Visualisierung Medizinischer Daten 2
4. Vorlesung
Surface, Volume and Hybrid Visualization

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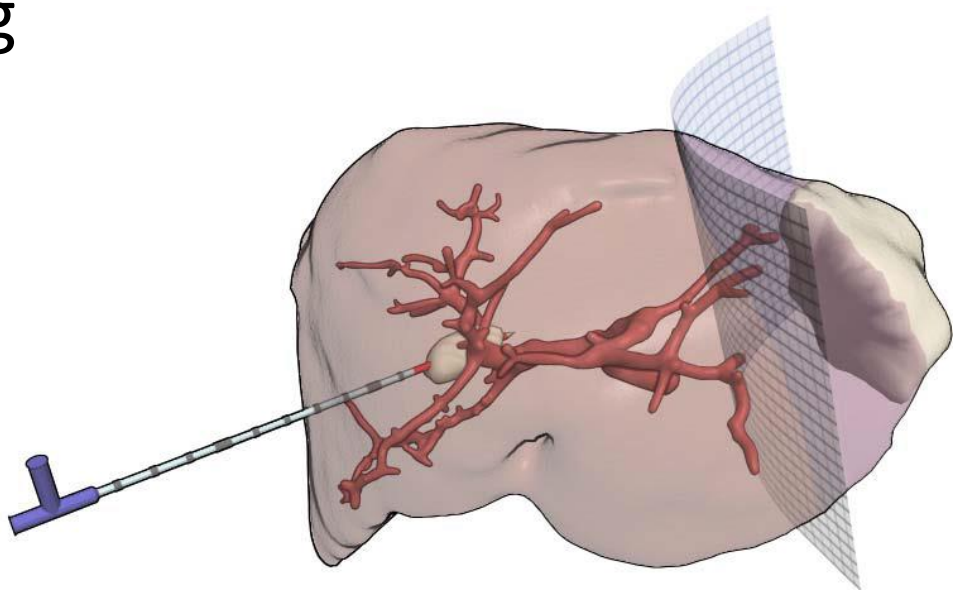
Surface Visualization

Surface Visualization – Motivation

- Surface models required for
  - Diagnosis
  - Intervention planning
  - Medical education

- Difficult to capture
  - Gas
  - Flames
  - Liquids



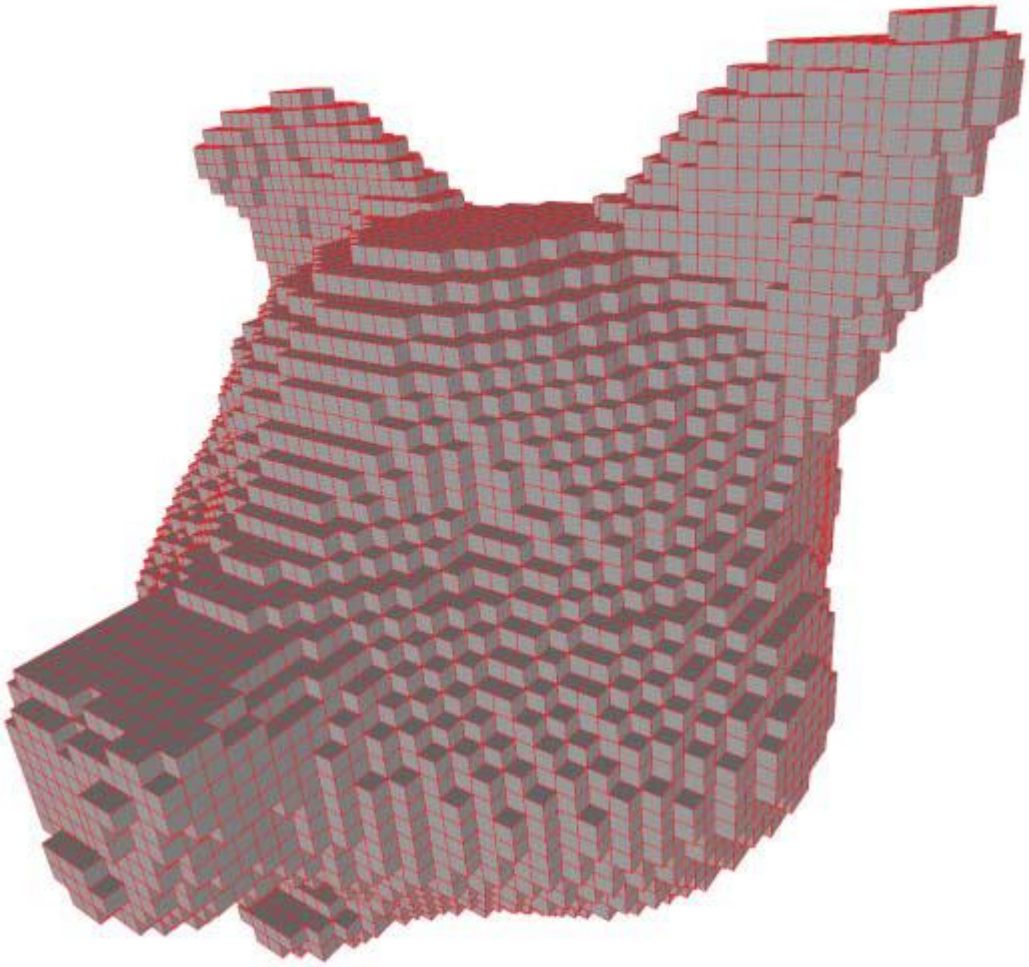
[Bade et al. 2006]

Assumption

- Segmented volume data
- Relevant structures or objects (e.g., tumors, organs, vessels)
- Binary representation (0 as background, 1 foreground or object)

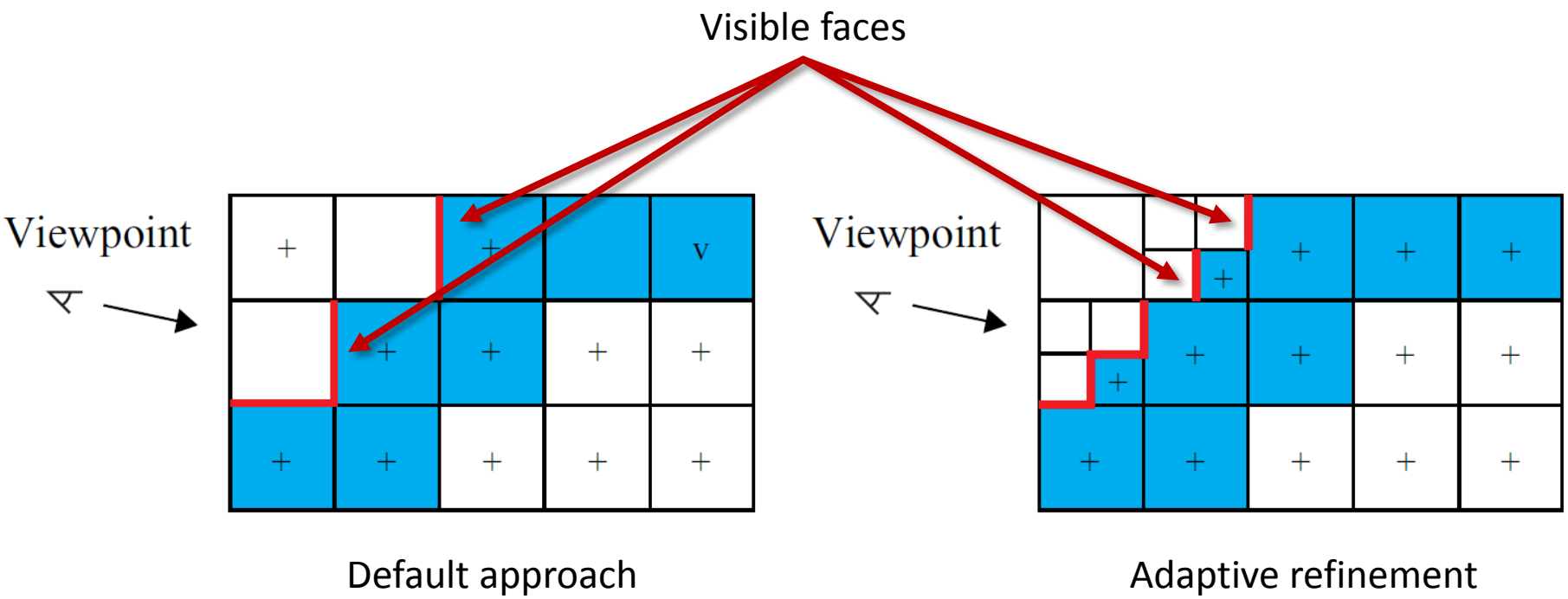
Cuberille

- Simple approach
- Represent / render voxels as cubes
- Introduced 1979 by Herman and Liu



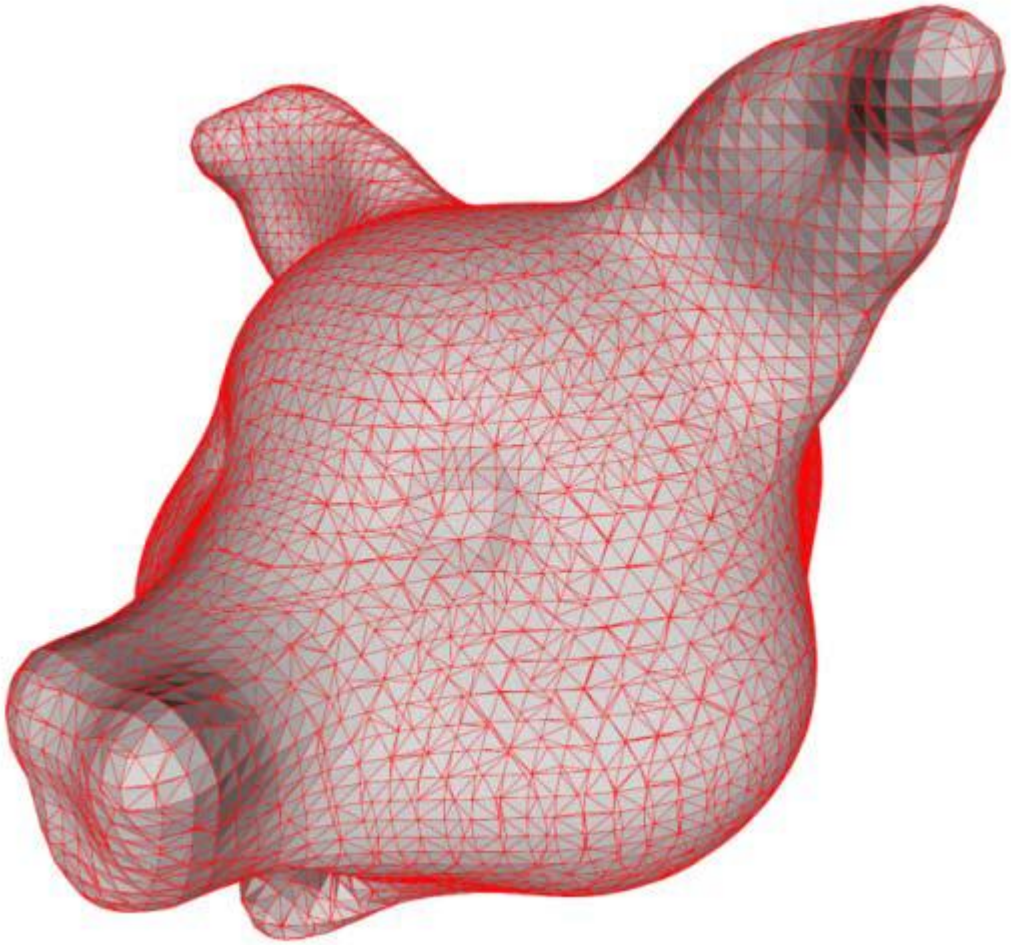
[J. Andreas Bærentzen http://www2.imm.dtu.dk/~jab/]

