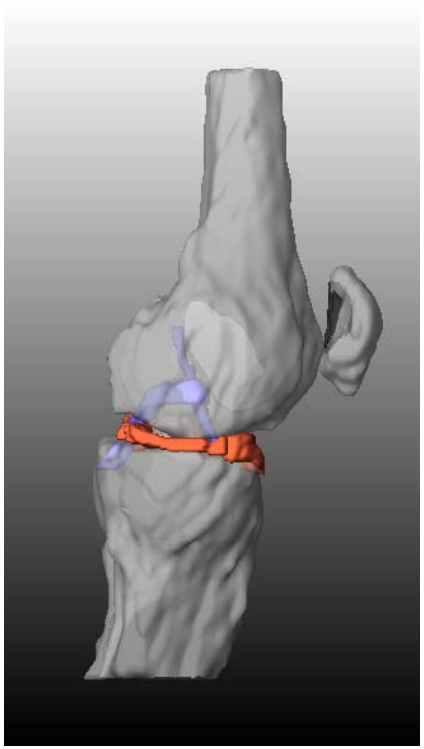
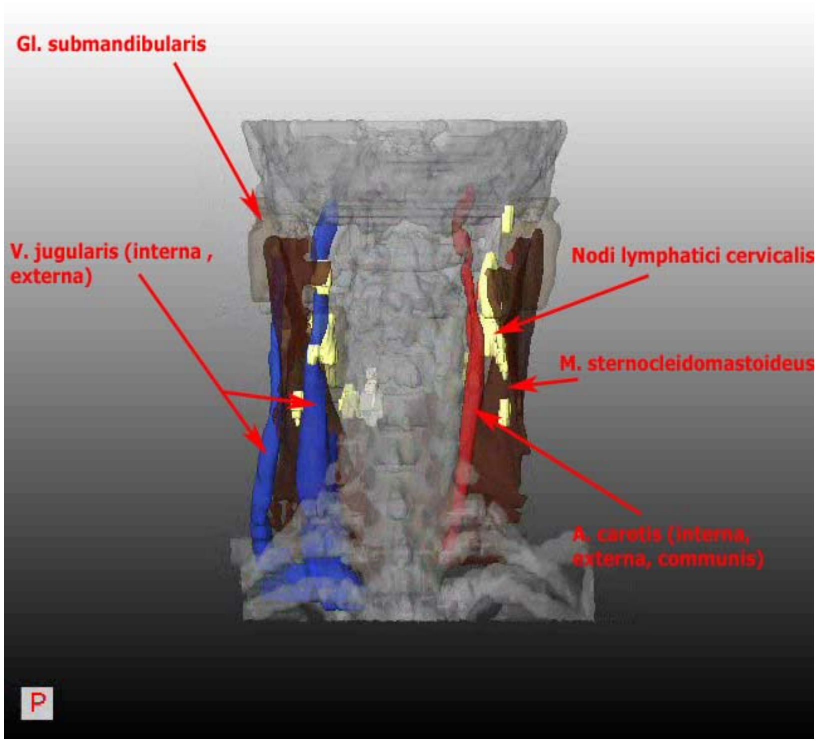
Tutorial Syllabus

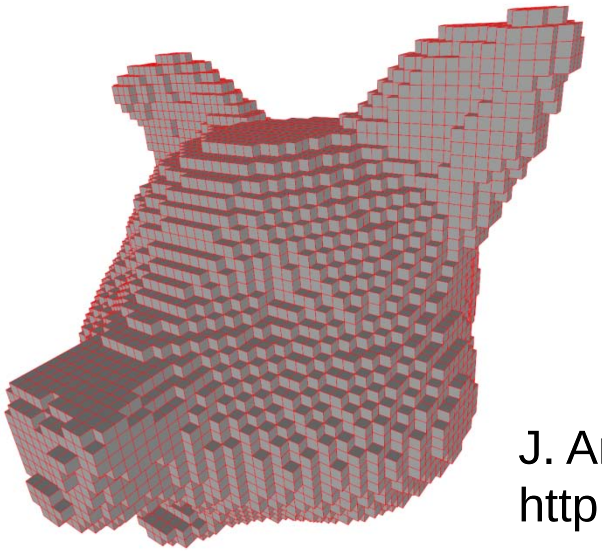
Surface Visualization - Marching Cubes and its improvements - Smoothing of surface visualizations	(30 min.)
Direct Volume Visualization - Ray casting and texture-based approaches - Projection methods	(30 min.)
3D Vessel Visualization	(30 min.)
Virtual Endoscopy	(30 min.)
Augmented Reality and Intraoperative Visualization	(20 min.)
Medical Training and Surgical Planning	(20 min.)

