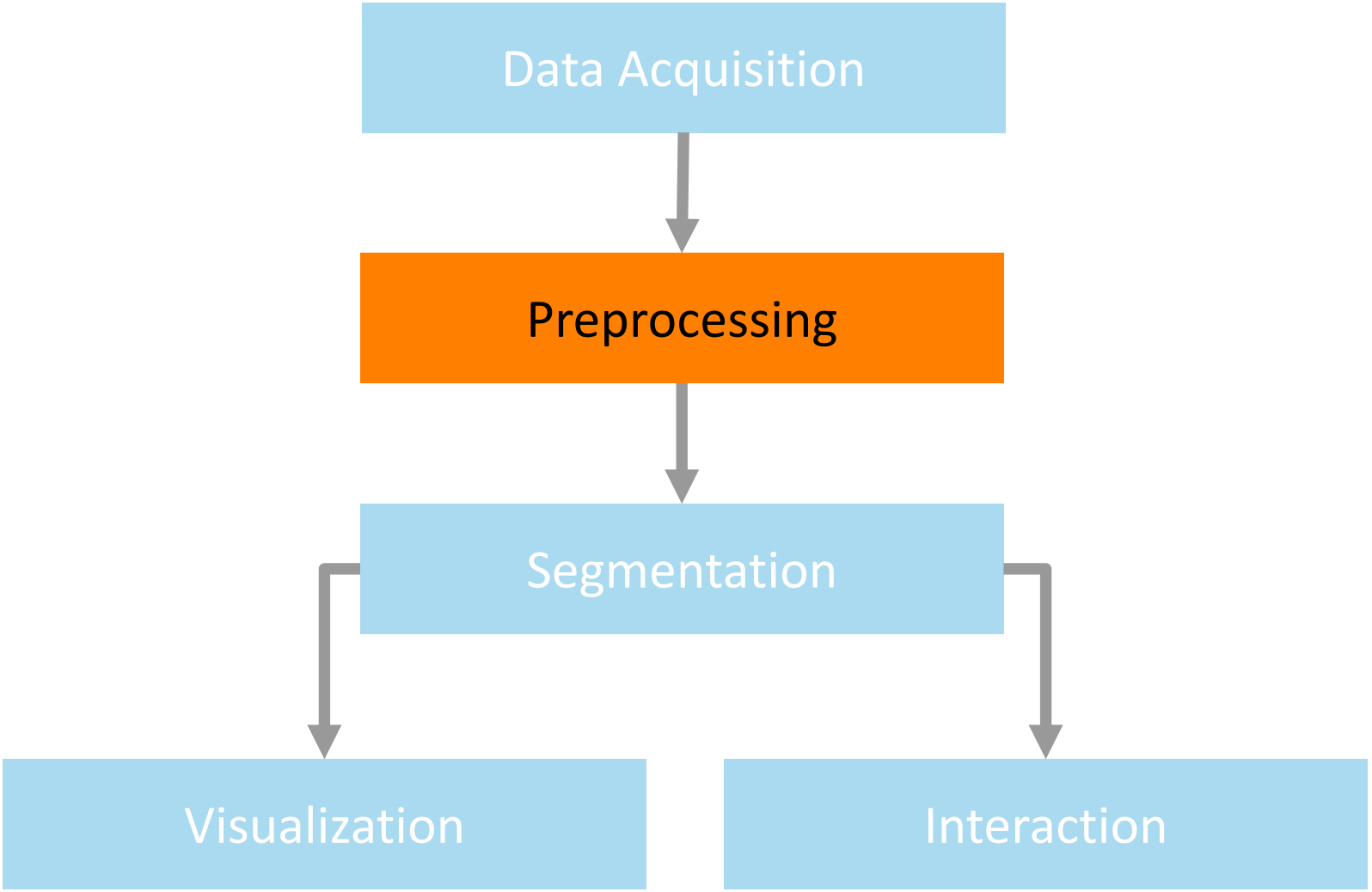

Data Acquisition
Preprocessing
Segmentation
Visualization
Interaction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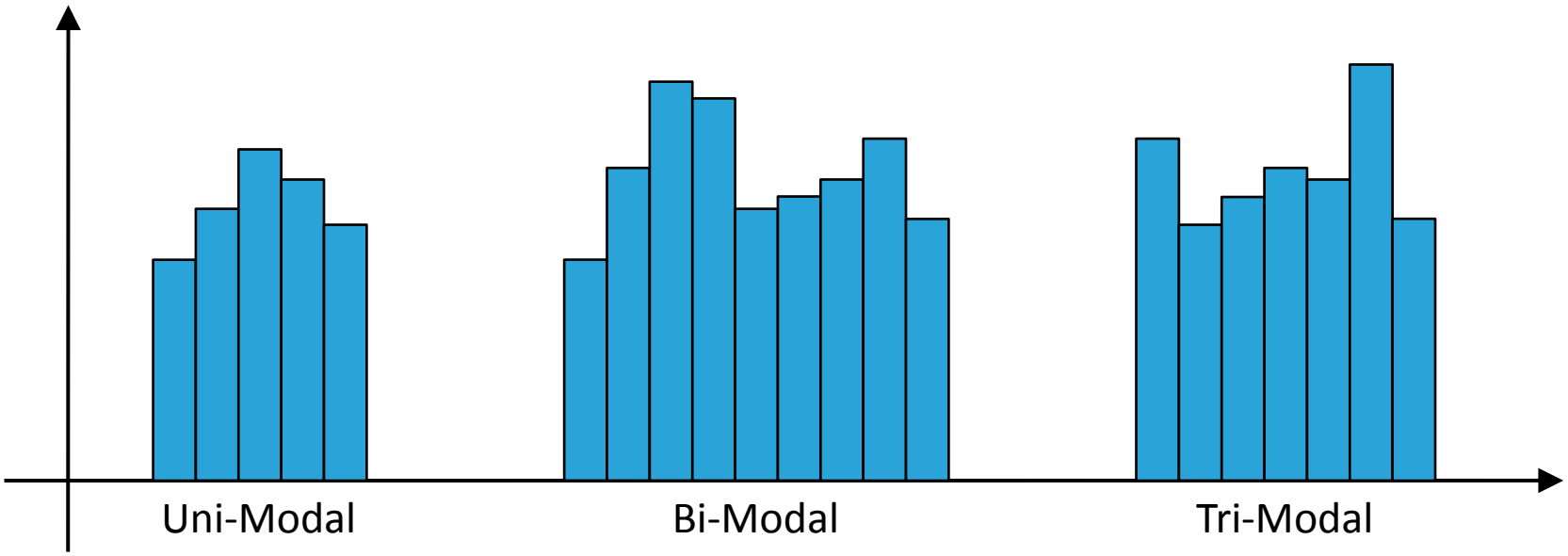
# Preprocessing

- Global vs. local image processing operations
- Noise reduction
- Edge enhancement
- Contrast enhancement

# Preprocessing Definitions

- Histogram: function that indicates frequency of each grayvalue or pixel/voxel intensity
- #num distintive maxima = #-modal histogram



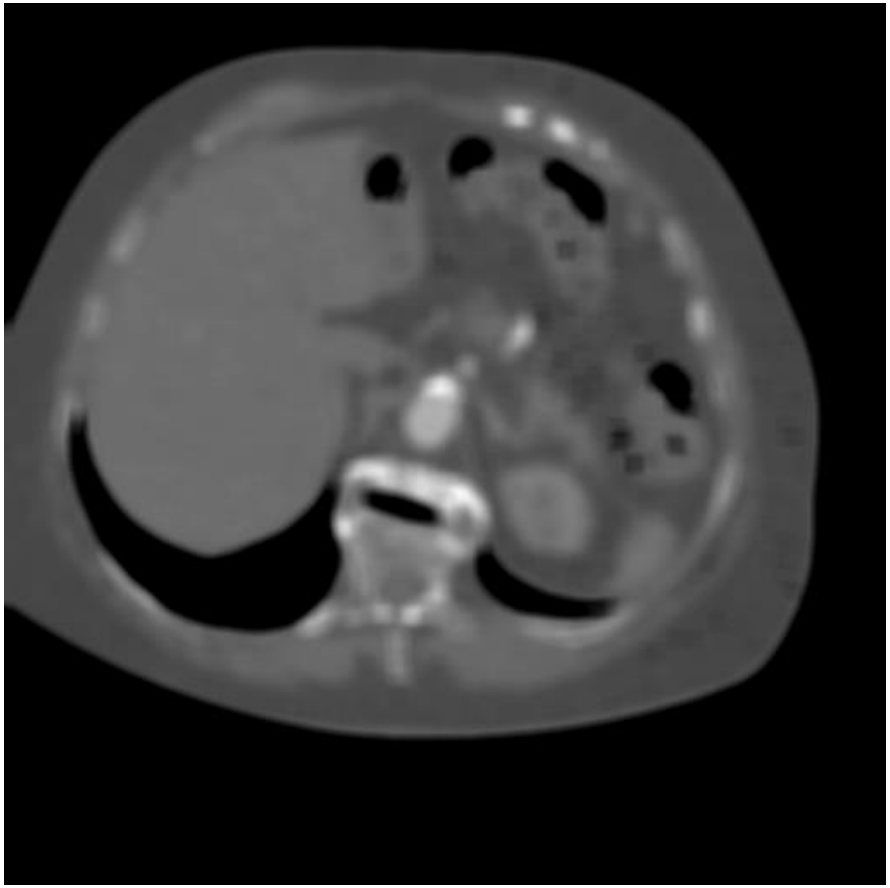
# Preprocessing Operations

- Point-oriented
  - Values of voxels changed isolated
  - Thresholding, subtraction, lookup table ...
- Local operations
  - Values of voxels changed taking neighborhood information into account
  - Static & dynamic filters
  - Problem: treatment of edges
- Global operations
  - Histogram equalization