Cuberille


Visible faces
Viewpoint
Viewpoint
Default approach
Adaptive refinement

Surface-Based Visualization

- Create polygonal surface mesh
- Determine
  - Positions
  - Triangles
  - Normals
- Utilize GPU for massive parallel rendering



[J. Andreas Bærentzen http://www2.imm.dtu.dk/~jab/]

Surface Extraction

- Determine contour in 2D
- Follow contour → connect in 3D
  - Cumbersome
  - Many cases to handle
- Idea:
  - Treat cells locally independent
  - Determine intersection of cells with the surface
    → Marching cubes
    → Marching tetrahedra
    → Dividing cubes

Surface Extraction – Issues

- **Correspondance** between contours of consecutive slices
- How to create a triangle mesh between two contours (**triangulation, tiling**)
- How to connect a different number of contours in two consecutive slices (**branching points**)
- **Problem**: if two contours from consecutive slices belong to the same object but do not intersect

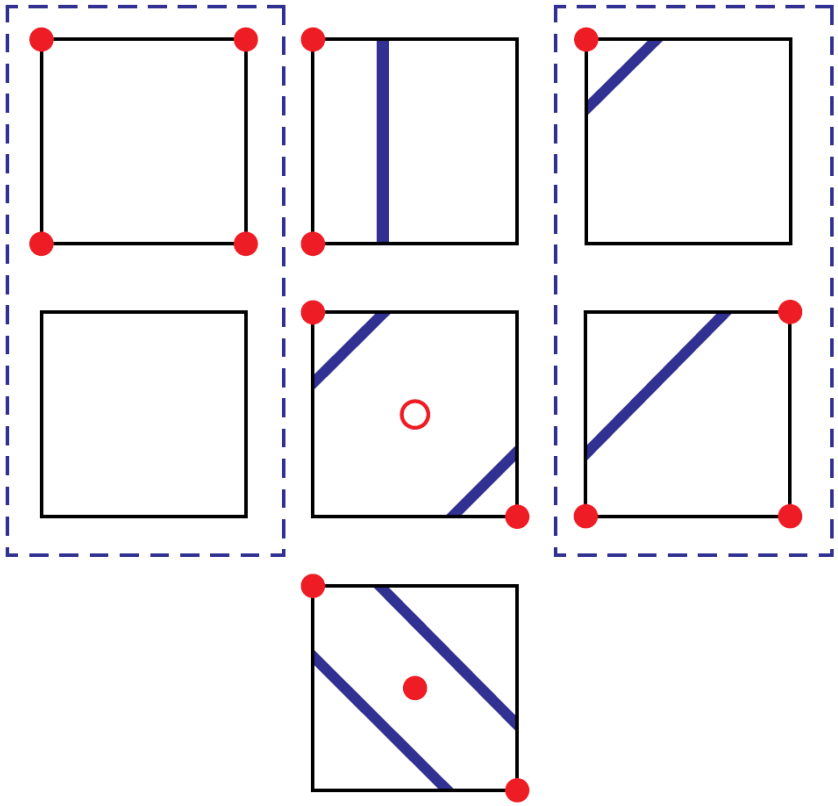
Surface Extraction – Issues

Marching Cubes

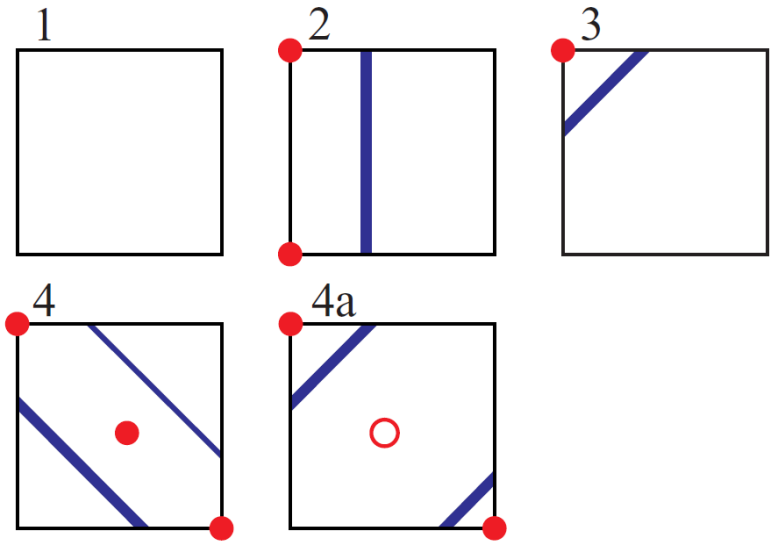
- **Requirement:** Overlapping contours within consecutive slices
- **Problem:** Large inter-slice distance with thin objects diagonal to the surfaces
- **Solution:**
  - Expensive in such cases
  - Generalized Elliptical Cylinder (Soroka, 1981)
  - Interpolation of intermediate slices

Marching Squares

Cases after reduction through rotation

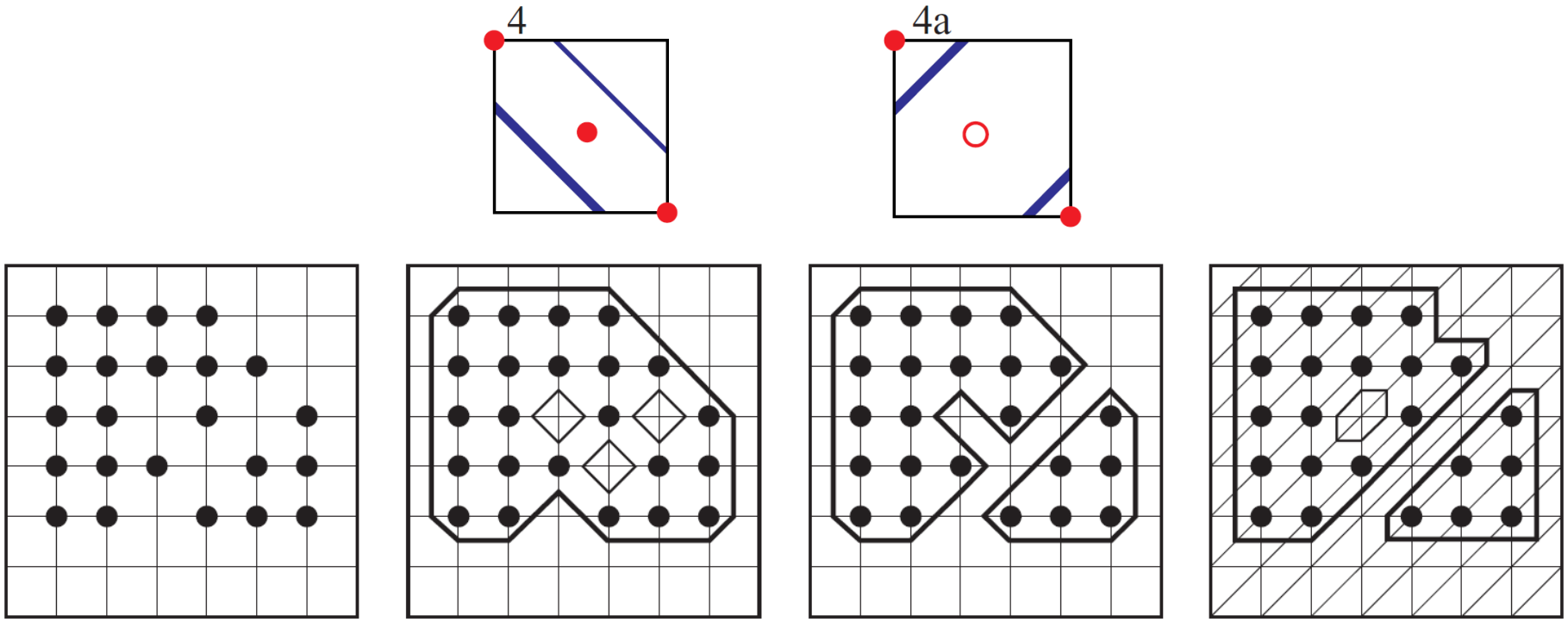


Cases after complementing



[Preim and Bartz, 2007]

Marching Squares – Ambiguities

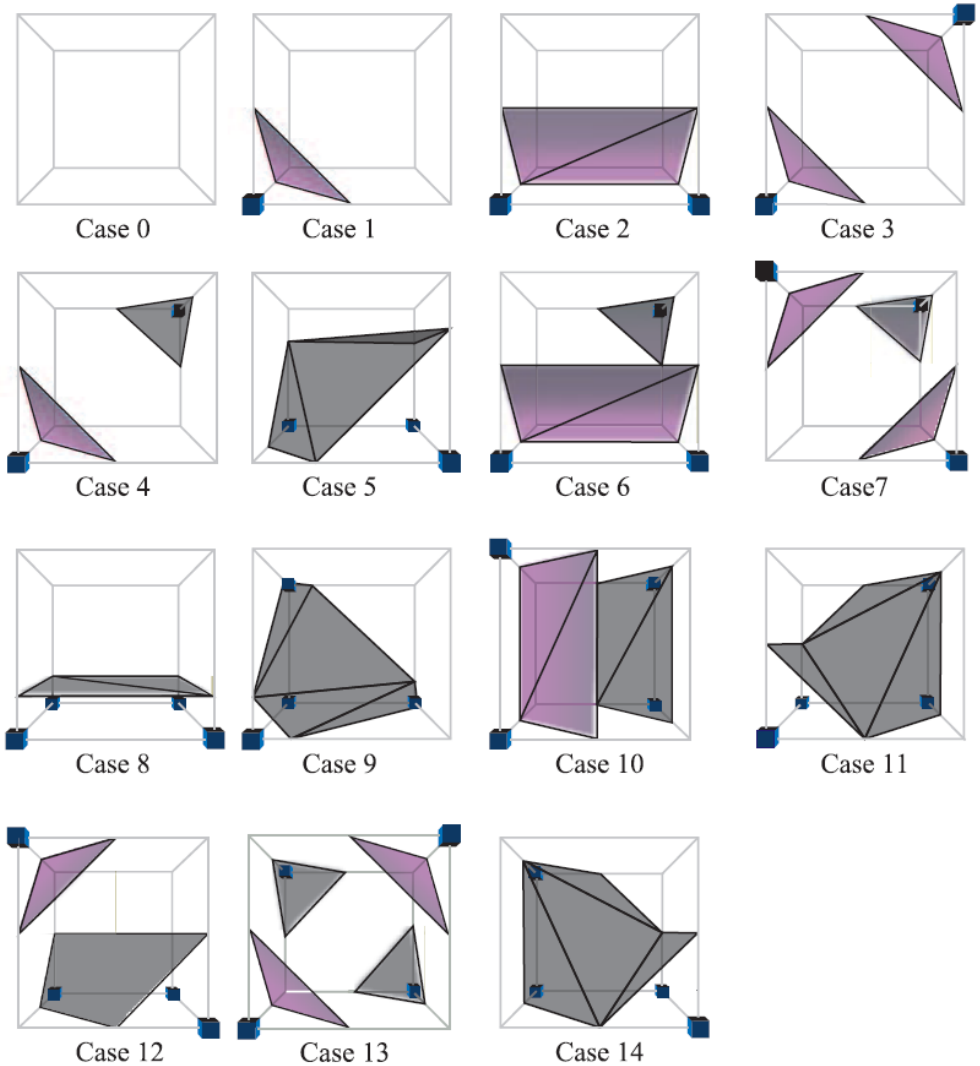


[Preim and Bartz, 2007]