Visualization of isosurfaces and segmentation results





- Assumption:
  - Relevant structures are segmented.
  - Segmentation is model-based (Snakes, …), with “classical“ procedures (Region Growing, Watershed, …), or manually
  - Segmentation result is binary represented at the voxel plane (1 for the foreground, 0 for the background).
- Visualization: 1st idea: presentation of the voxels (“Cuberille“ approach, Herman & Liu 1979)



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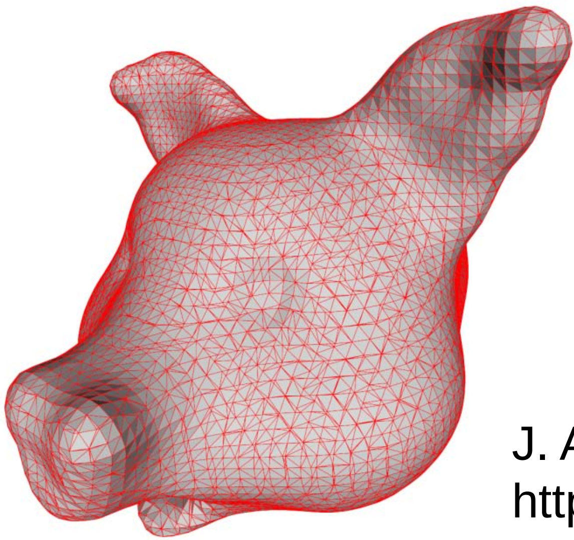
http://www2.imm.dtu.dk/~jab/

- Visualization, better idea:
  - linear interpolation, depiction on a polygonal surface (isosurface for the value 0.5)
  - definition of vertices, triangulation, definition of normals
  - rendering by using the graphics hardware