# Average Filter

- Linear filter
- Flattens edges

Original



5x5 Average filter

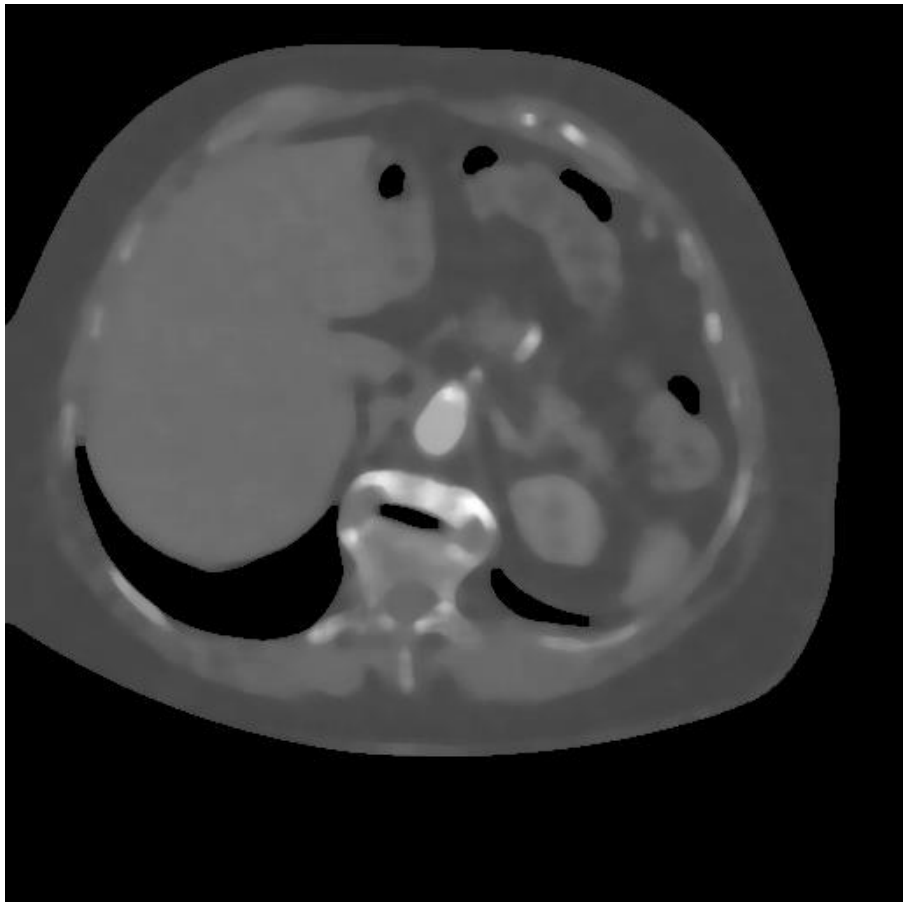
# Median Filter

- Edge-preserving filter
- Nonlinear filter
- Sequence of grayvalues in a local neighborhood
- Example:
  - 3x3 filter size
  - Center: value 17,
  - Neighbors: 8, 12, 12, 17, **19**, 19, 21, 22, 24

  → Replace 17 by 19
- Similar filters: replace current value with the minimum or maximum value

# Median Filter

Original



5x5 Median filter

# Median Filter

- Characteristics
  - Suppresses outliers (pulsed noise)
  - Preserves edge transitions
  - Suppresses thin lines
  - Average grayvalue of image might vary
  - Does not introduce new density values

# Gaussian Filter

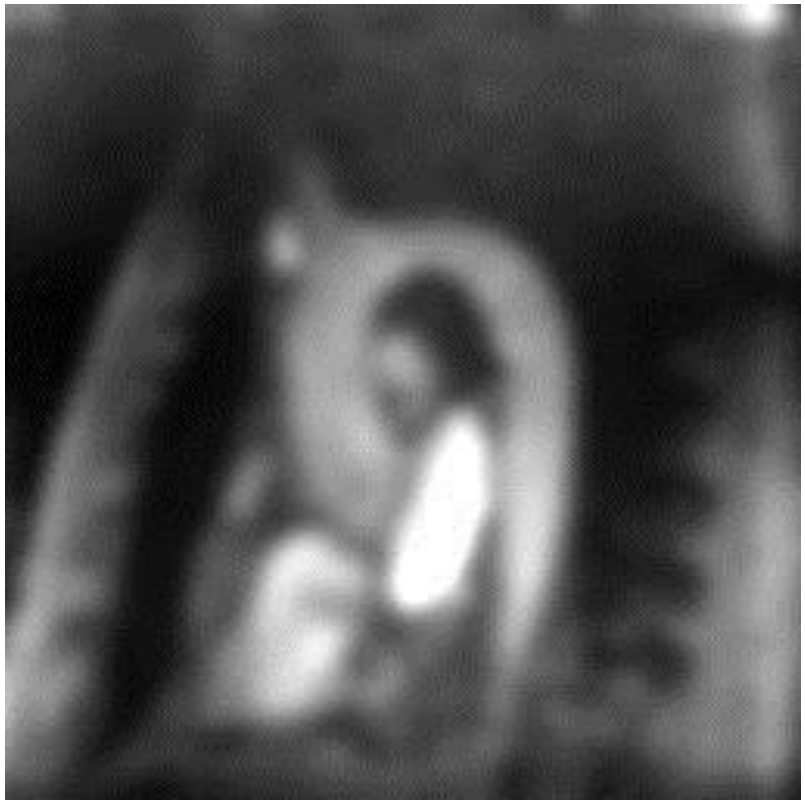
- Nonlinear noise filter
- Filtering with discretized Gaussian function (Gaussian bell curve, weighted mean value)
- Valus correspond to binomial coefficients

- Characteristics
  - Noise suppressed in small areas
  - Edges smoothed

# Gaussian Filter

[Bernhard Preim, Screenshots VTK]

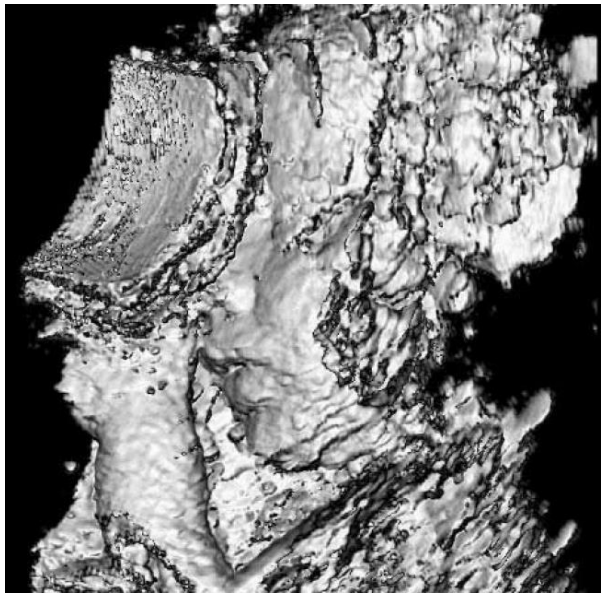
Original



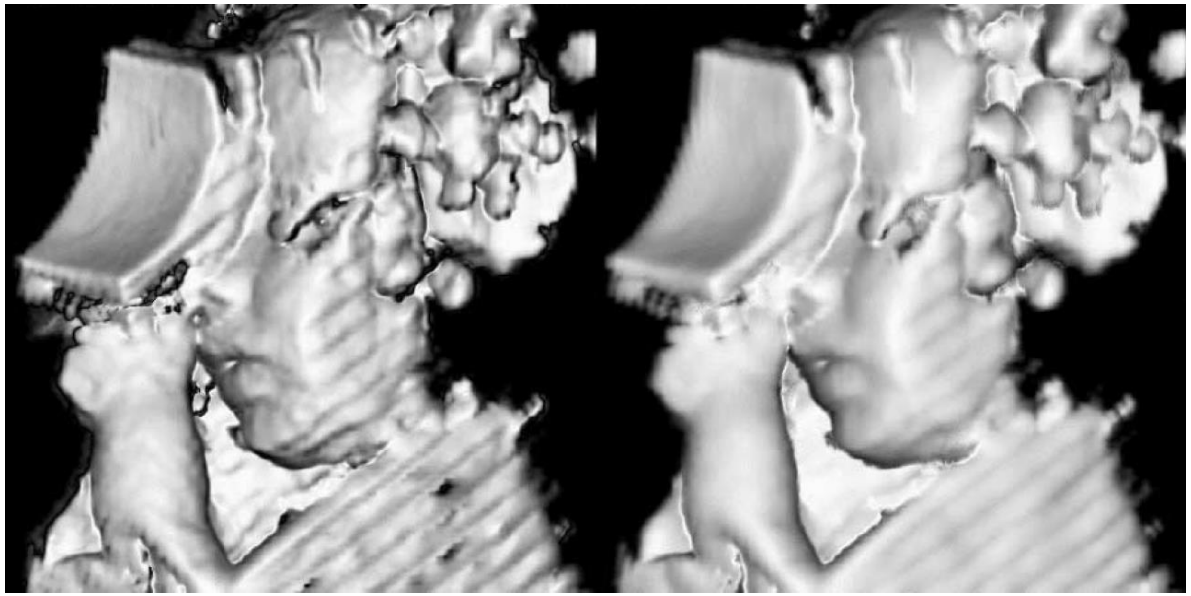
Gaussian filtered

# Gaussian Filter

[Sakas and Walter, 1995]



Unfiltered



Gaussian filtered

# Sigma Filter

- CT & X-ray: normal distributed noise
- MRI: asymmetric Rician distribution

- Sigma Filter:
  - Nonlinear noise filter
  - Filtering limited to pixels (voxels) not deviating strong from the average value
  - Parameter *sigma* specifies the range

# Sigma Filter

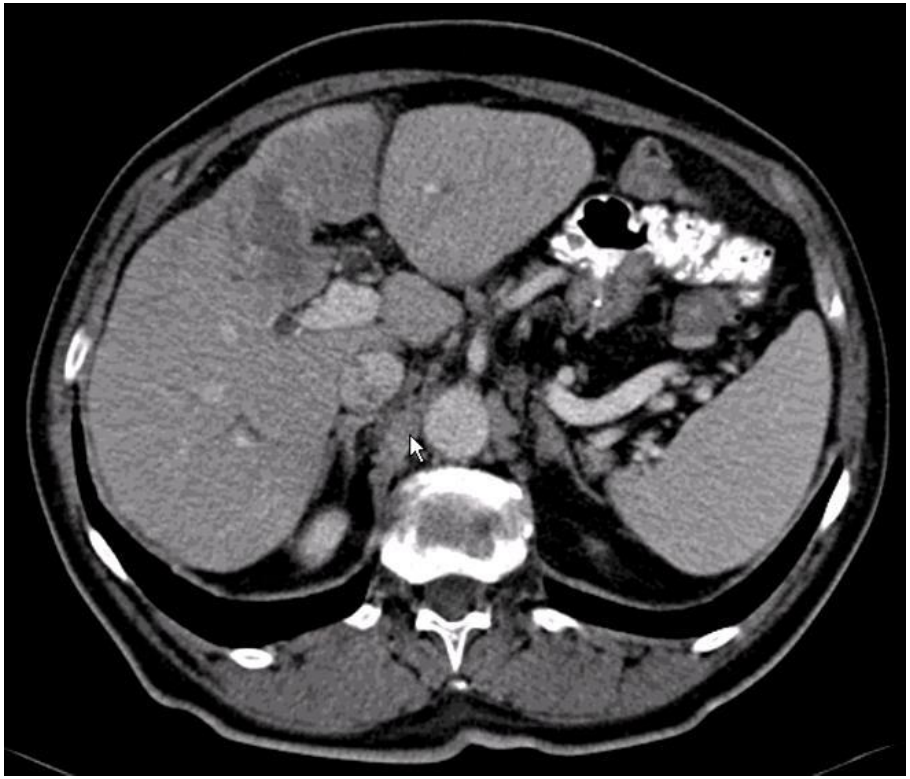
1: Calculate standard deviation *SD* within kernel