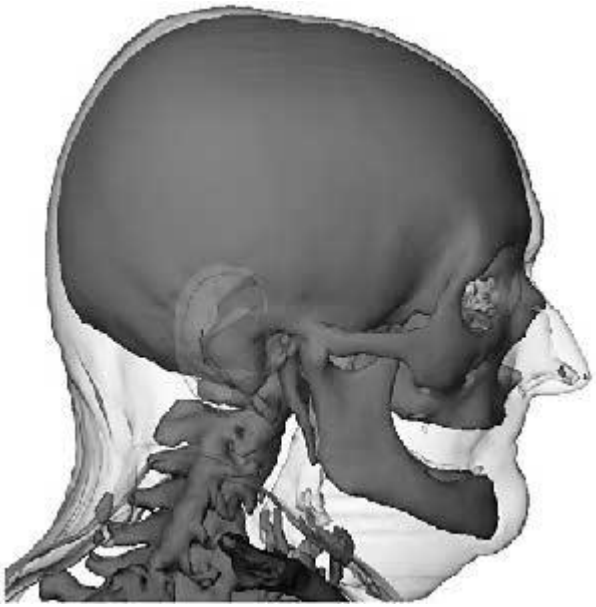
Marching Cubes

- Extension of marching squares to 3D
- Converts a volume data into a triangle mesh
- 15 topologically different cases of surface cutting through the cell
- Workflow
  - Determine case for cell
  - For every cut edge, interpolate linear
  - Connect intersection points to triangles
  - Compute normal vectors

Marching Cubes



[Preim and Bartz, 2007]



[Stalling et al. 1999]

Marching Cubes – Problems

- Quality issues
  - Linear interpolation
  - Gouraud shading
- Does not tackle correspondance problem → ambiguities
- Does not properly account for tile & branching problem

Virtual bronchoscopy

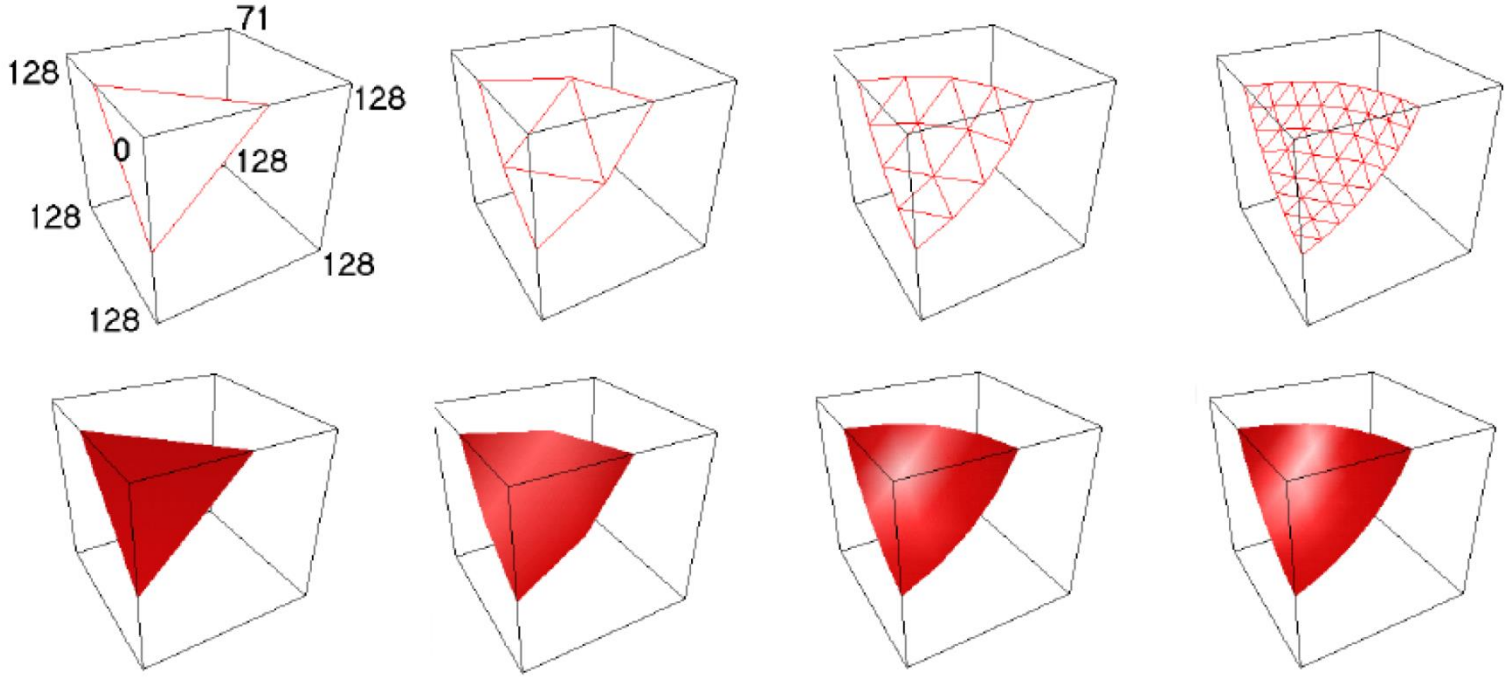
[Preim and Bartz, 2007]

Marching Cubes – Summary

- Simple
- Fast rendering
- Fast computation
  → But, a lot of time is spent on cells that do not belong to the surface
- Disconnected segments removed by connected component analysis

Precise Marching Cubes

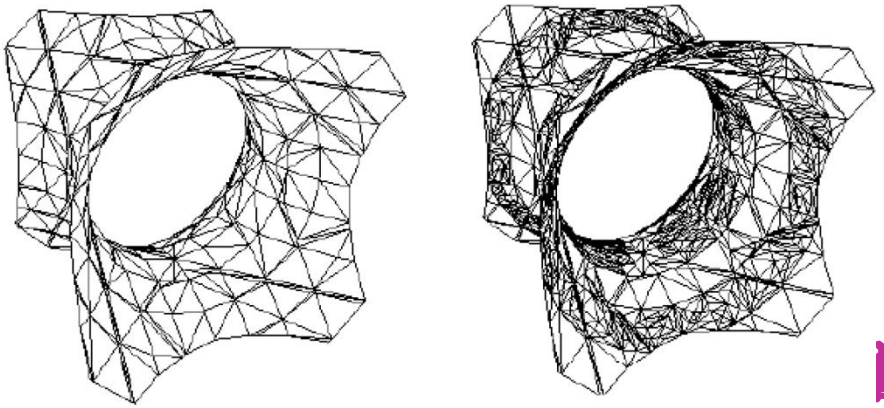
- **Improvement:** Adaptively refine the surface (Allamandri et al. 1998, Cignoni et al. 2000)
- Triangles refined if error larger than threshold
- Recursion level depends on accuracy



[Allamandri et al. 1998]

Precise Marching Cubes

- Error measure:
  - Distance to exact surface measured at samples (center of triangle sides or center)
  - Measured in direction of normal
  - If distance > threshold, subdivide (recursive)
- Exact surface defines by trilinear interpolation
- 100x more expensive than marching cubes
- Surface 2-3x larger



[Allamandri et al. 1998]

Surface Smoothing

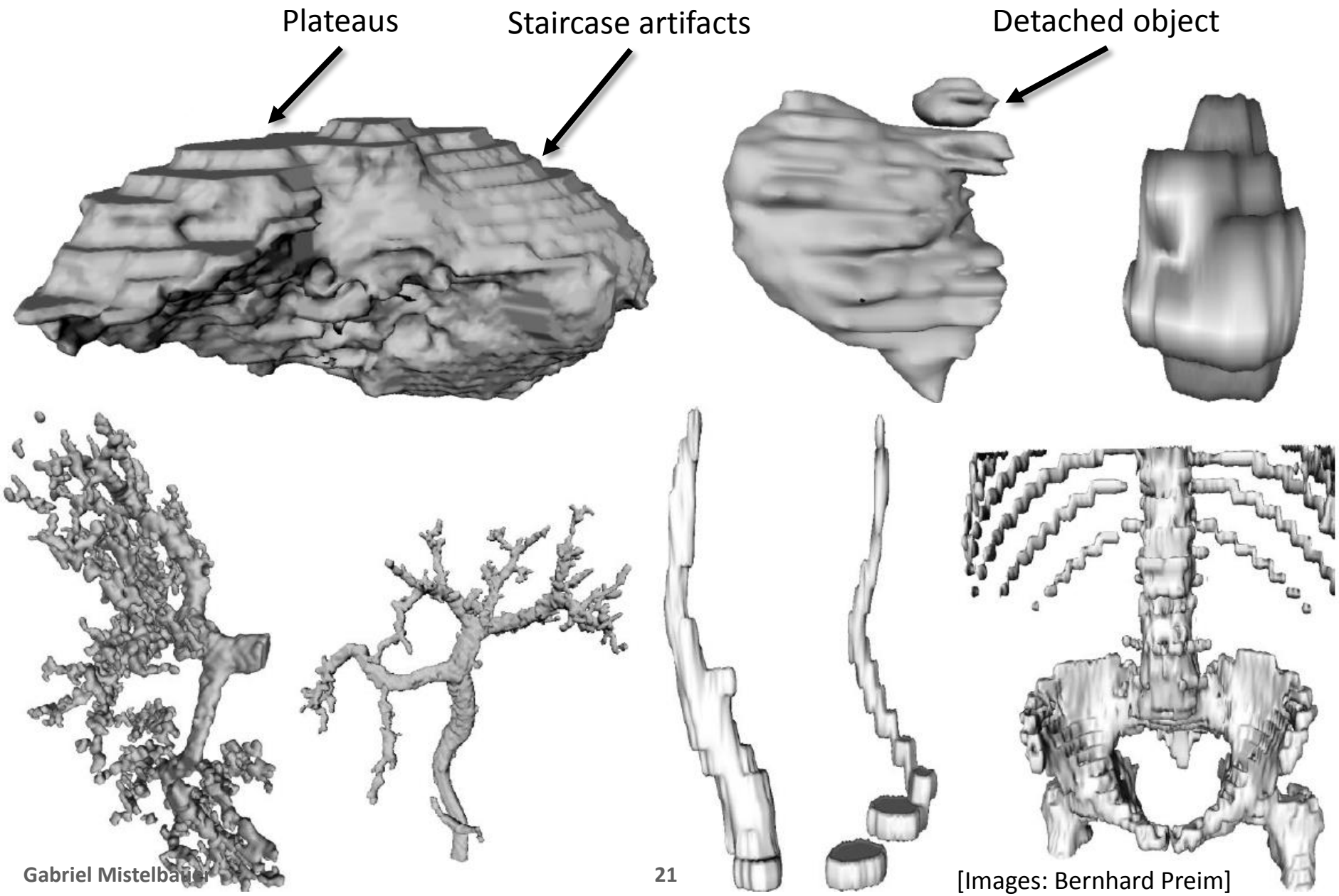
- **Problem:** Creating surfaces from segmented data leads to artifacts, especially if highly anisotrop
- Illustrative visualization techniques enhance artifacts (e.g., silhouettes)
- **So far:**
  - Interpolation of intermediate slices
  - Manual smoothing of surface (Laplace filter)
- Time-consuming error-prone process
- Not reproducible neither standardized
- Only visual examination

Surface Smoothing

- **Problems:**
  - Noise on the object boundary
  - Small detached parts
  - Holes

- → Undesired surface artifacts

Surface Smoothing



[Images: Bernhard Preim]

Surface Smoothing – Requirements

- Reduction of high-frequency noise, while preserving features
- Speed / performance
- Accuracy
- Measurements
  - Small distance between smoothed and original surface
  - Volume preservation
  - Curvature plots

Surface Smoothing

- Smoothing of segmentation result using morphological operations (dilation, erosion)

0	0	0	0	0	0	0
0	0	0	100	100	100	0
0	100	100	100	100	100	0
0	100	100	100	100	100	0
0	0	0	100	100	100	0
0	0	0	0	0	0	0