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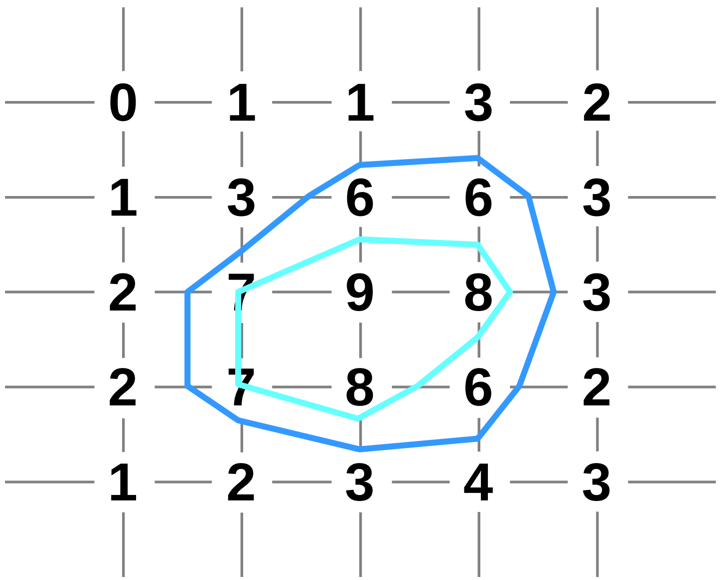
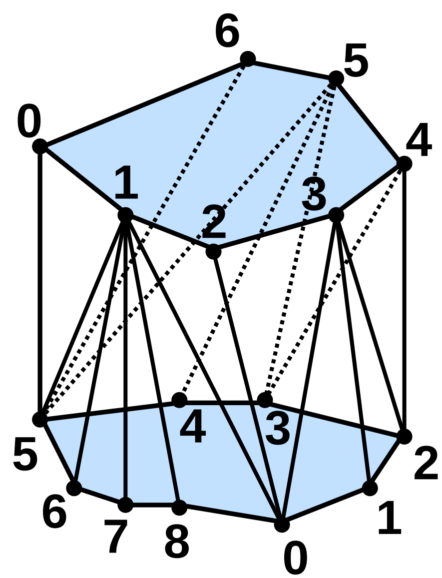
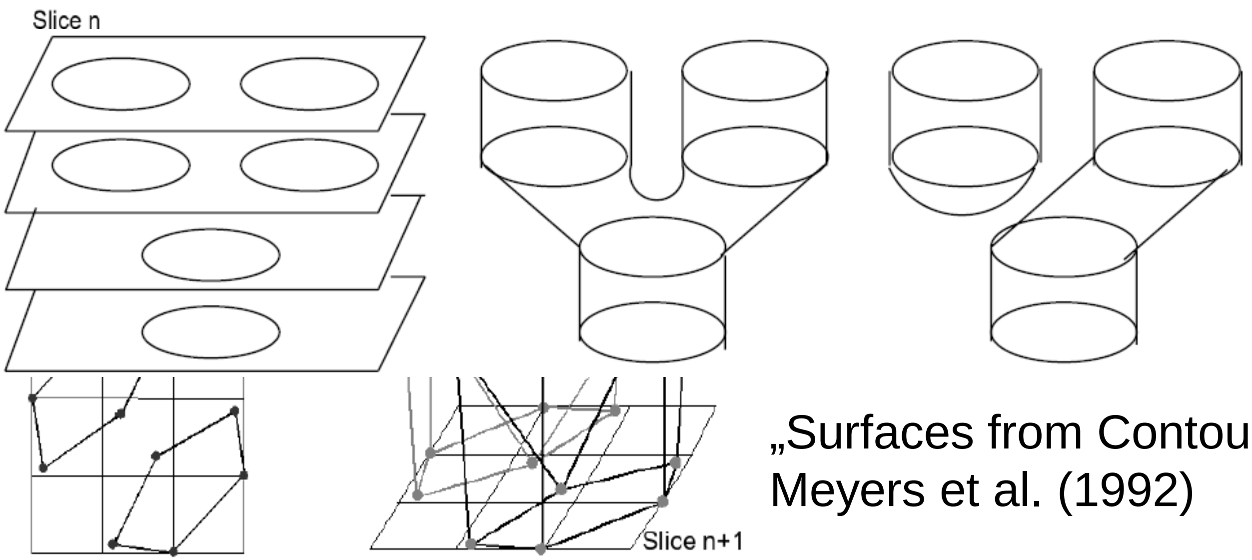
- How can this be realized?
  - Follow the outlines: very difficult in 3D, many case distinctions
  - Locally independent inspection of the cells. Determine how the cell is cut from the surface.
    - ➢ **basic idea of Marching Cubes (patented in 1985, published in 1987)**





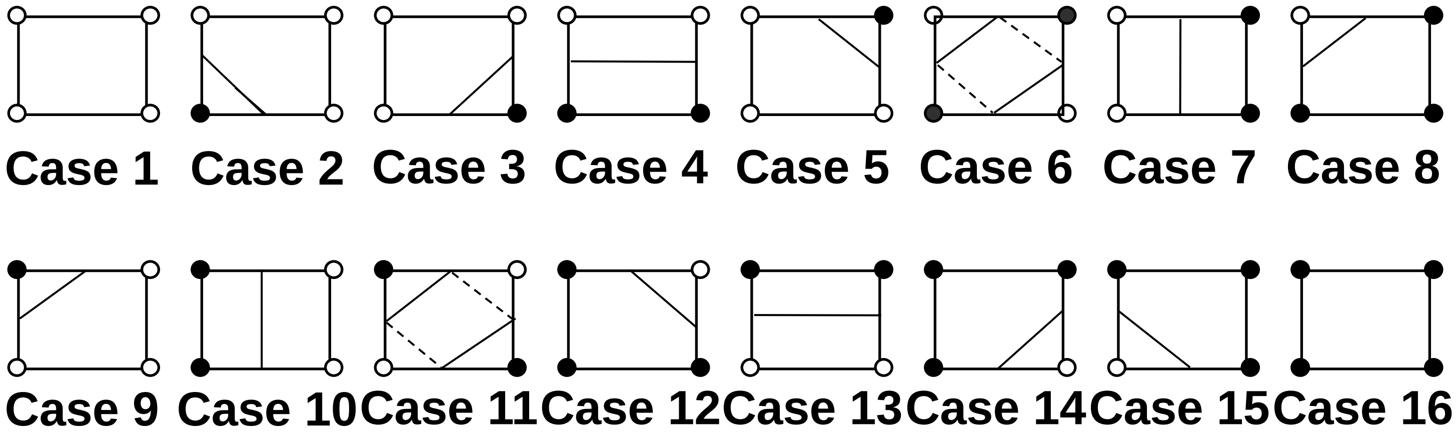
- Which problems need to be solved?
  - *Correspondence:* Which contour of one slice belongs to a contour at the next slice
  - *Triangulation (Tiling):* C_1 and C_2 be corresponding contours. How shall these contours be connected through triangulation nets?
  - *Branching problem:* If the number of contours in one slice S_n is different to the number of contours in the neighbor slice S_{n+1}.