2: For each pixel (voxel) p within the kernel with p(i) in [-sigma*SD, sigma*SD]
→ Calculate average *AVG*

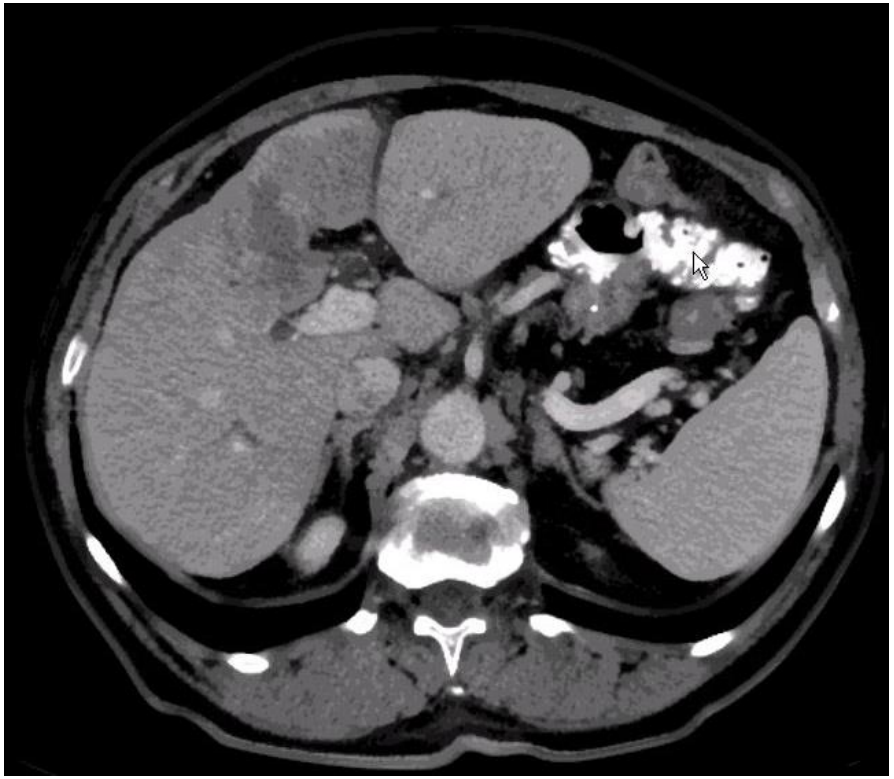
3: For each pixel (voxel) p within the kernel with p(i) in [-sigma*SD, sigma*SD]
→ p(i) = *AVG* *// assign average*

# Sigma Filter

[Preim and Bartz, 2007]



Orignial



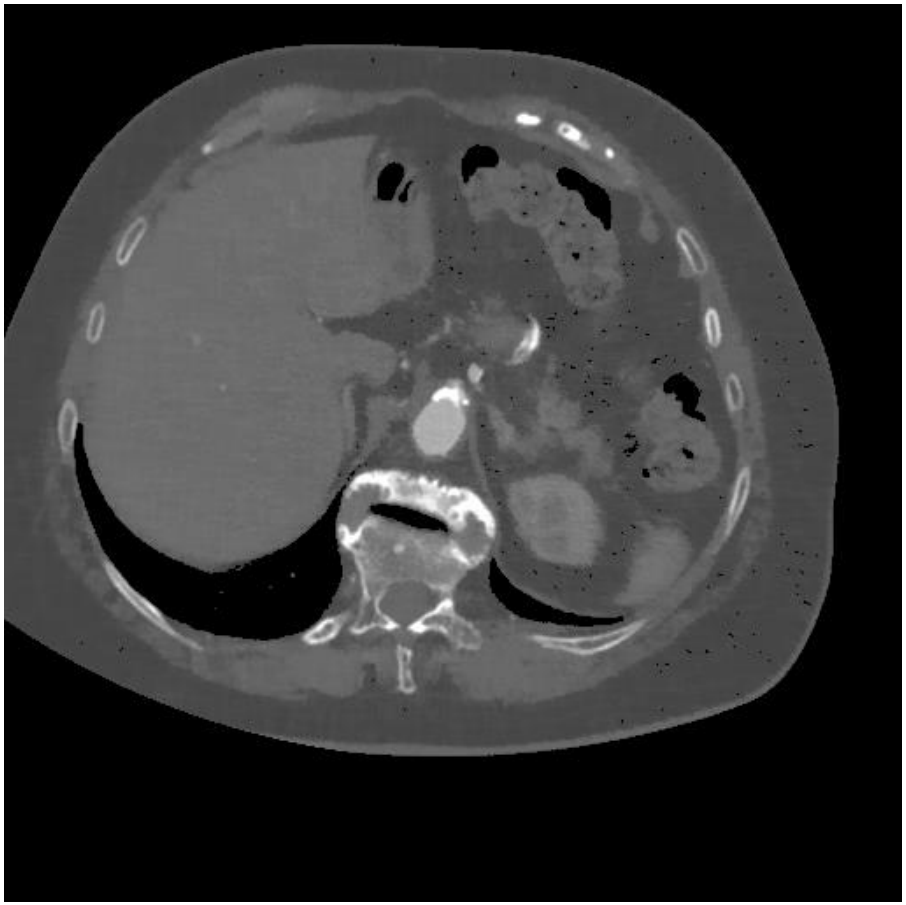
Sigma filtered (11x11, sigma = 1.0)

# Bilateral Filter

- Nonlinear filter
- Edge-preserving filter
- Weighted average depends on
  - the distance of pixels from the center
  - the intensity value differences
- Weighting can be based on Gaussian distribution

# Bilateral Filter

Original



Bilateral filter

# Bilateral Filter – DECT

- Application scenario DECT
  - Filter the low energy level (noisier, more contrast)
  - Edges sharper in high energy level

→ Compute edge weight using high energy level

# Bilateral Filter – DECT

80 kV

Bilateral

140 kV

# Contrast Enhancement

- Increase contrast at object edges
- Compute Laplace-filtered image (= edge detector)
- Compute difference with original image

[Bernhard Preim, Screenshots VTK]

# Sharpen

- Contrast enhancement due to negative values around center pixel (voxel)
- Sum of pixels (voxels) equals 1

| | | |
|---|---|---|
| 0 | -0.5 | 0 |
| -0.5 | 3 | -0.5 |
| 0 | -0.5 | 0 |

Factor = 0.5
Radius = 1

| | | |
|---|---|---|
| -0.5 | -0.5 | -0.5 |
| -0.5 | 5 | -0.5 |
| -0.5 | -0.5 | -0.5 |

Factor = 0.5
Radius = 1.5

# Sharpen

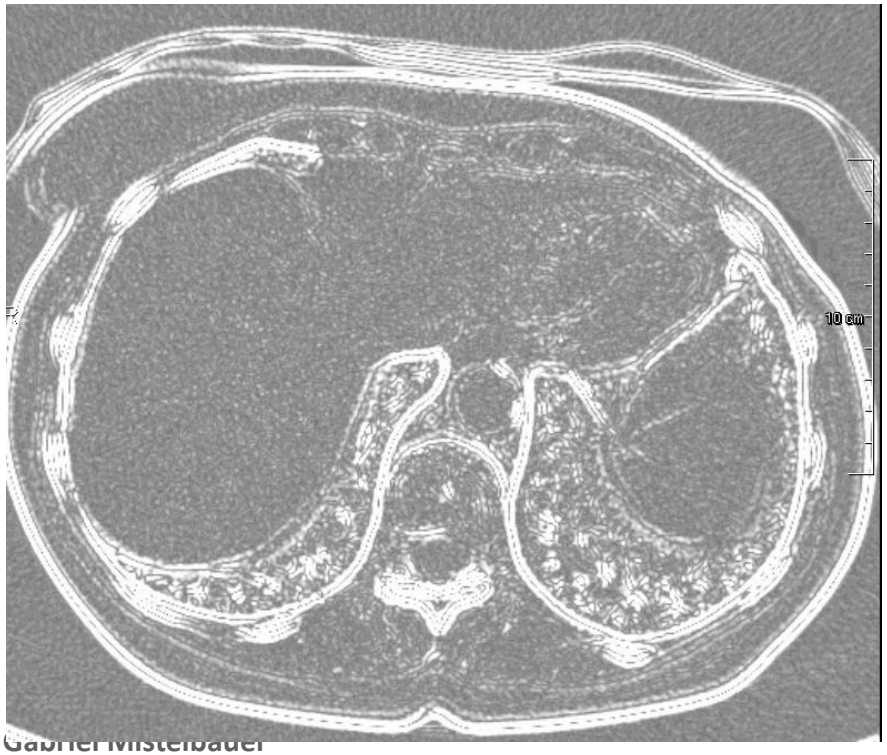
Gaussian filtered

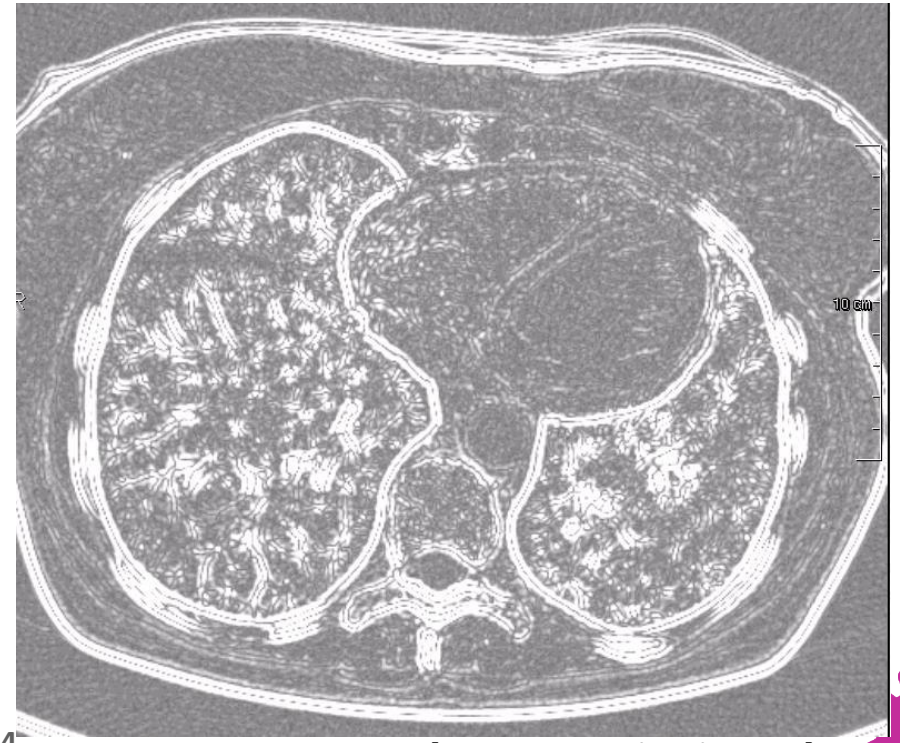
10x10 sharpen kernel

[© Bernhard Preim]