→

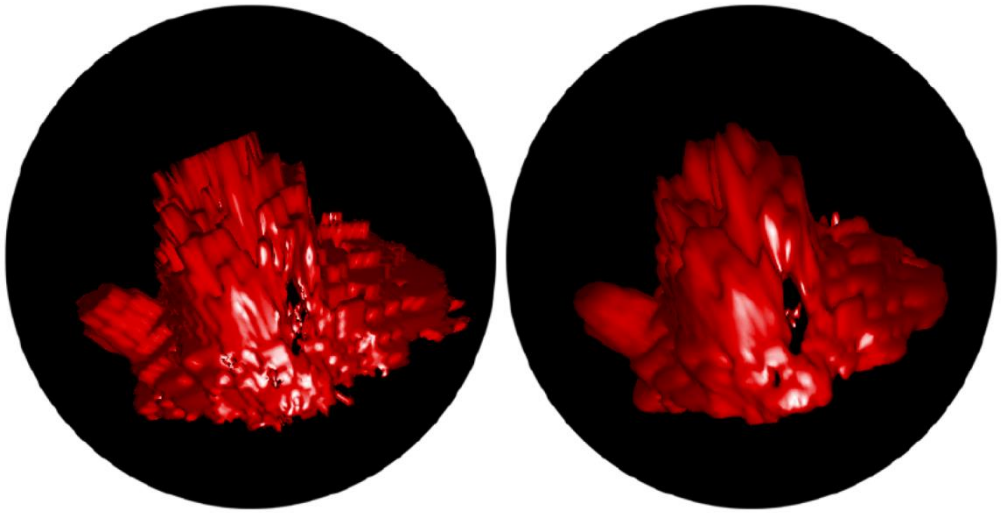
0	6	26	33	33	26	6
20	33	54	66	66	54	26
33	66	66	100	100	66	33
33	66	66	100	100	66	33
20	33	54	66	66	54	26
0	6	26	33	33	26	6

1. Erosion (modified)

$$v = v_2 - (v_2 - v_1) * \frac{1}{3}$$

2. Dilation twice (modified)

$$v = v_{ref} - (v_2 - v_1) * \frac{d}{3}$$



[Neubauer et al. 2004]

Surface Smoothing

- Could be seen as optimization problem
  - Minimize total curvature
  - Minimize total surface area
- Important publications
  - Welch and Witkin, *Free-form shape design using triangulated surfaces*, SIGGRAPH 1994
  - Kobbelt and Stamminger and Seidel, *Using Subdivision on Hierarchical Data to Reconstruct Radiosity Distribution*, Eurographics 1997

Surface Smoothing

- Iterate over all vertices, replace with weighted average of its value and its neighboring ones within a certain vicinity

- Defined by
  - Distance (Euclidean distance)
  - Vertices connected with the current (directly or via a path of length *n*) → topological distance
  - Typical: Vertices with topolog. distance of 1 or 2

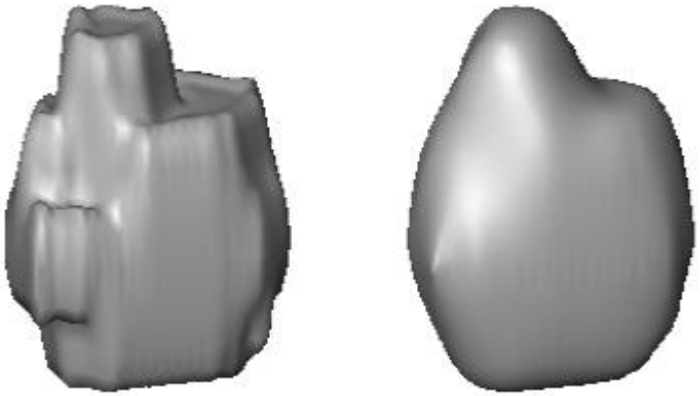
Laplace Smoothing

- Considers vertices q_i within topological distance of 1 around vertex p

$$p' = p + \frac{\lambda}{n} \sum_{i=0}^{n-1} (q_i - p)$$

- Smoothing factor λ
- Number of iteration n
- Simple and fast

Smoothing, $\lambda = 0.5$, 20 iterations



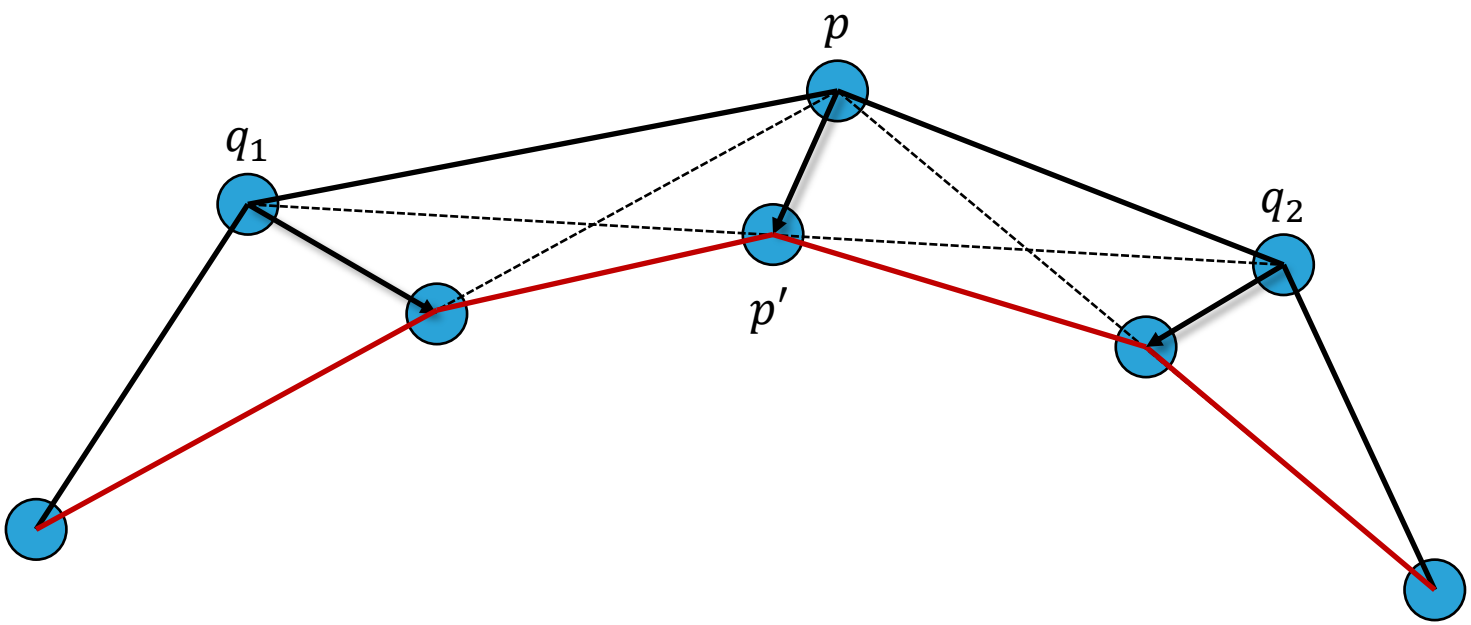
[Bade et al. 2006]

Original,
Volume = 100%

Laplace smoothed,
Volume = 80.8%

Laplace Smoothing

- Iterative smoothing
- Vertices moved towards center of neighbors



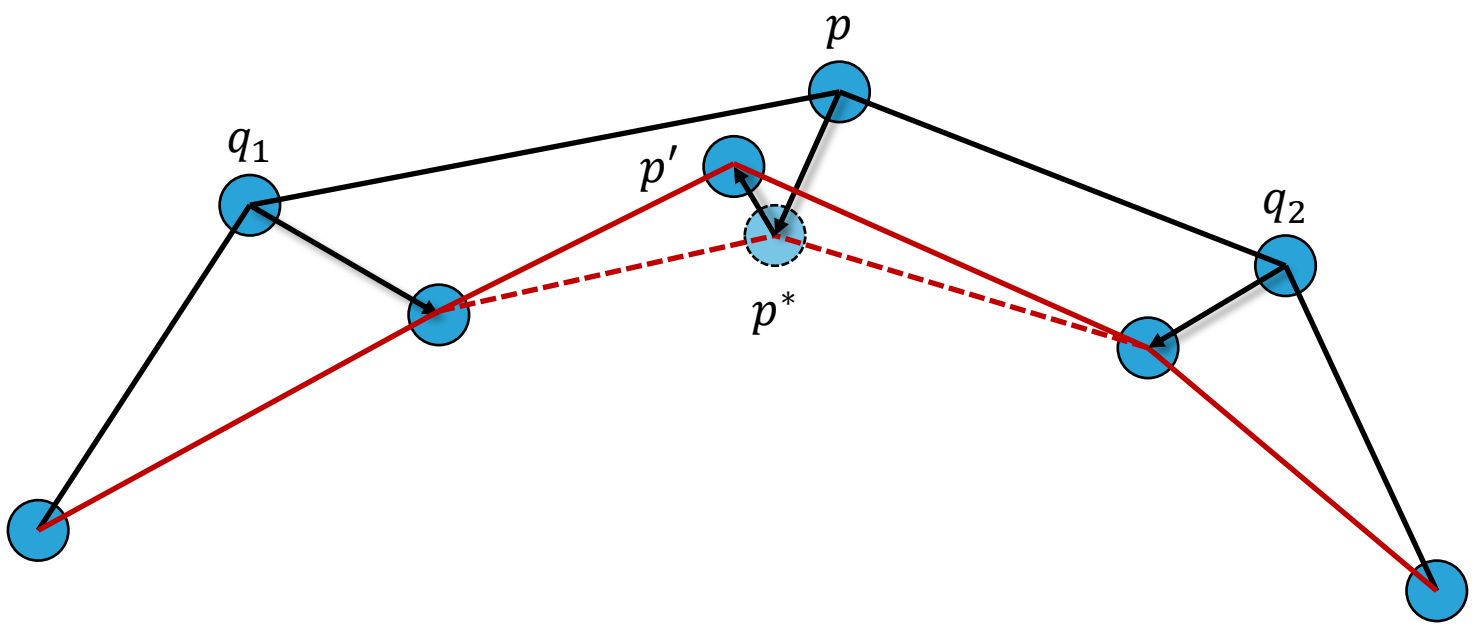
Laplace Smoothing

- **Problems:**
  - Undesired (uncontrolled) shrinking
  - Small features often fully smoothed to obtain required smoothness

- **Improvements:**
  - Vertices moved some distance back per iteration
  - Additional parameters
    - How much to move back
    - How much neigbhoring vertices should influence