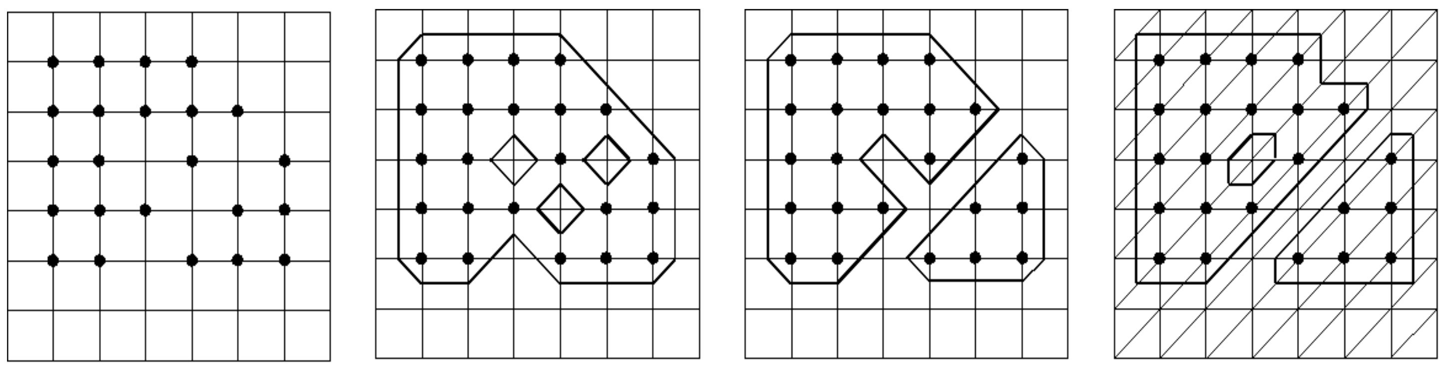
„Surfaces from Contours“, Meyers et al. (1992)

  - *Correspondence problem:* Comes up, if the following applies:
    - **The contours in slice S_n and S_{n+1} belonging the same object do not overlap themselves, and the number of contours belonging to one object is > 1 in S_n and/or S_{n+1}.**
- What does Marching Cubes?
  - An overlapping of contours in neighbored slices is assumed.
  - Limit of this assumption? In case of a large slice distance or thin objects which proceed diagonal to the slices.
  - If the requirements are not fulfilled, separate surfaces are generated.
- In such cases, correct solutions are complex.
  - Interpolation of intermediate slices often helps.

- Consideration of the 2D case (Marching Squares). Isoline for iso=0.5.