# Unsharp Masking

- Strongly smooth the original image (e.g., by using a Gaussian filter)
- Digitally subtract the smoothed from the original
  → Unsharp regions are faded out



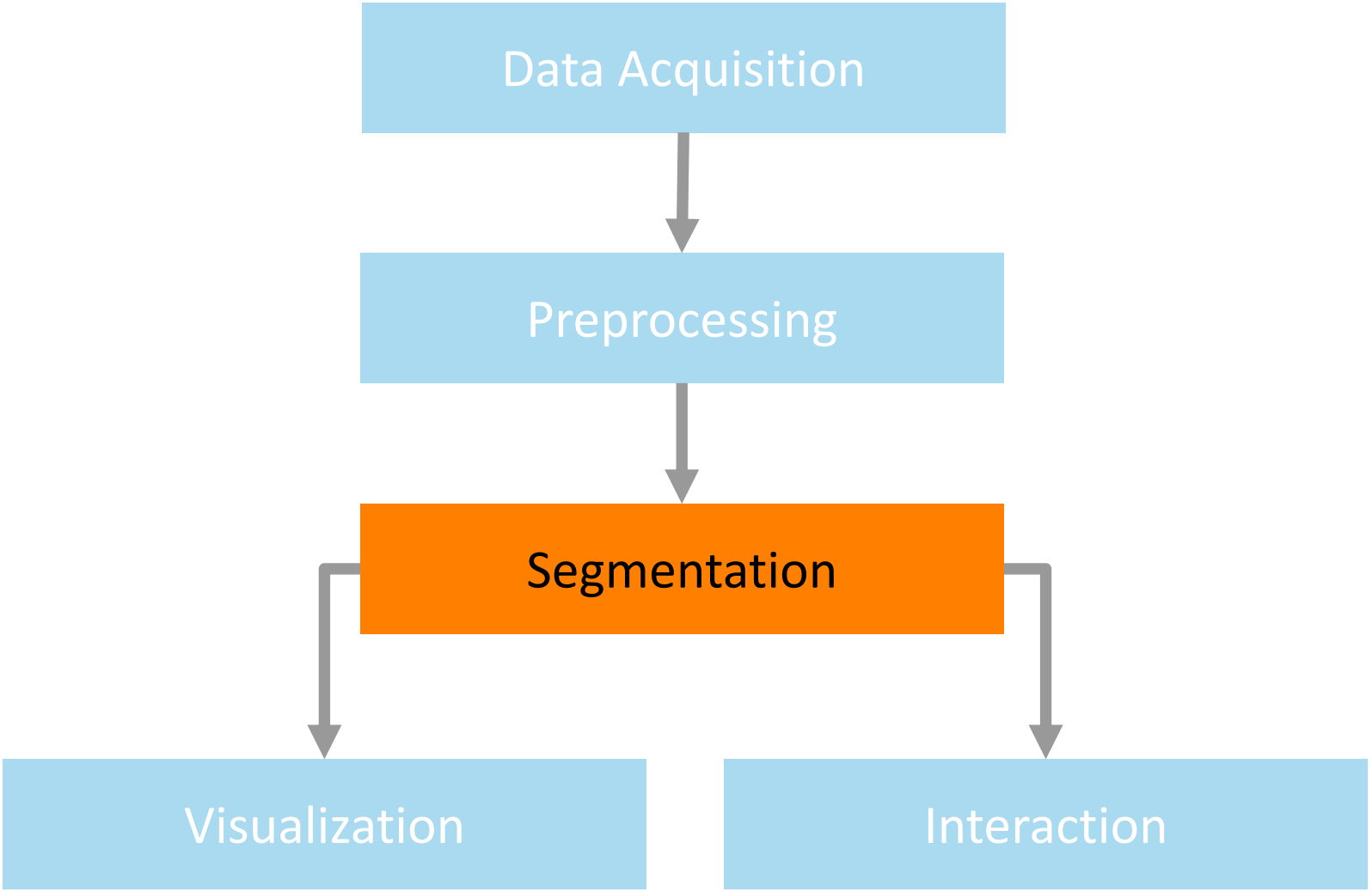




[Images: Bernhard Preim]

# Preprocessing Problems

- Enhancing contrast
  → enhancing noise

- Reducing noise
  → reducing contrast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# Segmentation

- Identification of pixels (voxels) with the same homogeneity criterion (similar characteristics)

- Basis for
  - highlighting specific objects within the data
  - classification (e.g., vessel / bone / tissue)
  - further processing (e.g., skeletonization)
  - quantitative analysis (e.g., volumetry, shape characteristics)

# Segmentation

- Application scenarios:
  - Pathological changes (tumors, calcifications ...)
  - Vessel / Bone segmentation
  - Different organs of the body (liver, lung, brain ...)

- Segmentation techniques depend on
  - the used acquisition modality (CT, MRI, US ...)
  - the scanning protocal (contrast agent administration, resolution, noise, sequence ...)
  - the object to segment (thin vessel, large organs)

# Thresholding

- Pixels (voxels) classified according to their density
- Histogram analysis to find suitable thresholds

- **Advantages:** Fast & simple
- **Disadvantages:** Spatial relations neglected

- Usually, thresholding does not provide satisfactory results, but acts as a good starting point

# Thresholding

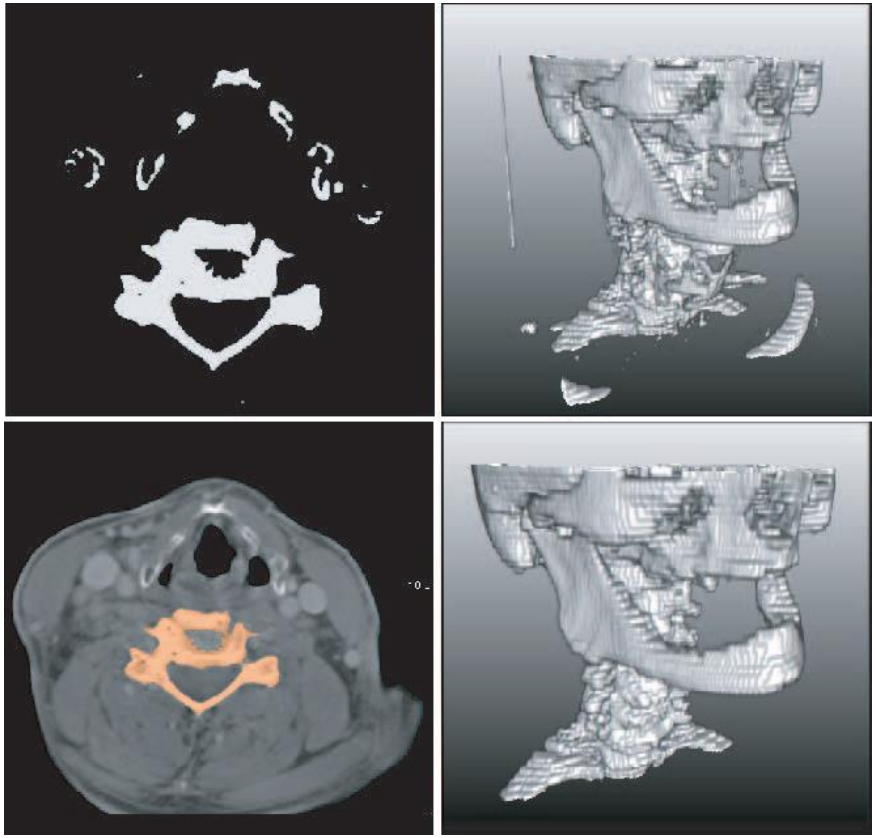
- **Variations:**
  - Single threshold
  - Hysteresis thresholding (requires 2 thresholds):
    → Pixels below lower threshold = background
    → Pixels above high threshold = object
    → Forall intermediate, if connected to object, mark as object too
  - Local threshold techniques
    (e.g., based on local histogram analysis)

# Connected Component Analysis (CCA)

- Usually done after segmentation (e.g., by using thresholding) to obtain regions within the data

Thresholding

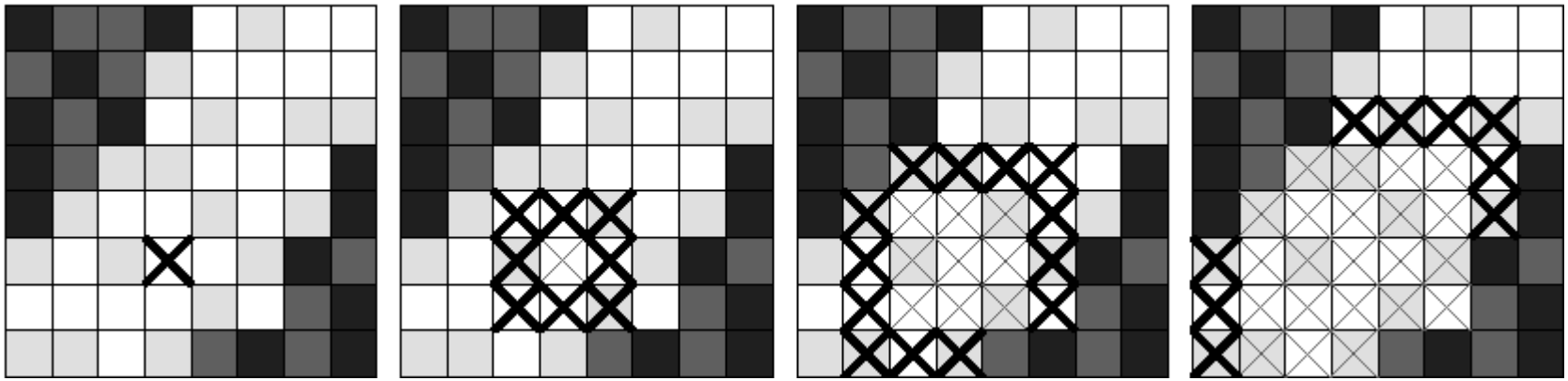
CCA of largest component



[Preim and Bartz, 2007]

# Region Growing

- Region growing (volume growing)
- Depends on inclusion criteria
  - Threshold-based
  - Similarity-based
- Starting from a seed pixel (voxel)
- **Problem:** Leakage through holes in the contour