Improved Laplace Smoothing

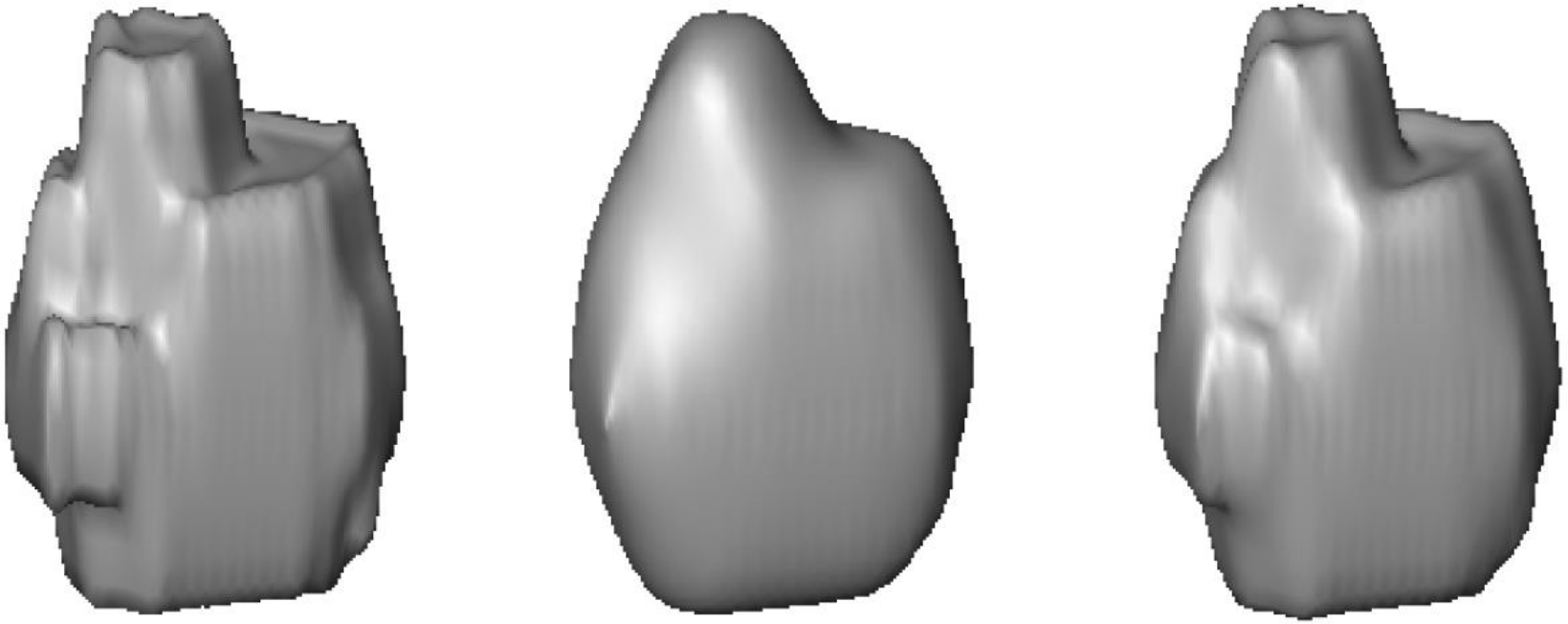
- Algorithms:
  - Laplace+HC [Vollmer et al., 1999]
  - Lowpass ($\lambda|\mu$-Filter) [Taubin, 1995]



Improved Laplace Smoothing

- Lymph node:

[Bade et al. 2006]



Original | Laplace filtered | Improved Laplace filtered

Lowpass Filtering

- Alternately apply two different Laplace-like filters (different factors λ and μ)

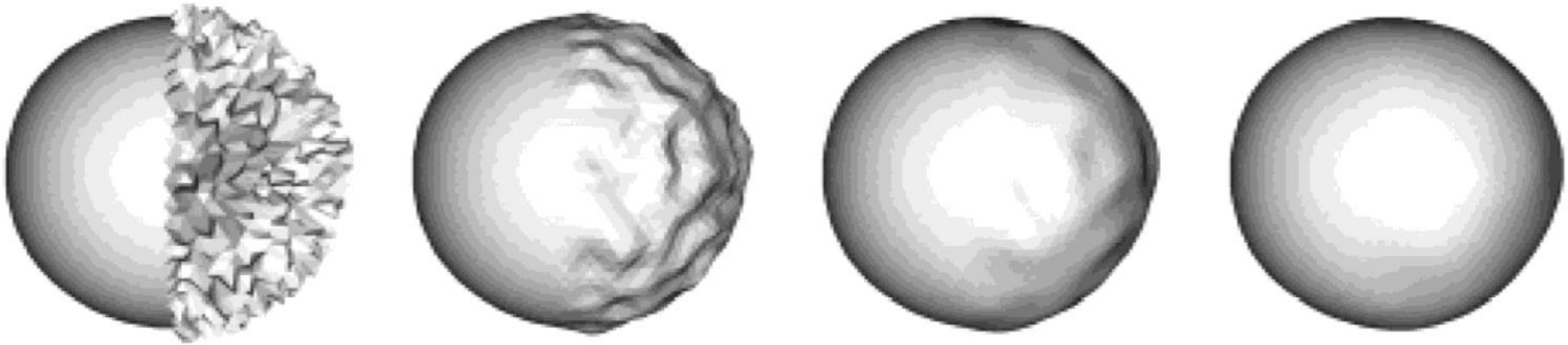
$$1.\ p' = p + \frac{\lambda}{n} \sum_{i=0}^{n-1} (q_i - p)$$

$$2.\ p' = p + \frac{\mu}{n} \sum_{i=0}^{n-1} (q_i - p)$$

- All neighbors have same influence: $\frac{1}{n}$

Lowpass Filtering

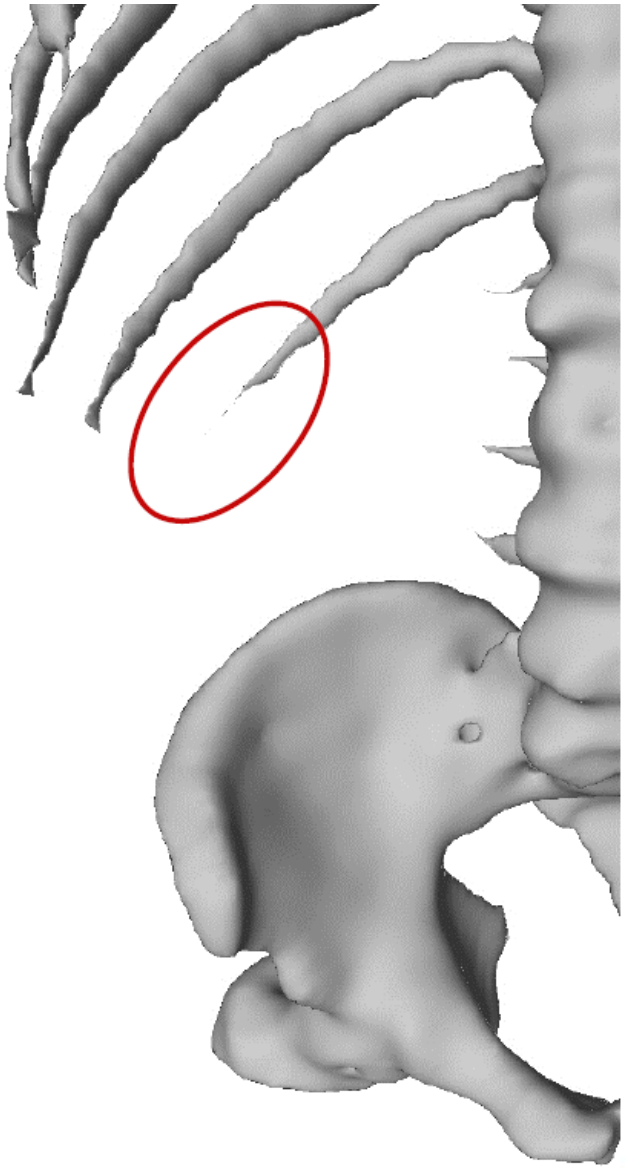
- Default $\mu = 1.02 * \lambda$ [Taubin, 1995]



[Taubin, 2000]

Lowpass Filtering

- **Problem:** Small details not preserved (even filter with correction)



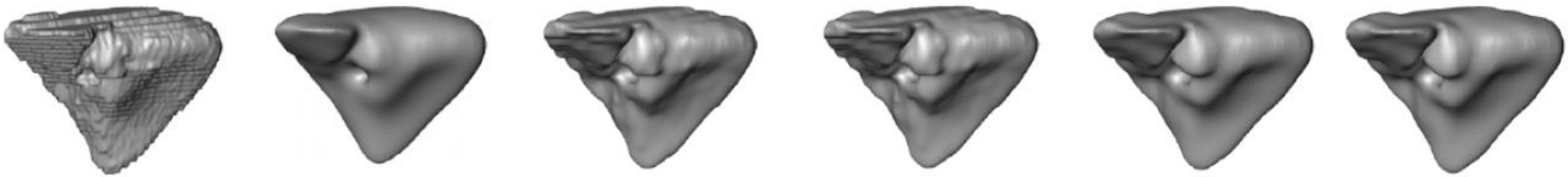
[Bade et al. 2006]

Comparion of Techniques

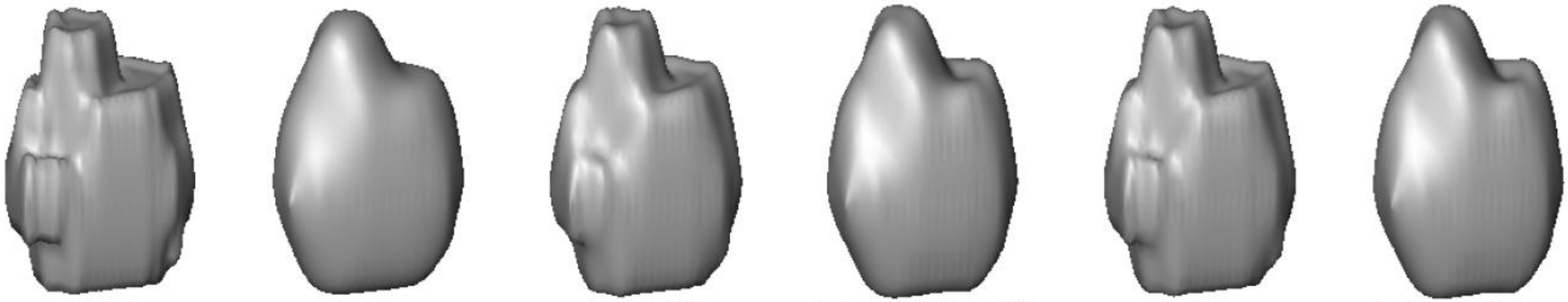
- Criteria:
  - Quality
  - Volume
  - Runtime
- Compared:
  - Iteration levels
  - Weighting factors
  - Neighborhood (1, 2 topologisch)

Comparions

- Smoothing factor = 0.5, 20 iterations



Original	Laplace	Laplace+HC	LowPass	Laplace+HC 2. Ordnung	LowPass 2. Ordnung
V=100%	V=91,0% 2,03s	V=99,9% 3,91s	V=100,1% 4,36s	V=99,6% 224,14s	V=100,2% 220,95s