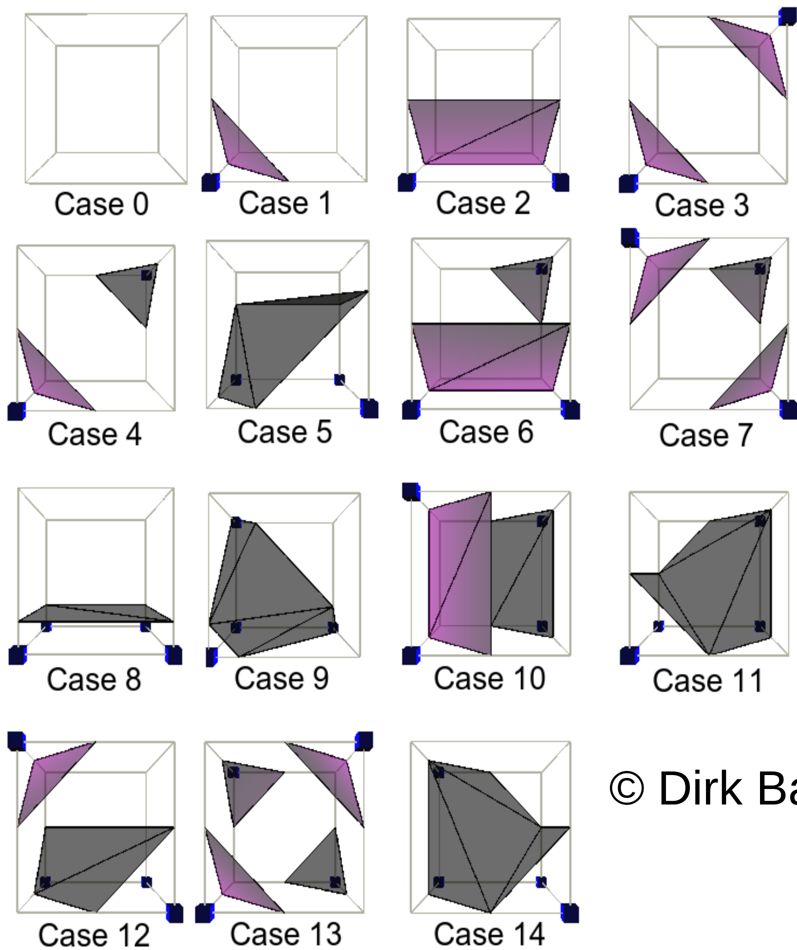


- Ambiguities:



- Extension to 3D:
  - there are 15 topologically different cases of how a cell can proceed through a surface.

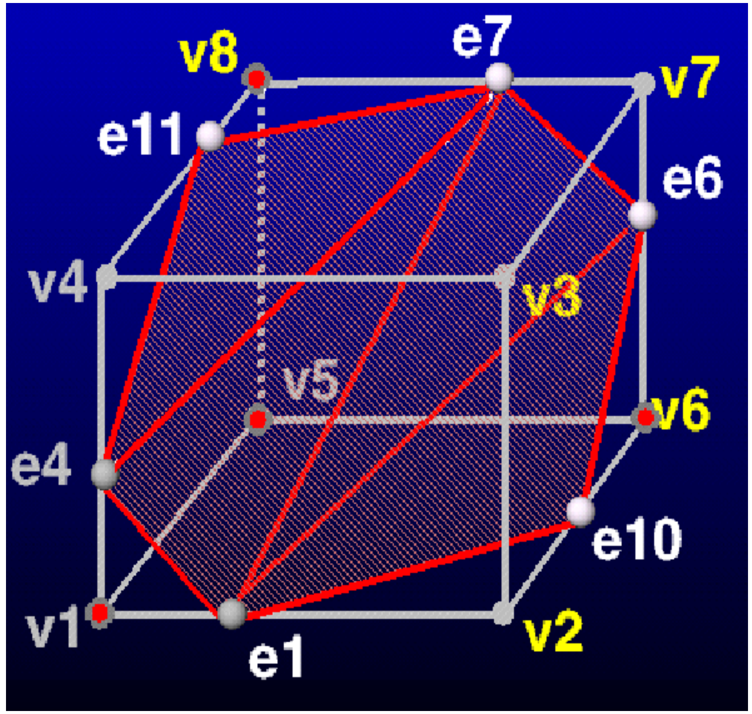
- Procedure (rough):
  - determine the case for each cell.
  - determine the triangles if the cell is cut.



- Marching Cubes
  - Purpose: transfer of the voxels of a volume with a given value into a triangulation net (Lorensen et al. [1987])

- Procedure:
  1. Consider cells from 4 voxels of the slice S_n and 4 voxels of the slice S_{n+1}
  2. Check which vertices have values above the threshold value, create an index
  3. Determine the involved edges
  4. Determination of points at these edges through linear interpolation
  5. Connection of these points to create triangles

- Marching Cubes
  - Step 2:
    - **v1, v5, v6, v8 – above,**
    - **v2, v3, v4, v7 – below**
    - **Index: 1000 1101**
  - Step 4: Linear interpolation
    - **Example: determination of e1 to the edge (v1; v2)**
      - **e1 = v1 + (isoval – f(v1)) / (f(v2) - f(v1)) * (v2 –v1)**
  - Step 5: Triangles
    - **(e4, e7, e11)** **(e1, e7, e4)**
    - **(e1, e6, e7)** **(e1, e10, e6)**