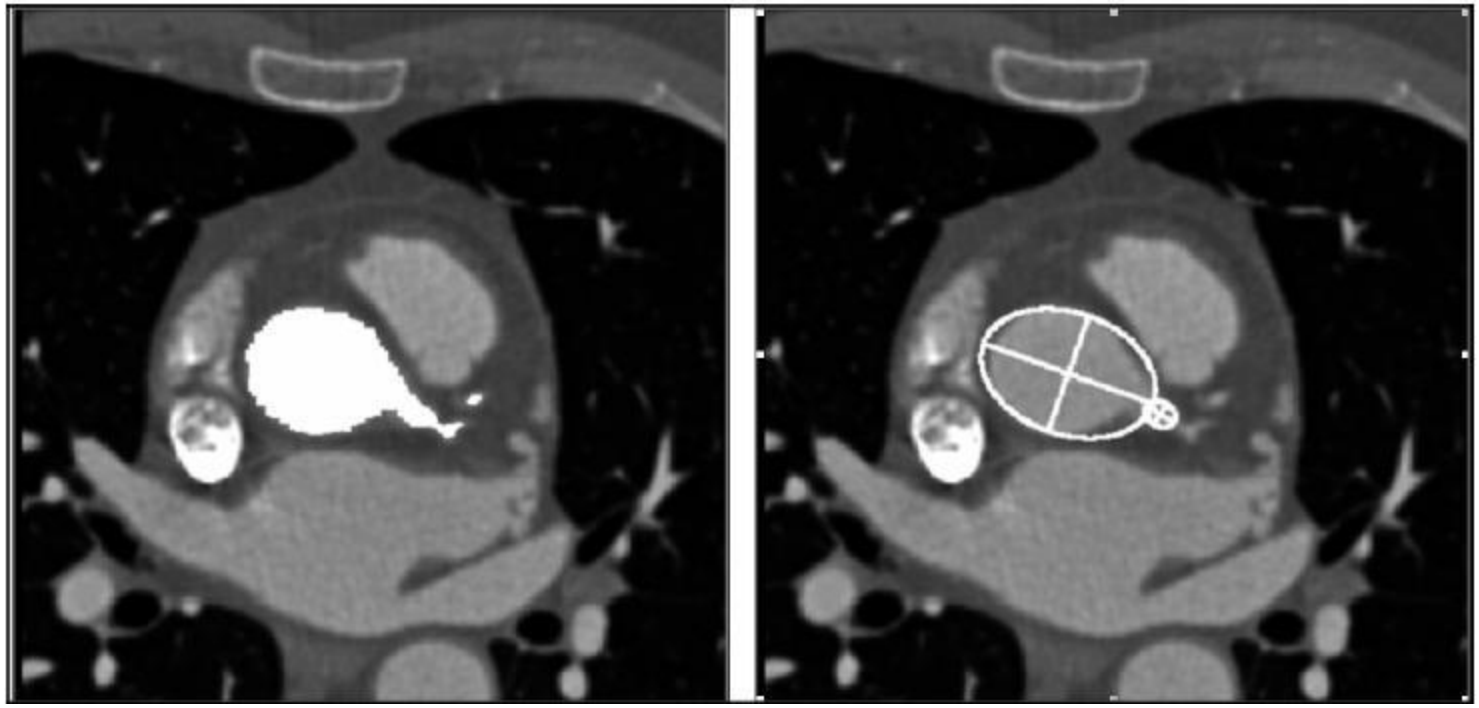
[Images: Bernhard Preim]

# Advanced Region Growing

- User specifies direction of growing
- Adaptive thresholds (e.g., to the local intensity distribution)
- Consider gradient magnitude (stop when encountering pixels with a high magnitude)
- Incorporate knowledge representation

# Advanced Region Growing

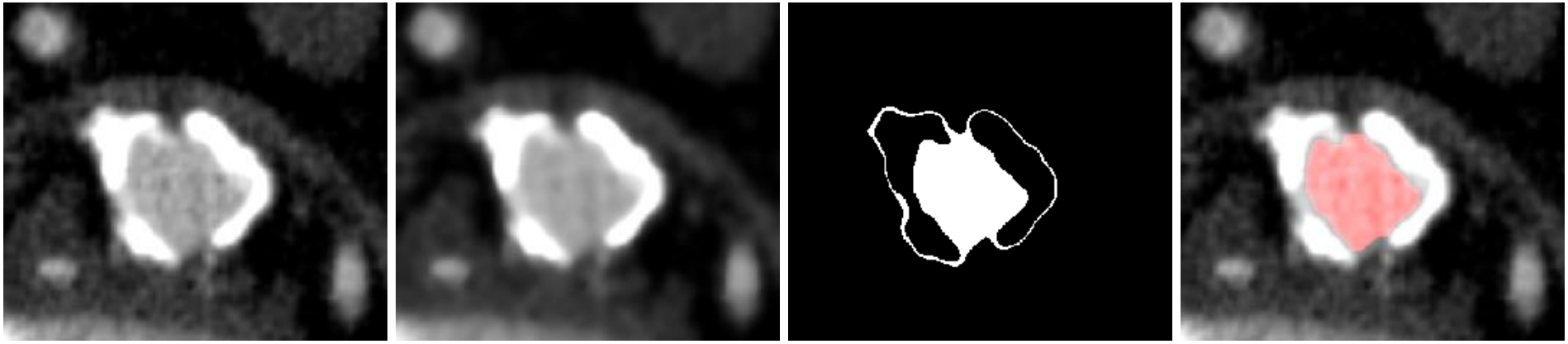
Incorporate model assumptions in region growing:
Fit an ellipse to avoid leakage.



[Hennemuth et al. 2005]

# Morphological Operations

- Postprocessing
- Dilation, Erosion
- Opening = erosion $\rightarrow$ dilation
- Closing = dilation $\rightarrow$ erosing



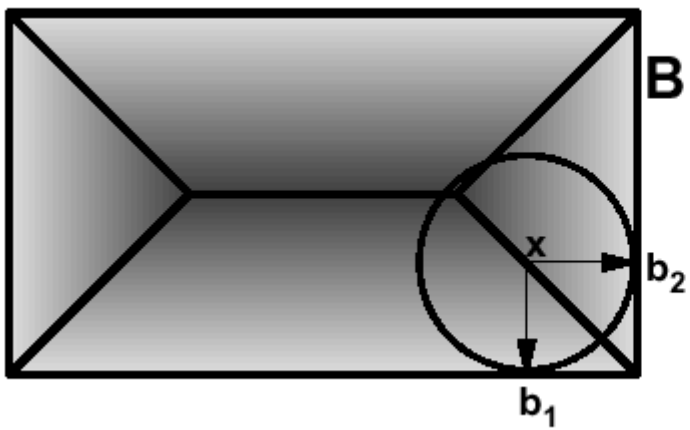
Original | Bilateral | Region growing | Opening + Closing

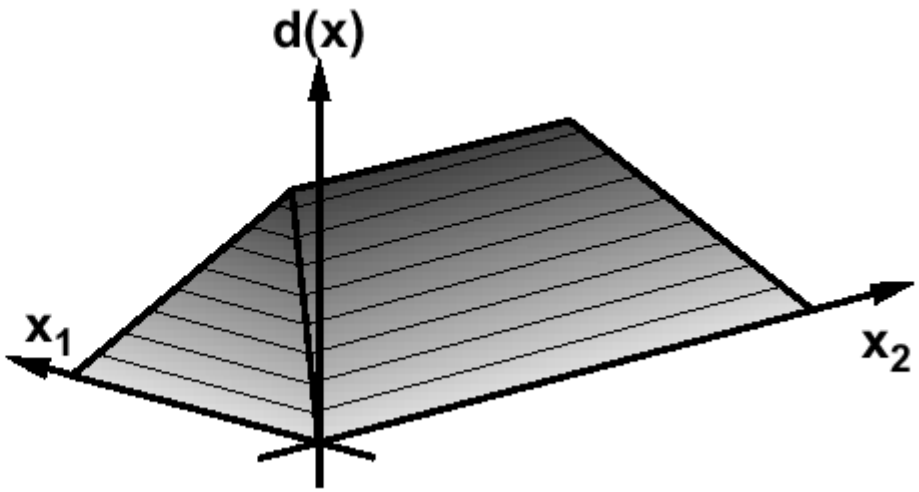
# Skeletonization

- Skeleton: describes shape of an object
- Discrete skeleton:
  - 1-pixel(voxel)-wide line
  - Proceeds through the middle of the object
- Basis for
  - measurements (e.g., vessel radii)
  - branch analysis
  - path planning (e.g., virtual endoscopy)
  - vessel visualization

# Skeletonization

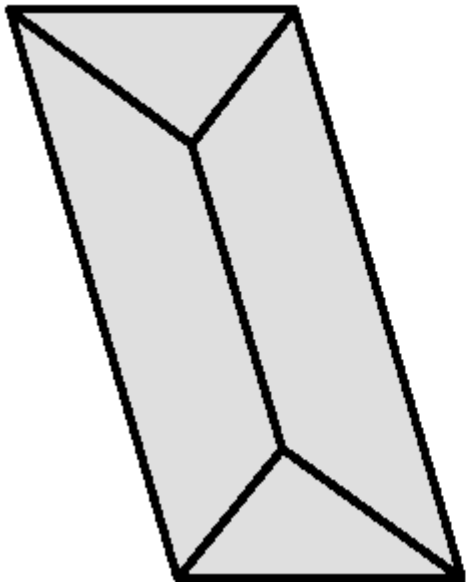
- Centers of maximum inscribed circles (spheres)
- Continued erosing (thinning)
- Grassfire transform: set outer areas on fire
  → Skeleton remains after burning



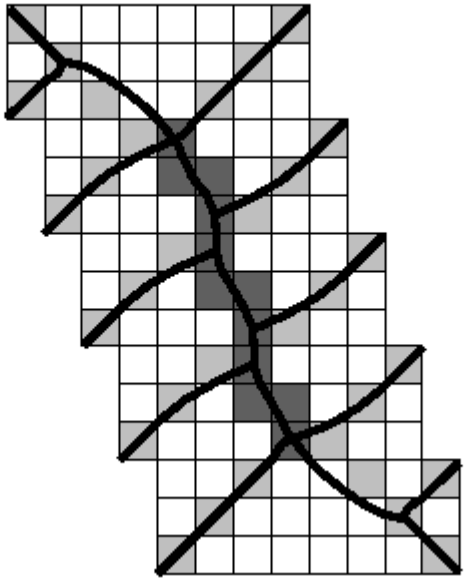




[Images: Bernhard Preim]