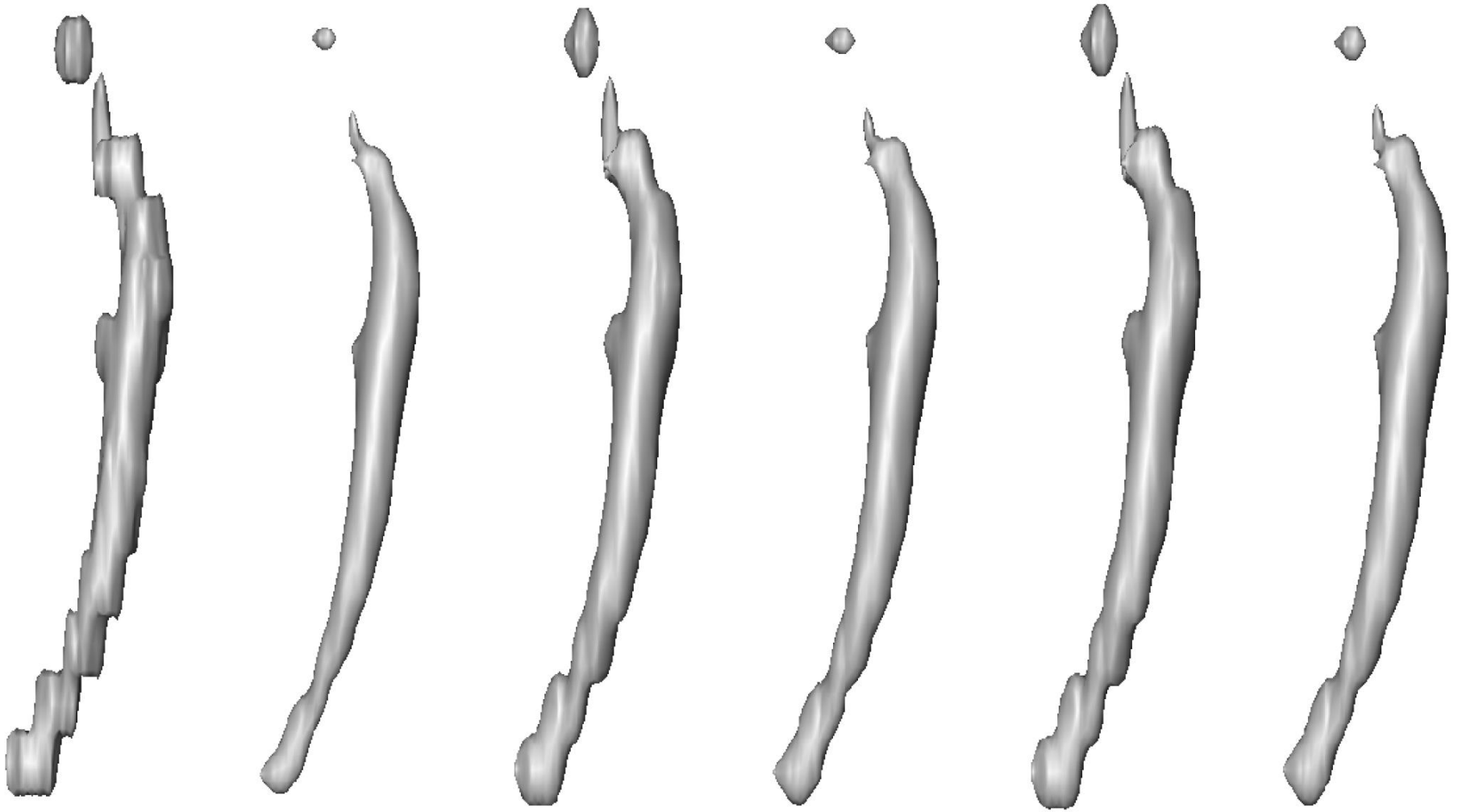


Original	Laplace	Laplace+HC	Laplace 2. Ordnung+HC	LowPass	LowPass 2. Ordnung
V=100%	V=80,8%	V=99,8%	V=96,2%	V=100,0%	V=99,2%

[Bade et al. 2006]

Comparions

- Smoothing factor = 0.7, 10 iterations



Original
V=100%

Laplace
V=102,2%

Laplace+HC
V=102,2%

Laplace 2. Ordnung+HC
V=82,7%

LowPass
V=104,3%

LowPass 2. Ordnung
V=99,3%

[Bade et al. 2006]

Other Techniques

- Average Filtering: Normal replaced by average within neighborhood
- Median Filtering: Sorts normals of neighboring voxels according to the angle of the current normal
- Mean curvature flow: Uses curvature of object for modifying its vertices

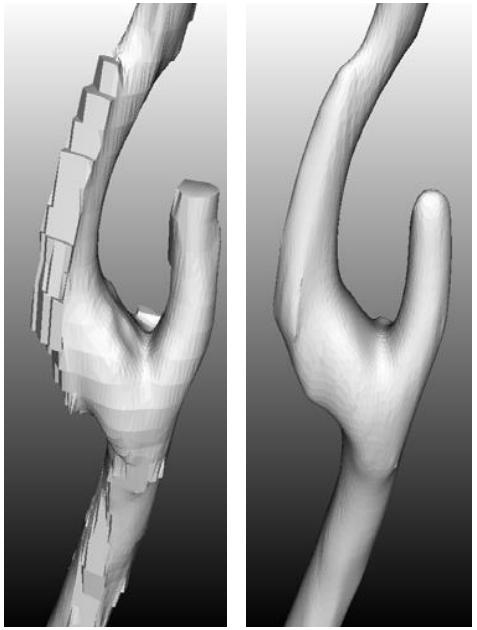
Guidelines

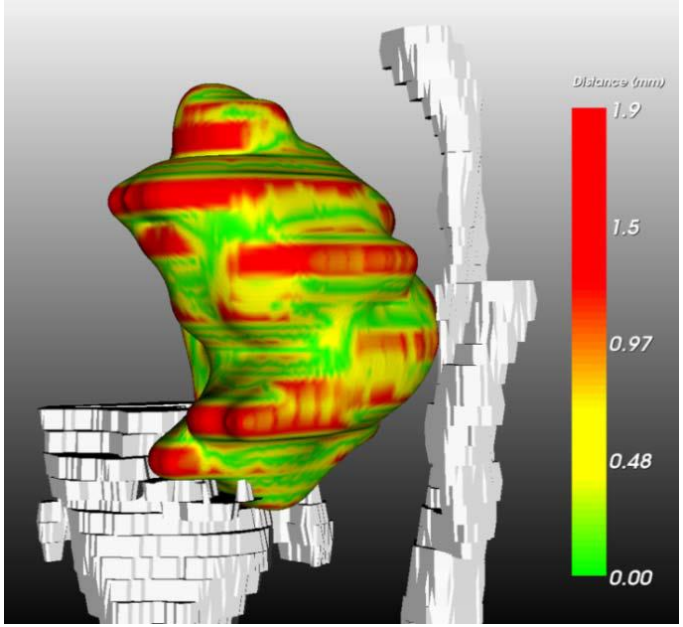
- Lowpass filtering for all objects suitable
- Small objects: Topological beighborhood 2, 20-50 iterations
- Flat objects with many problems: Topological beighborhood 1, 20 iterations
- Elongated and branching objects: Somewhat no suitable filter
- Less branched structure: Lowpass filter with topological neighborhood 1 and 10 iterations

Distance-Aware Smoothing

- Smoothing while considering clinically relevant aspects:
  - Volume reductions (e.g., tumors)
  - Shape changes
  - Distance changes of stuctures

[Mönch et al., 2010]

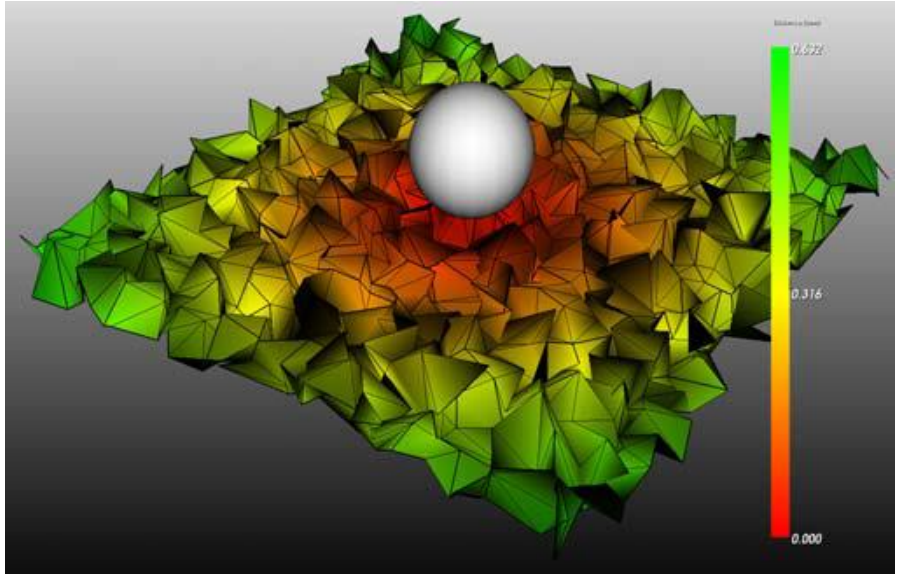


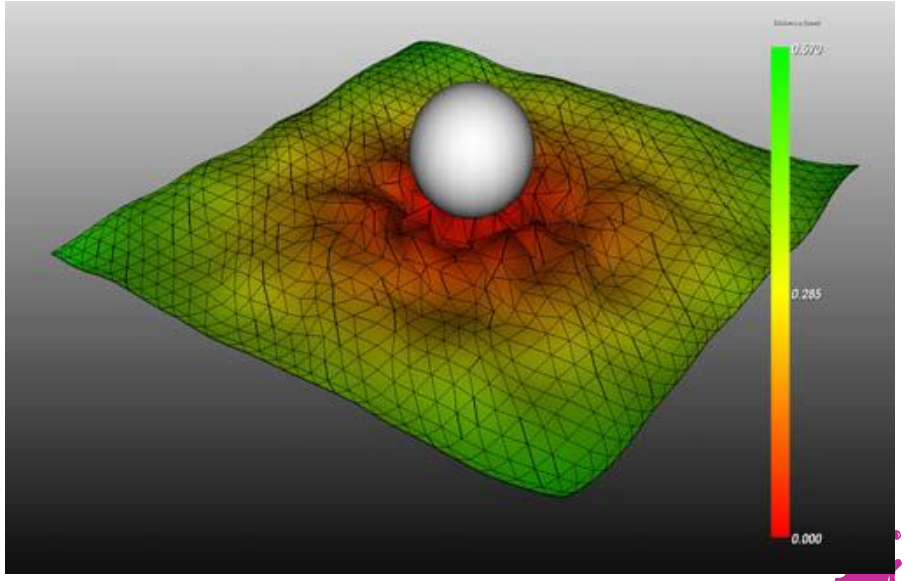


Distance-Aware Smoothing

- Clinically relevant aspects:
  - Determine safe-margins
  - Risk estimation for treatment planning or surgery
- → Consider spatial aspect during smoothing

[Mönch et al., 2010]





Distance-Aware Smoothing

- Smoothing
  - Reduces volume of object
  - Removes potentially relevant details

↕

  - Not sufficient staircase artifact reduction

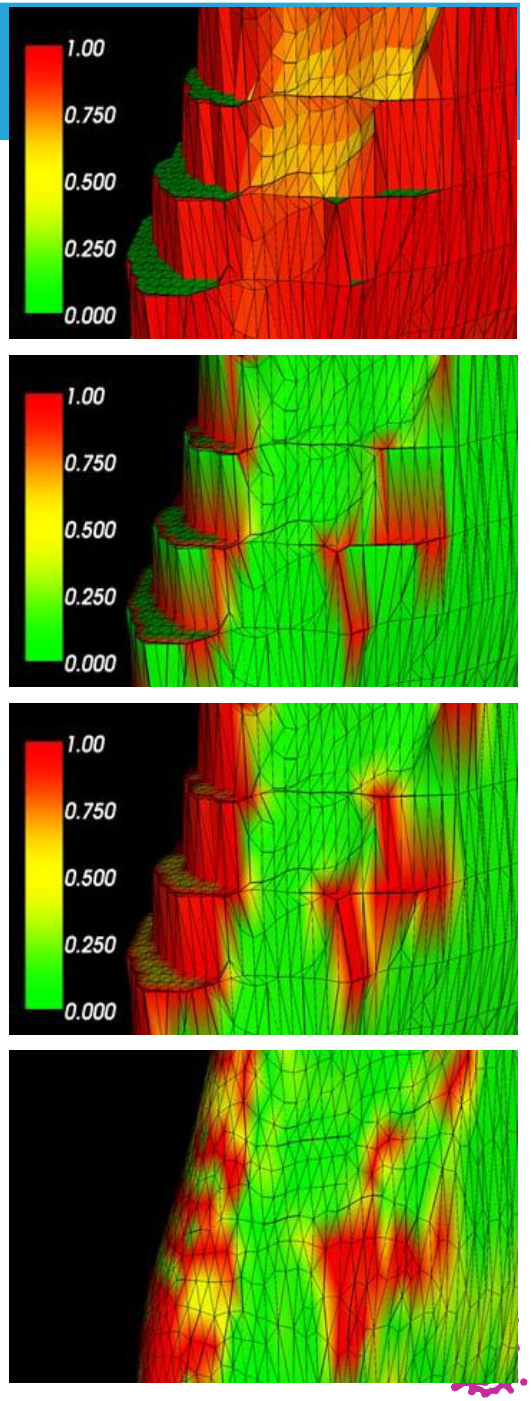
- Identification of critical artifacts
- Apply smoothing only there
- Preserve volume, shape and details