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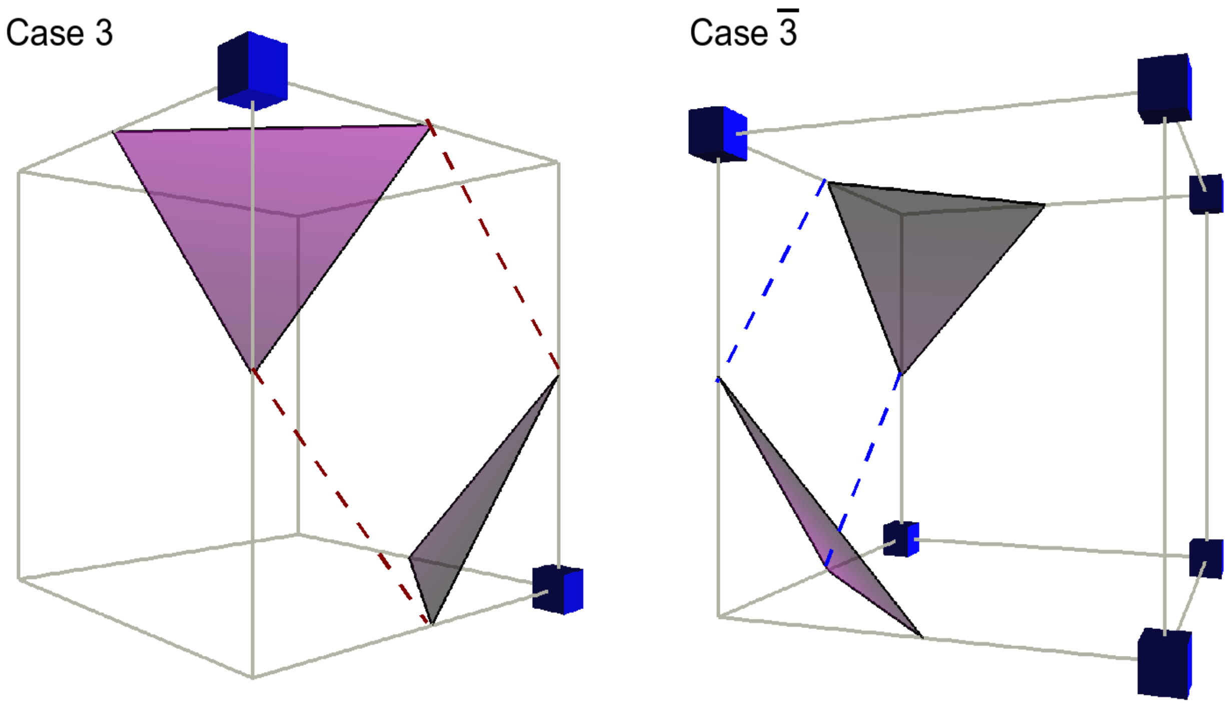
- What is important about Marching Cubes?
  - Very simple
  - Compared to Cuberille: Better description through linear interpolation
    - **But: Viewers are also sensitive for discontinuities of the first and second derivative**
  - Ambiguities and inconsistencies, no treatment of the correspondence problem, no optimal solution for the tiling problem
  - Relatively precise, but improvable (only interpolation along the edges)
  - Relatively fast procedure
    - **But: A lot of time is spent on cells which do not contribute to the surface**
  - Fast rendering

- Quality problems through linear interpolation and Gouraud shading

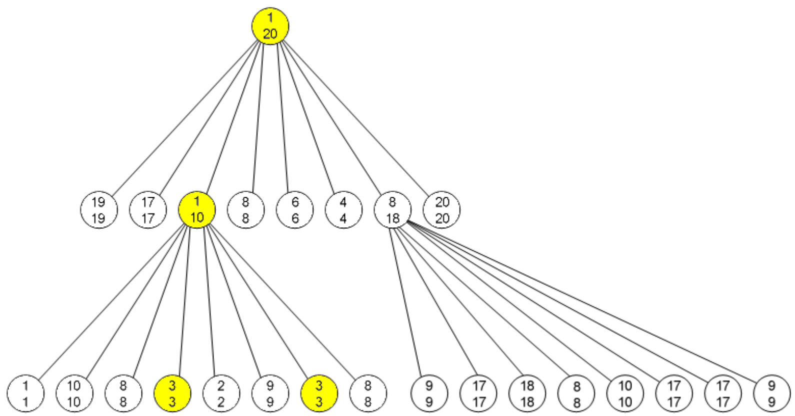
Virtual bronchoscopy

- Holes in the surface arise, if, for the neighboring cells,…
  - the decision is made to divide the intersections and …
  - the decision is made to connect them in the second cell.