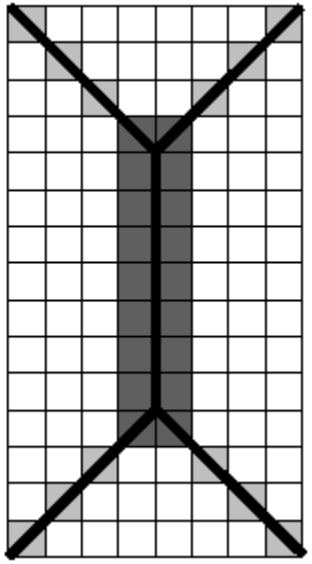
# Skeletonization – Problems



Ideal Skeleton



Irrelevant side branches

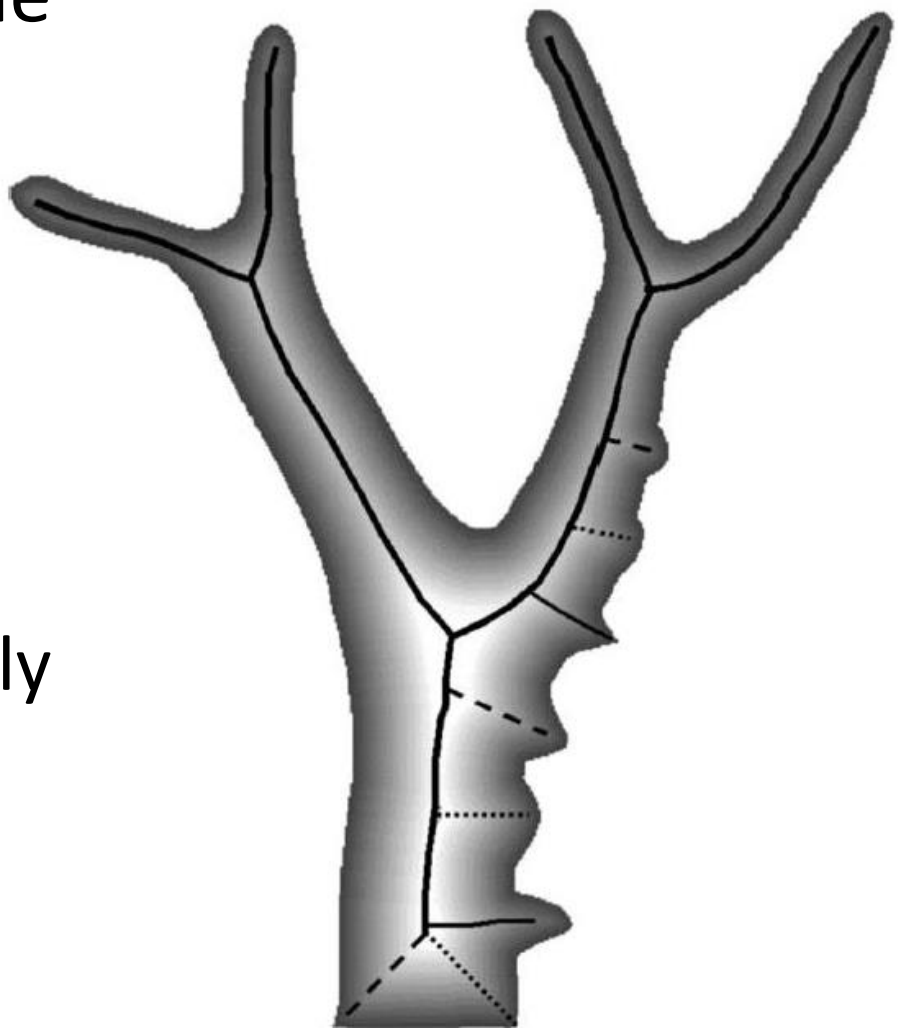


2 pixel wide lines

[Images: Bernhard Preim]

# Skeletonization – Pruning

- Filtering of irrelevant side branches
- Criteria:
  - Length
  - Ratio: length side branch / main branch
  - Hierarchy position (only leaf branches can be irrelevant)



[Preim and Bartz, 2007]

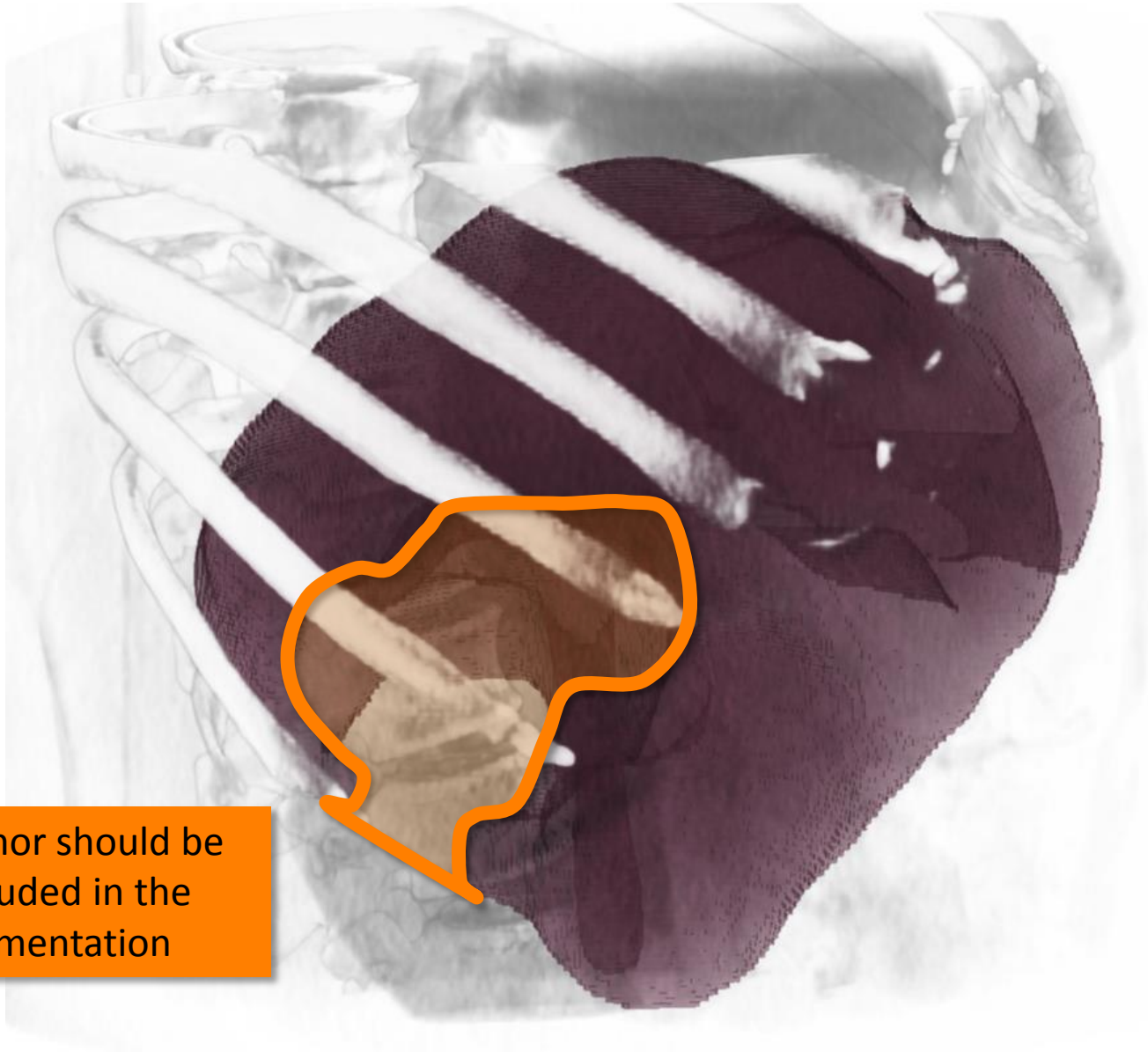
# Segmentation Problems

- Over segmentation
- Under segmentation
- Caused by:
  - Density variations due to severe disease of the respective organ
  - Non-uniform contrast enhancement
  - Scanning artifacts

- Interactively corrected by the user
- Require intuitive tools

# Over Segmentation

# Under Segmentation



Tumor should be included in the segmentation

# Quality Criteria

- Speed
  - Determines application areas
  - Emergency cases, intraoperative use ...
- Robustness against noise
  - Patient movement
  - Metal artifacts
  - Pathological changes
- Fast feedback
- Reproducibility

# Quality Criteria

- Reference solution (e.g., manually segmented by an expert)
- Precision: compared with reference
- Jaccard coefficient $J(A,B) = \frac{A \cap B}{A \cup B}$
  → The closer to 1, the more similar

- If segmenting pathologies (e.g., tumors):
  - False positives (type 1 error)
  - False negatives (type 2 error)

# Quality Criteria

Before correction: 86% quality

After correction: 93% quality

# Quantitative Analysis

Why is a quantitative analysis done?

- Additionally to a visual review
- Make a diagnosis or course of disease more objective
- Support decision for continuation/termination of a thearpy (chemo, hormone, drug therapy)
- Therapy planning (security edges)
- Geometrical modeling of implants (hip joints)
- Visualization of the quantitative analysis (e.g., bone density)

# Quantitative Analysis

What is analyzed?

- Number, dimension and volume of pathological structures (e.g., tumors, infarct region, stenoses)
- Angle between anatomical structures (e.g., assessing malpositions)
- Distance between pathological structures and anatomical landmarks (description of localization)
- Distance between pathological structures and organ at risk (for therapy planning)
- Intensity values of object (mean value, deviation)

# Quantitative Analysis – Object Extent

- Identification of the prolongation of an object

<u>Naive approach:</u>

- **Idea:** Identify the axis-aligned bounding box
- **Method:** Identify min/max in x, y and z direction
- **Problem:** Extent changes if object is rotated

# Quantitative Analysis – Object Extent

- Identification of the prolongation of an object

<u>Advanced approach:</u>

- **Idea:** Apply main axis transformation
- **Method:** Identify the barycenter and the main axes characterizing the orientation of the object
- **Result:** Local, rectangular coordinate system with barycenter as origin

# Quantitative Analysis – Object Extent

1: Identification of the barycenter vector $m$

2: Subtraction of the barycenter: $\forall p_i$ from $P$: $p_{\tilde{i}} = p_i - m$

3: Identification of covariance matrix $A$:

$$\mathrm{A} = \frac{1}{\mathrm{N}} \cdot \begin{matrix} \sum (p_{\tilde{i}x})^2 & \sum ((p_{\tilde{i}x})(p_{\tilde{i}y})) & \sum ((p_{\tilde{i}x})(p_{\tilde{i}z})) \\ \sum ((p_{\tilde{i}x})(p_{\tilde{i}y})) & \sum (p_{\tilde{i}y})^2 & \sum ((p_{\tilde{i}y})(p_{\tilde{i}z})) \\ \sum ((p_{\tilde{i}x})(p_{\tilde{i}z})) & \sum ((p_{\tilde{i}y})(p_{\tilde{i}z})) & \sum (p_{\tilde{i}z})^2 \end{matrix}$$

4: Identification of the Jacobian matrix $C$, such that $A = C^{-1}AC$
(these are the normalized eigenvectors of covariance matrix $A$)