Distance-Aware Smoothing

- Staircase artifacts:
  - Depending on orientation of image data
  - Depending on the inter-slice distance
  - Manifest as sharp edges

Distance-Aware Smoothing

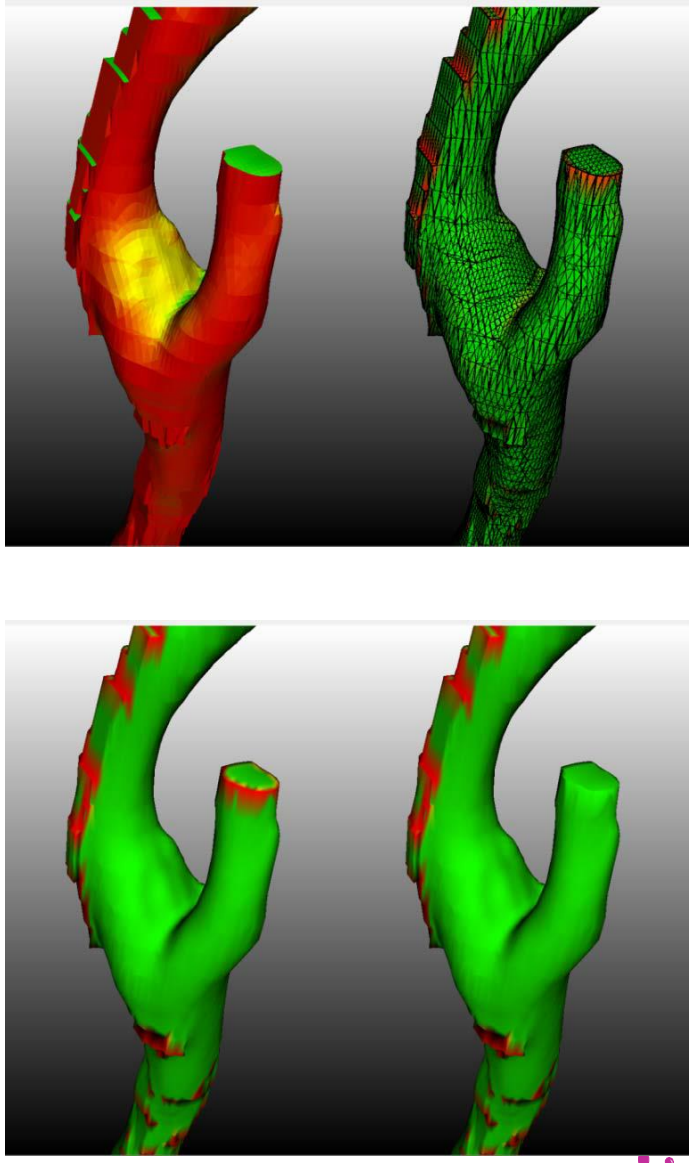
- 1. Determine surfaces coinciding with the slices
- 2. Deterine changes of surface orientation
- 3. Determine weights according to the distance to the edges at the staircase artifacts
- 4. Apply distance weighted smoothing



[Mönch et al., 2010]

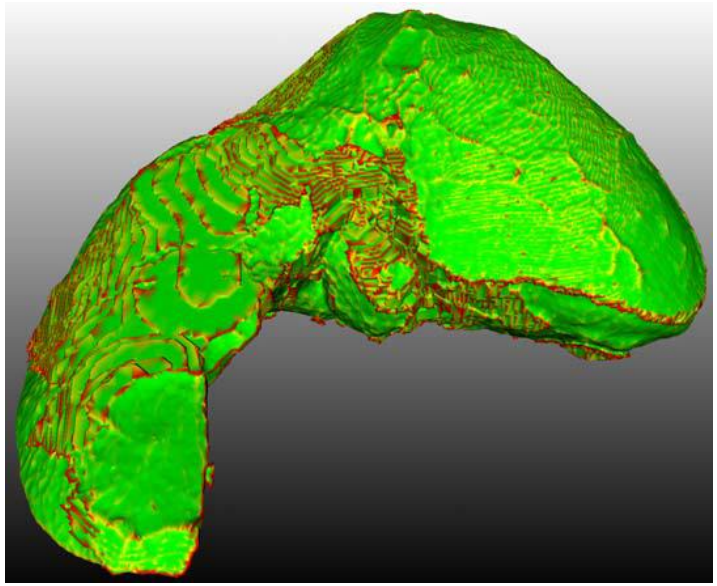
Distance-Aware Smoothing

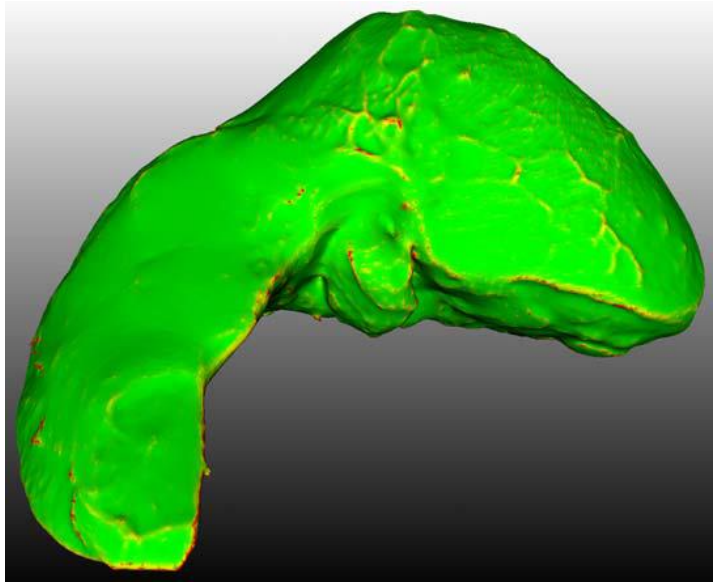
- Preserves caps
- Iterate over all potential artifacts
- Determine surface orientation on edge vertices (positiv or negative in direction of the slices)
- Count changes of direction
- Remove plateaus / staircases if its count is constant

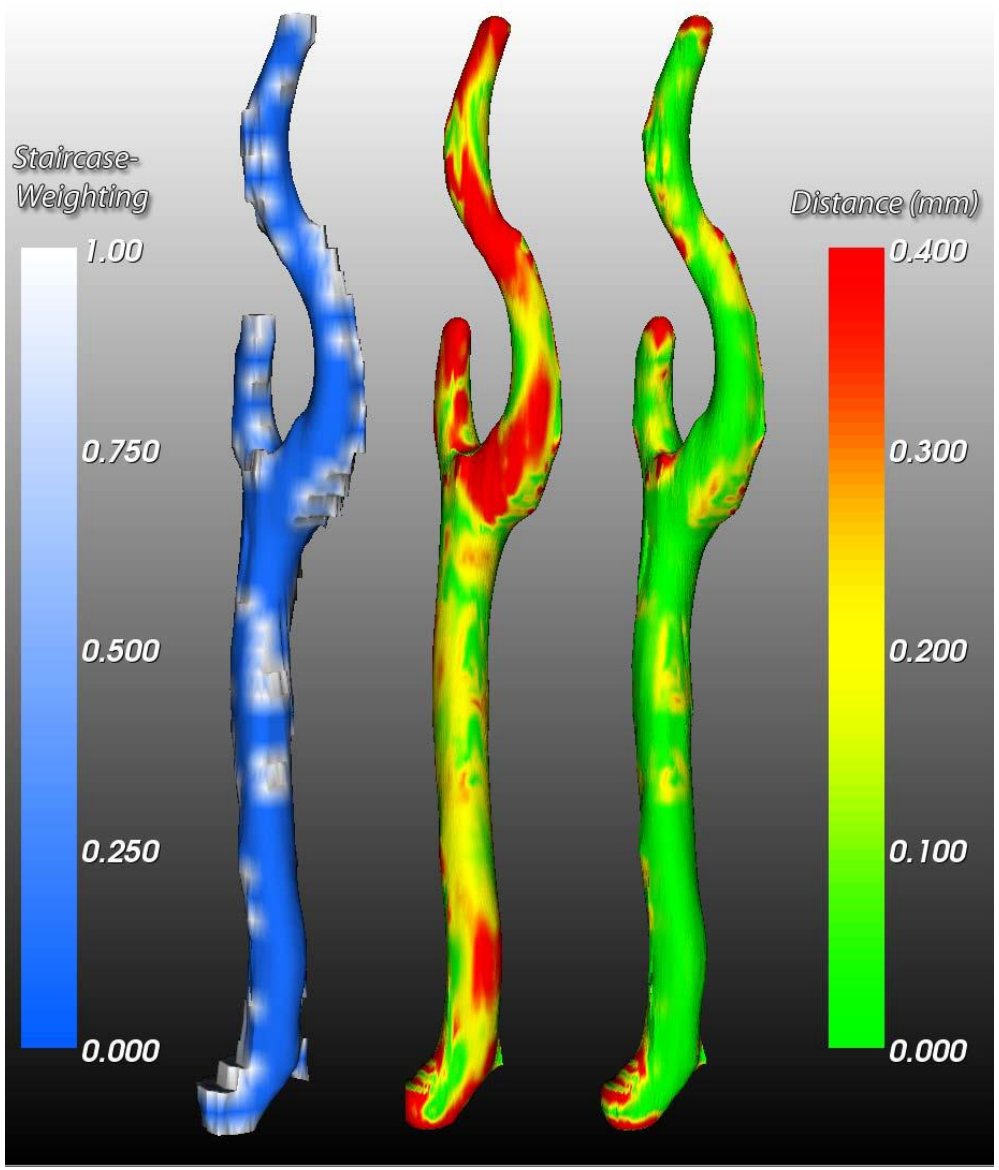


[Mönch et al., 2010]

Distance-Aware Smoothing







[Mönch et al., 2010]

Volume Visualization

Volume Visualization – Medical Applications

- Anatomy:
  - Education (visible human data sets)
  - Functional investigation (gas exchange)
- Radiology:
  - Diagnosis of blood vessel diseases (stenosis)
  - Assessment of tumors (localization)
- Therapy planning:
  - Radiation dosage planning
  - Surgery planning (path planning)
  - Simulation of surgeries for educational purposes

Volume Visualization – Requirements

- Detailed visualization of original data
  → Relevant for diagnostic, therapeutic purposes
- Good representation of spatial relations
  → Visual cues: shadows, highlights
- Fast rendering
- Applicable to various data types
  → 8 bits, 16 bits, intensity values, color
- Integration of surface and volume data
  → Hybrid techniques

Volume Visualization – Terms

- **Voxel:** Basic element of a volumetric data set with constant intensity value
- **Cell:** Basic element of a volumetric data set (= voxel for radiological data)
- **Tagged Volume:** Volume data set with every voxel corresponding to a segmented object
- **Transfer function (TF):** Function that maps the data to color and opacity
- **Classified Volume:** Volume data set with voxels having opacity values (after applying a TF)