- How can this inconsistency be corrected?
  - Interpolation of points at the shared face. The state of this point (above/below) is decisive (Nielsen, Hamann [1991])
  - Usage of the complete case list (Schröder et al. [1998])
  - Decomposition of the cells into tetrahedrons (Shirley, Tuchman [1990])

- How can Marching Cubes be accelerated?
  - Fast recognition of areas that are not affected by the surface.
  - Representation of the scene through hierarchic data structures, e.g., min-max-octrees (Wilhelms, van Gelder [1992])



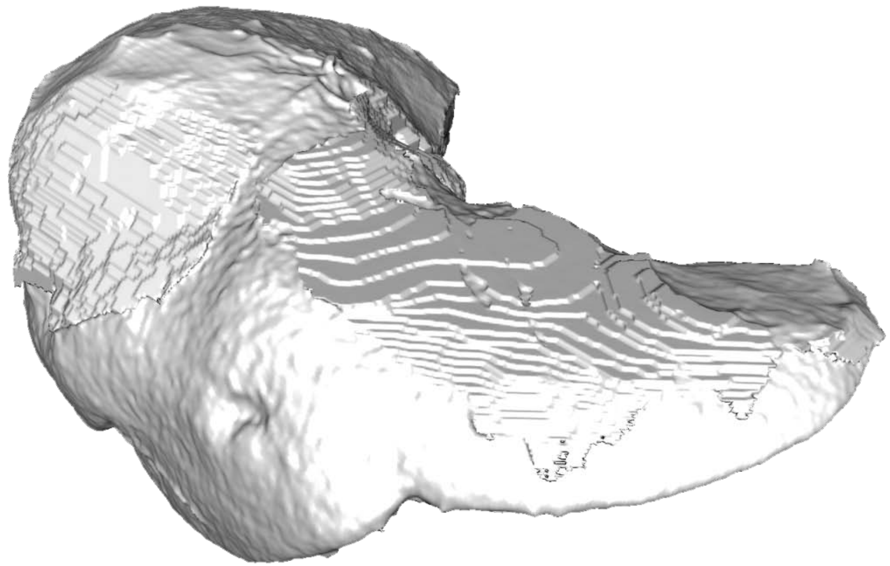
Source: http://de.wikipedia.org/wiki/Octree

- Problem:
  - Generation of surface models from segmentation results leads to artifacts, especially in case of strongly anisotropic data


MR data

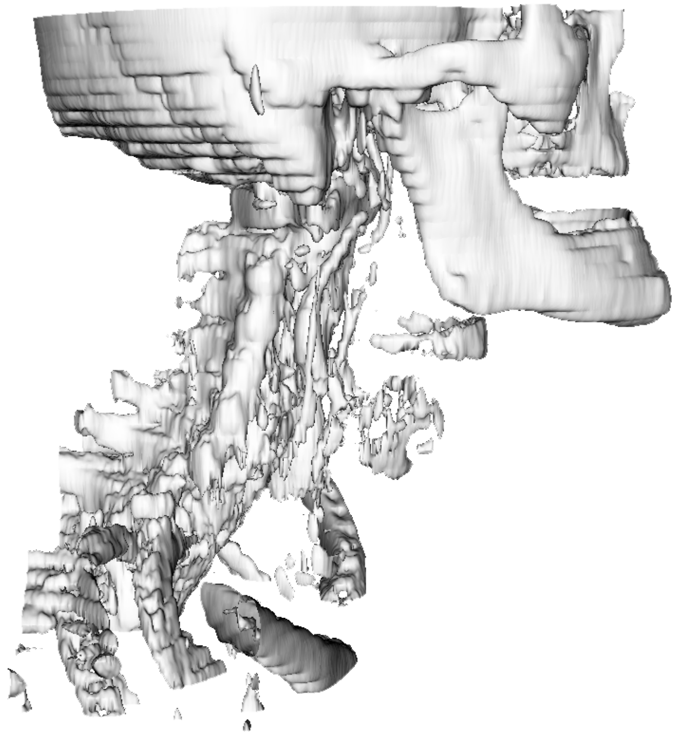

3D


Photo


Liver from almost isotropic CT data

Surface Visualization: Smoothing and Noise Reduction

- Problem: Development of many small surfaces which represent artifacts
- Purpose: Restriction of the extraction to the largest surface (or a given amount of surfaces)
- Method: Connected Component Analysis (according to Schroeder et al.[1998])
- VTK: vtkConnectivityFilter



- Algorithm Connected Component Analysis:

  While there are cells which are not “visited”,

  - Start with any cell z and mark it as „visited“.