5: Virtual object rotation according to matrix $C$

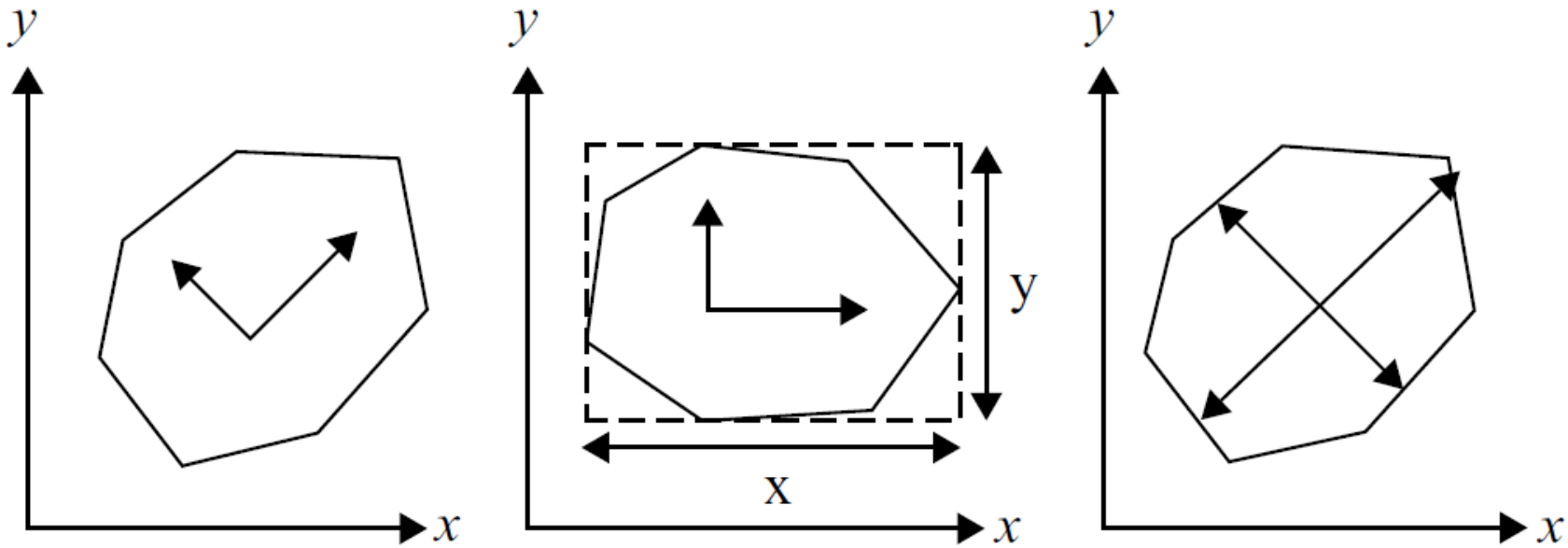
6: Compute the axial-aligned bounding box of the rotated object to define the length of the main axes

7: Back-transformation of the object according to $C^{-1T}$ through transposition

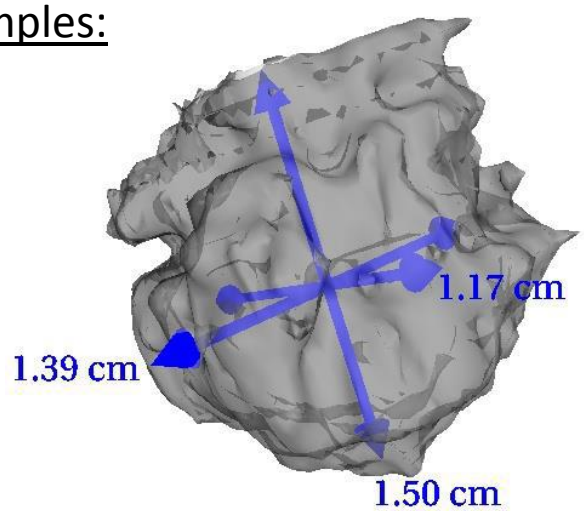
# Quantitative Analysis – Object Extent

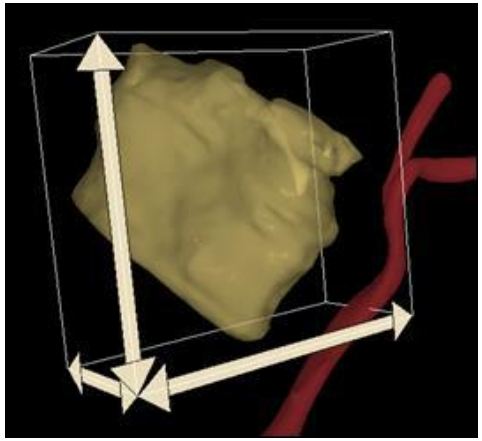
Calculation principle:

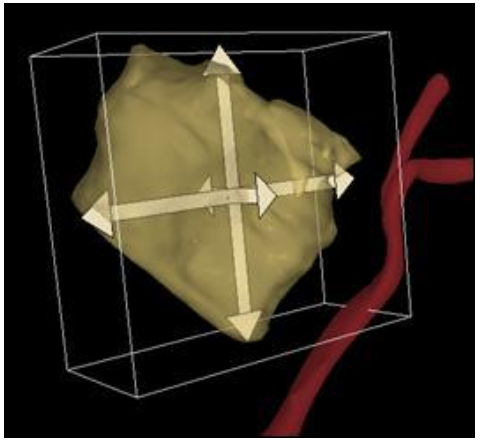
[Preim and Bartz, 2007]



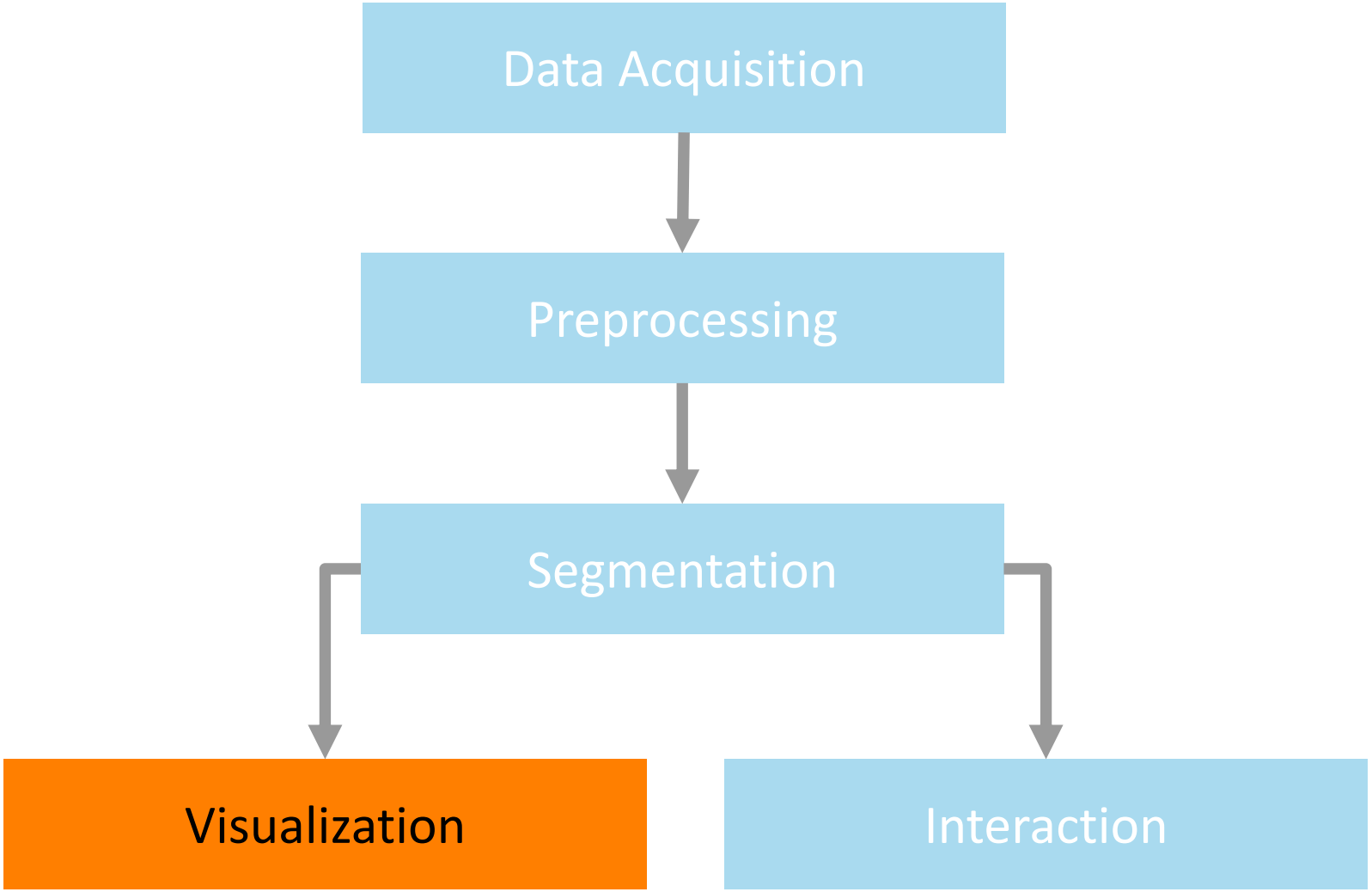

Examples:





[Images: Bernhard Preim]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# Visualization of Segmentation Results

- Standard approach: use binary mask
  (0 = background, 1 = object)