Direct Volume Visualization

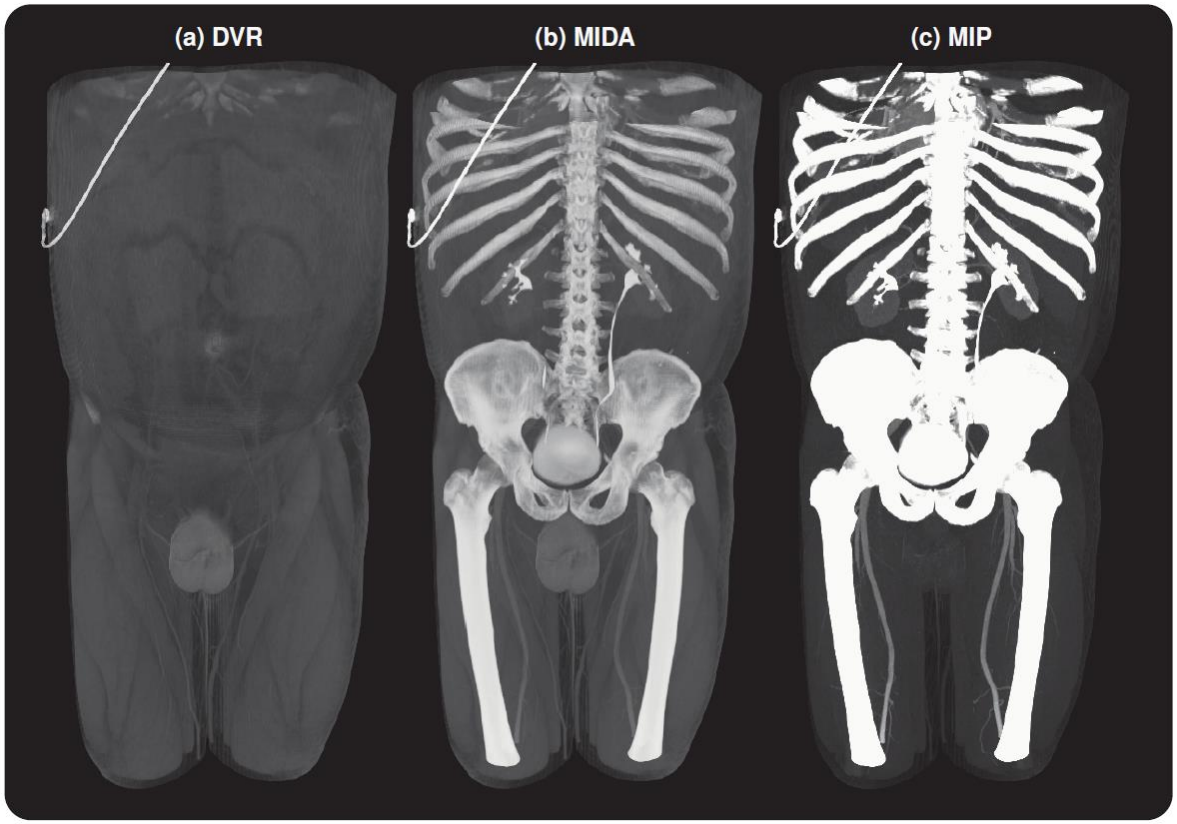
- **Image-based:**
  - Shoot rays through the scene for all image pixel
  - Color computed from hit voxels, weighted by their transparency
- **Object-based:** Determine voxels contributing to the final image (splatting)
- **Texture-based:** Utilize modern 3D texture memory and hardware

Medical Data Sets

- Data on a regular orthogonal grid
- Usually anisotropic data (inter-slice distance > distance of pixel within slice)
- Typically: CT & MRI 512x512 per slice, 100-2000 slices, 12 bits per pixel (16 bits, unsigned short)
- High resolution: 1024x1024 per slice, up to 2500 slices
- PET, SPECT, 3D-US with less resolution

Projection Methods

- **NO** transfer function specification required
- TFs can be used to make, e.g., bones transparent



[Bruckner and Gröller 2009]

Projection Methods

- Local Maximum Intensity Projection (LMIP)
- Depicts first maximum greater than a user-specified threshold

[Sato et al. 1998]

Hybrid Visualization

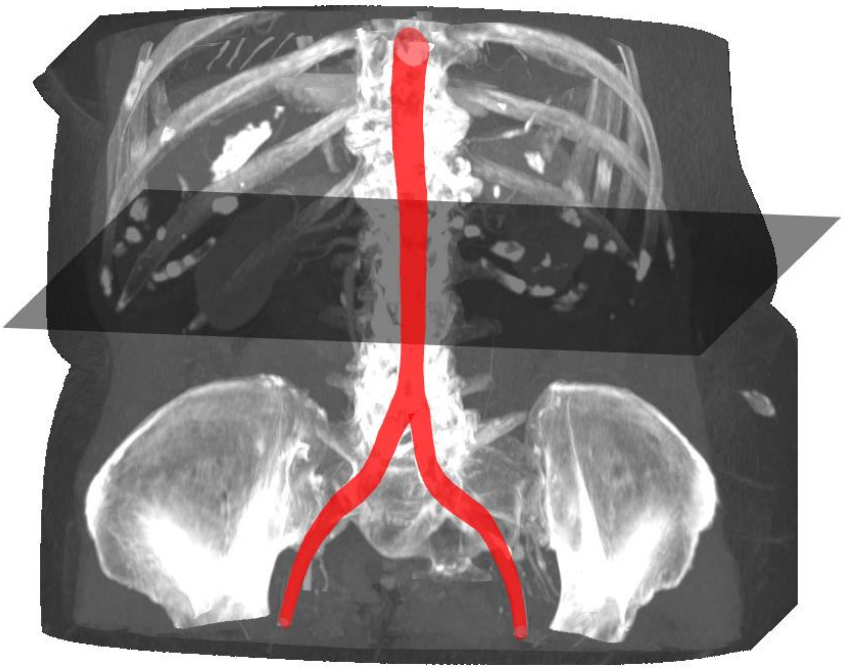
Hybrid Visualization – Motivation

- Integrate surface visualizations of segmented objects in to the original volume data
- Integration of volume data with additional graphical elements
- Examples:
  - Geometric models of tools for volume editing (virtual scalpel)
  - Visualization of the vascular system within the original volume data

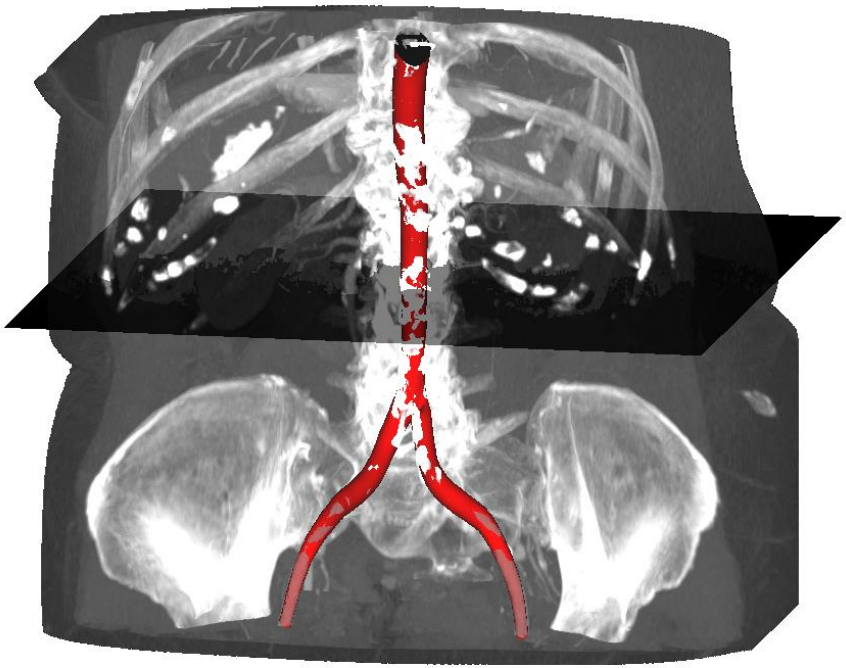
Hybrid Visualization

- Solution 1:
  - Render surfaces using z-buffer
  - Then render the volume
  - → Problem with transparent surfaces
- Solution 2:
  - Voxelize surface representation
  - Render scene using direct volume rendering
- Solution 3:
  - Split volume into slices of textured triangles
  - Depth sort the triangles during rendering

Hybrid Visualization

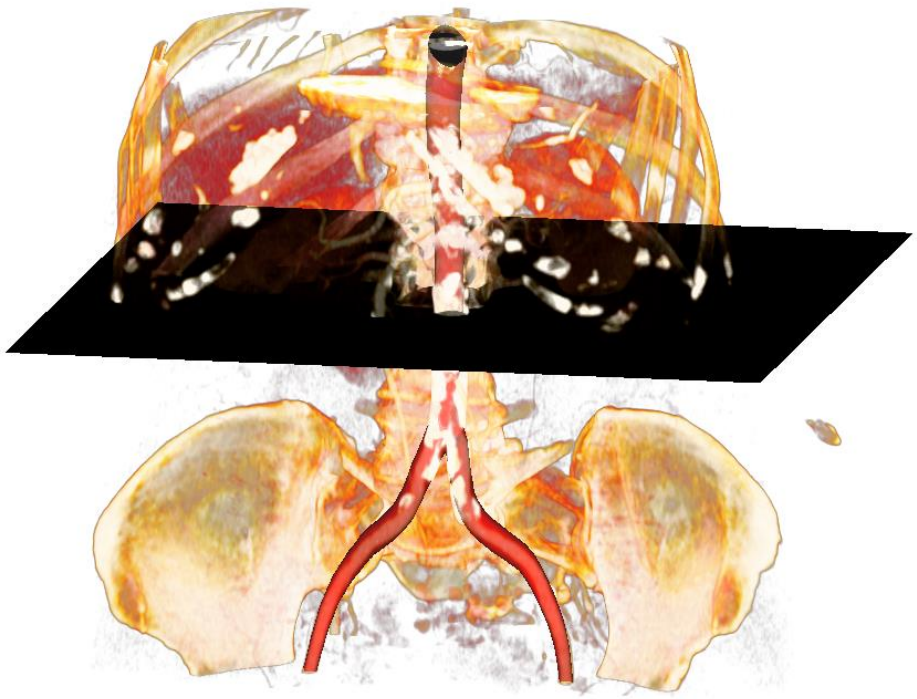


Slice plane and vessel tree overlaid

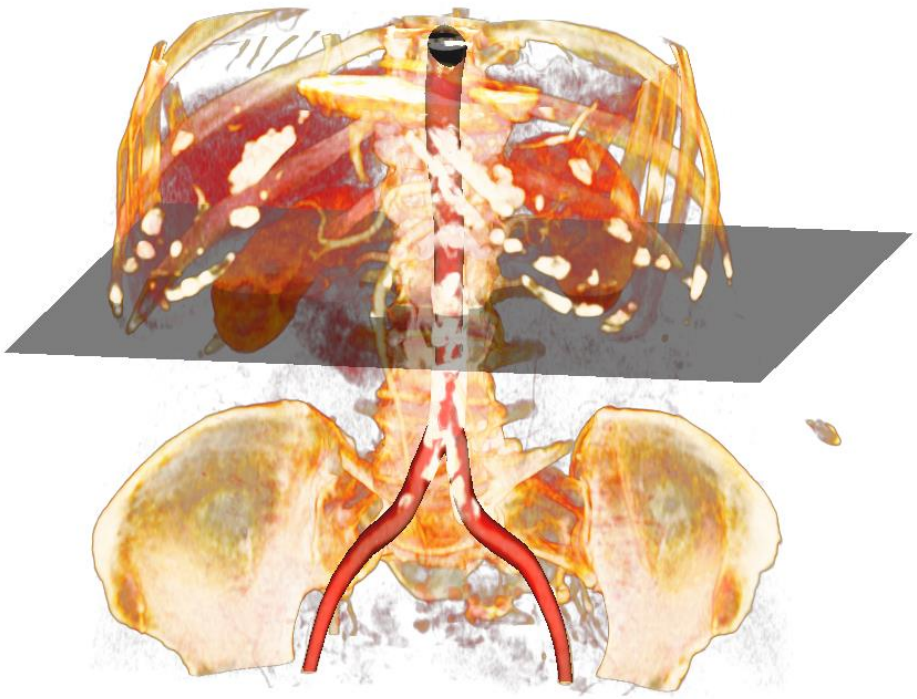


Slice plane and vessel tree embedded into the volume

Hybrid Visualization



Opaque slice plane



Transparent slice plane

Questions?

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

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