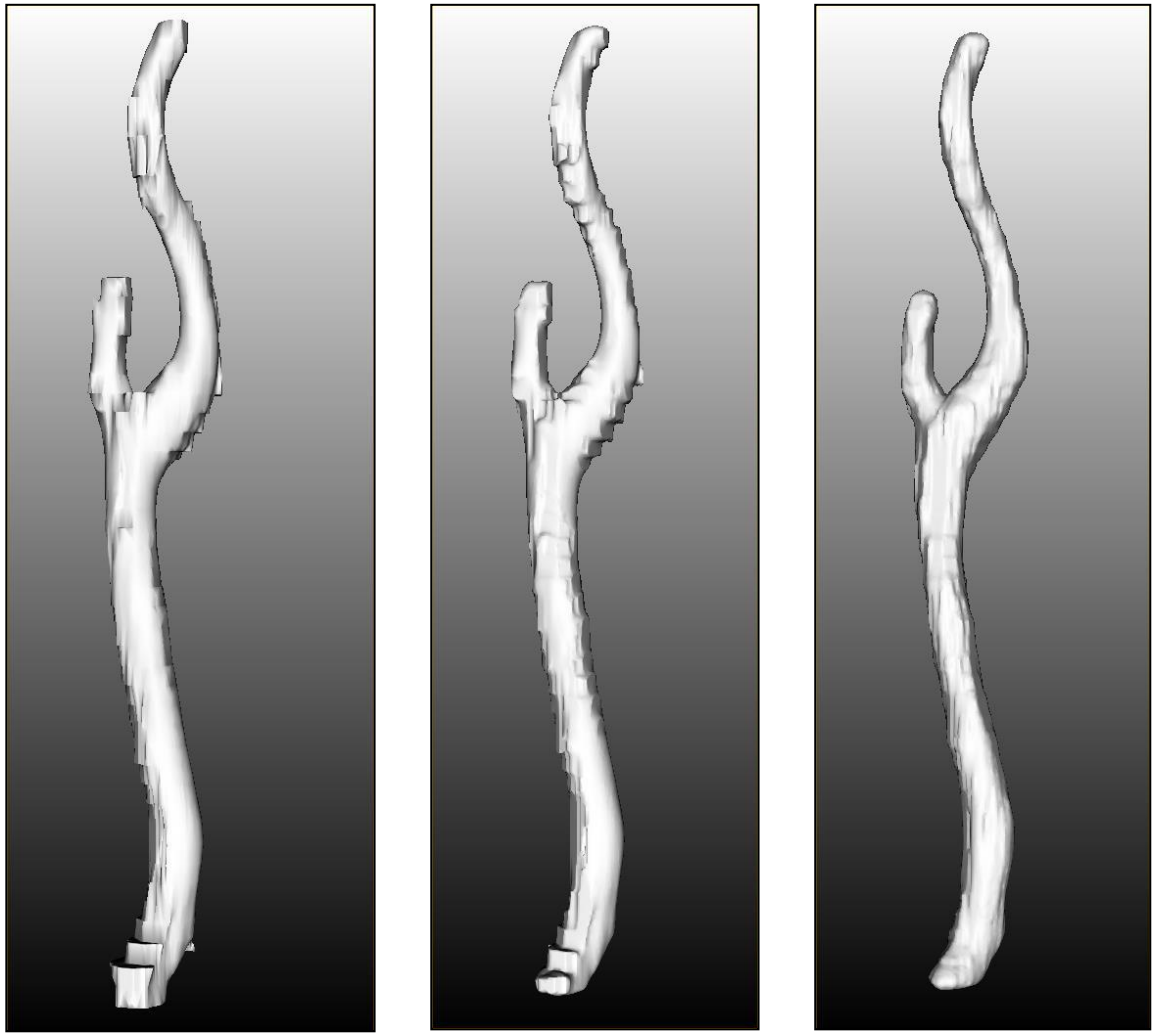
- Visualization using Marching Cubes
- **Problems:** in case of large inter-slice distance
- **Possible solution:** interpolation of inter-layers
  (e.g., cubic interpolation)
  → high storage requirements

- Instead of Marching Cubes, cubic interpolation

# Visualization of Segmentation Results

- Arteria carotis
- Inter-slice distance: 4mm

[Images: Bernhard Preim]



Original | Cubic interpolation of inter layers | Form-based interpolation

# Visualization of Segmentation Results

- Surface relaxation
- Small deformations
- Smoothes and minimizes the surface
- The binary volume defines constraints (minimizes the error)

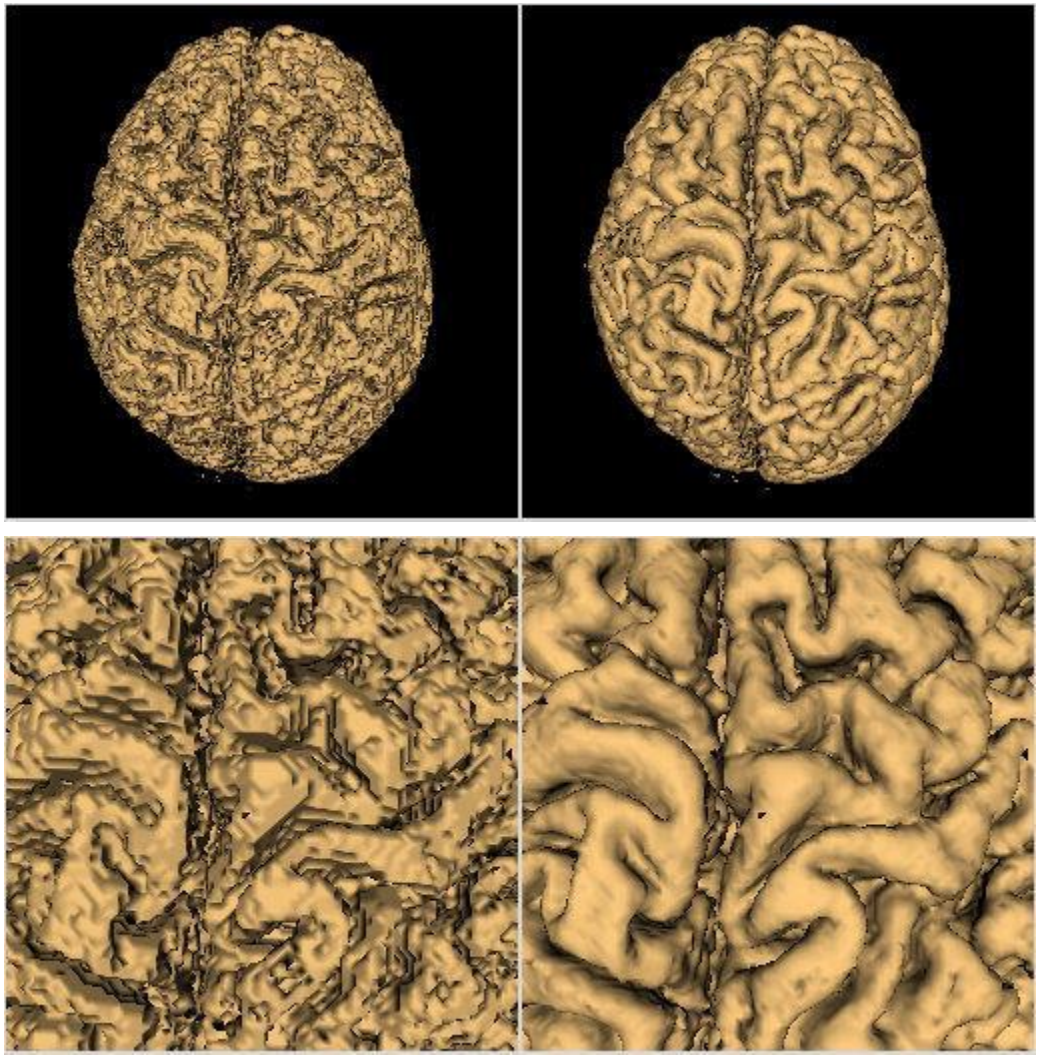
Eye with optic nerve [Source: Insight Toolkit]

# Visualization of Segmentation Results

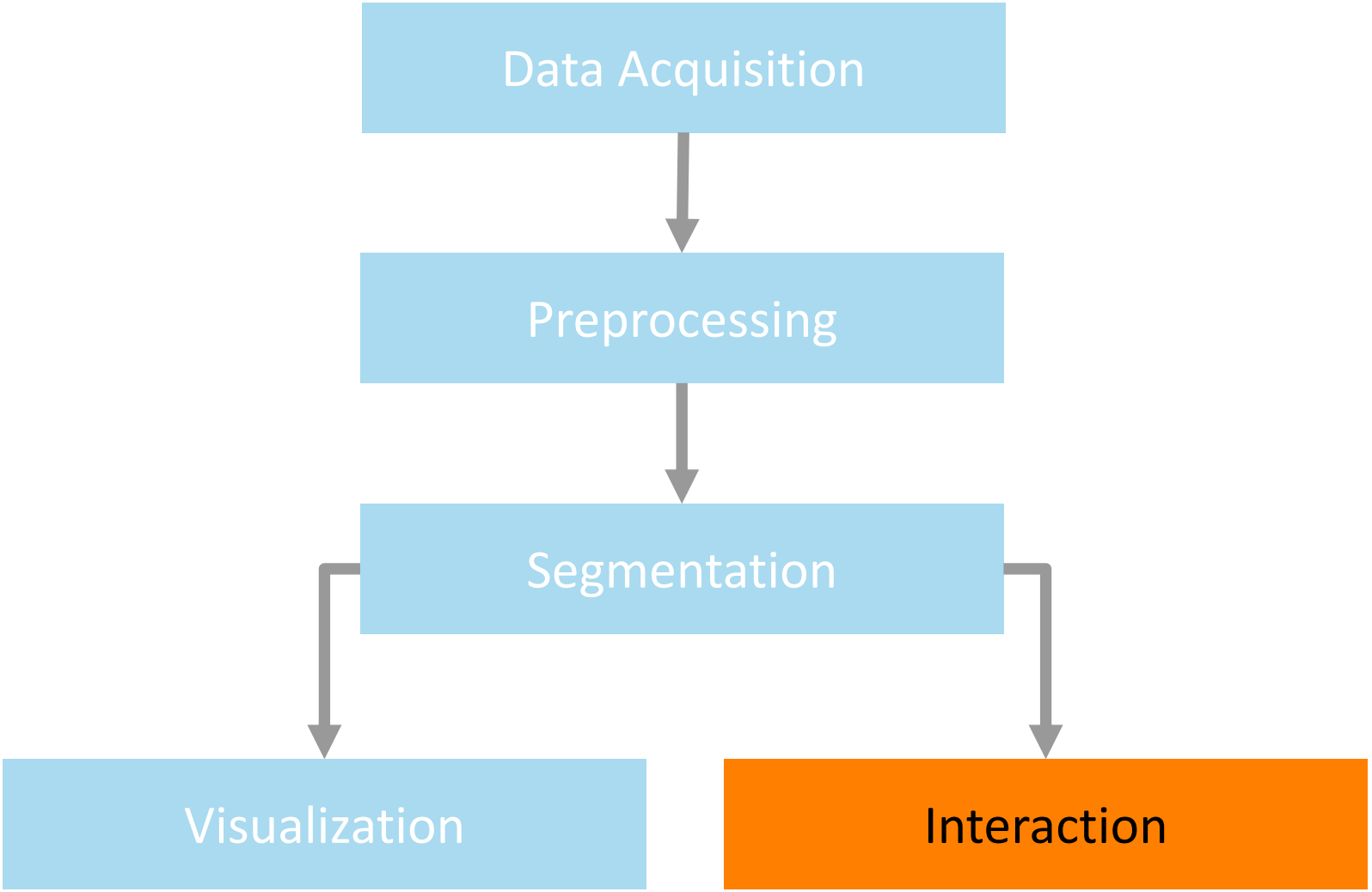
- Brain illustration

[Source: Insight Toolkit]

Marching Cubes



Reduction of aliasing artifacts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# Segmentation – Interaction

- Fully automatic segmentation rarely performed
  → Manual interaction necessary

- Interaction types:
  - Threshold adjustment
  - Limit segmentation to a certain region-of-interest
  - Stepwise refinement (include, exclude)

# Segmentation – Correction

- Scenario:

  ViviSection: Skeleton-based Volume Editing, Alexey Karimov et al. 2013

# Questions?

- Webpage: http://cg.tuwien.ac.at/courses/MedVis2/VU.html
- Abgabesystem: https://lva.cg.tuwien.ac.at/vismed2/

# References


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- G. Sakas and S. Walter: Extracting surfaces from fuzzy 3D-ultrasound data, *In Proceedings of the 22Nd Annual Conference on Computer Graphics and Interactive Techniques*, 465-474, 1995



## Acknowledgements

- Bernhard Preim
- Alexey Karimov