  - Initialise the component k

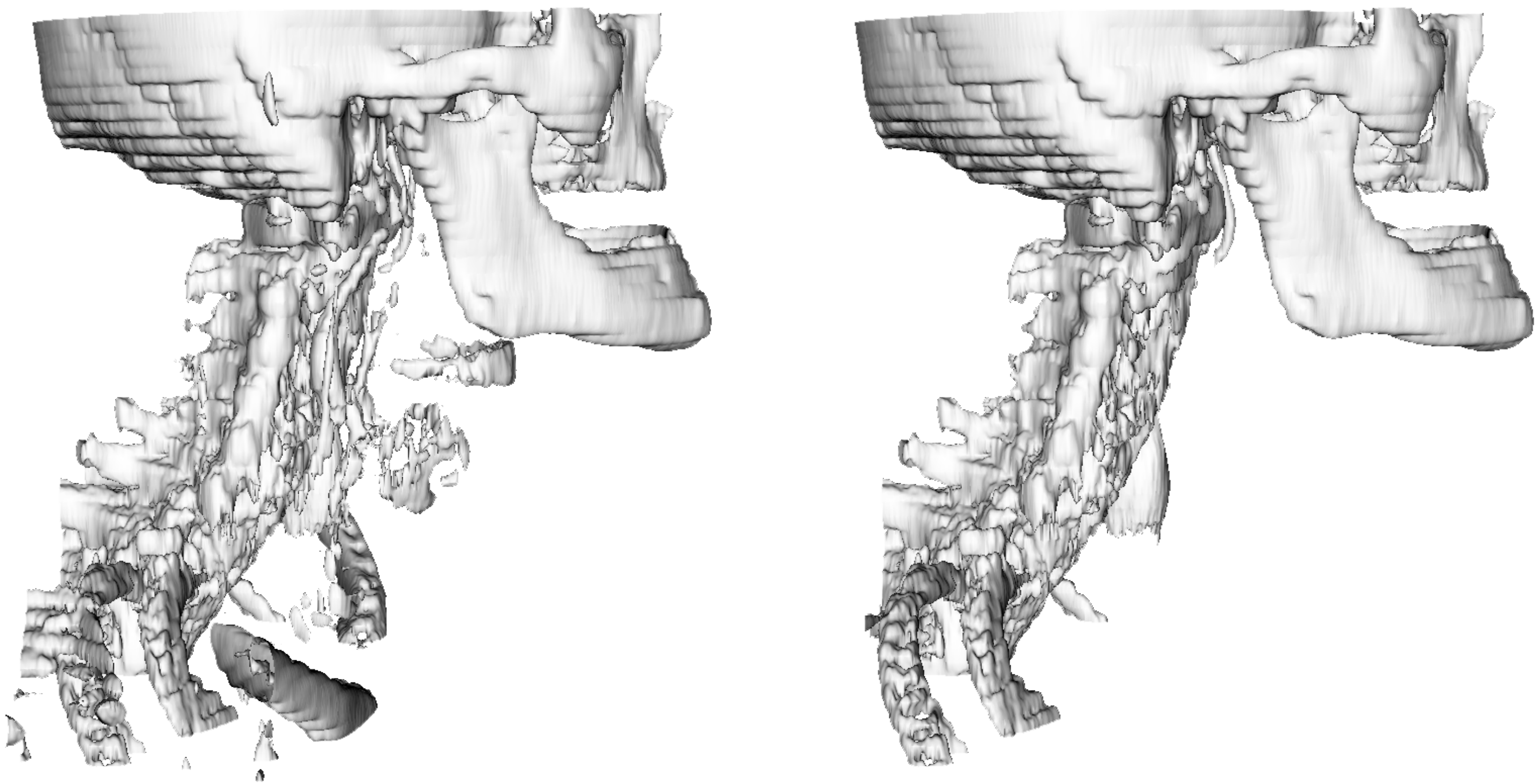
  While there is a cell z_n adjacent to z which contributes to the surface and has not been “visited“ yet:

  - add z_n to the component k and mark it as “visited“.

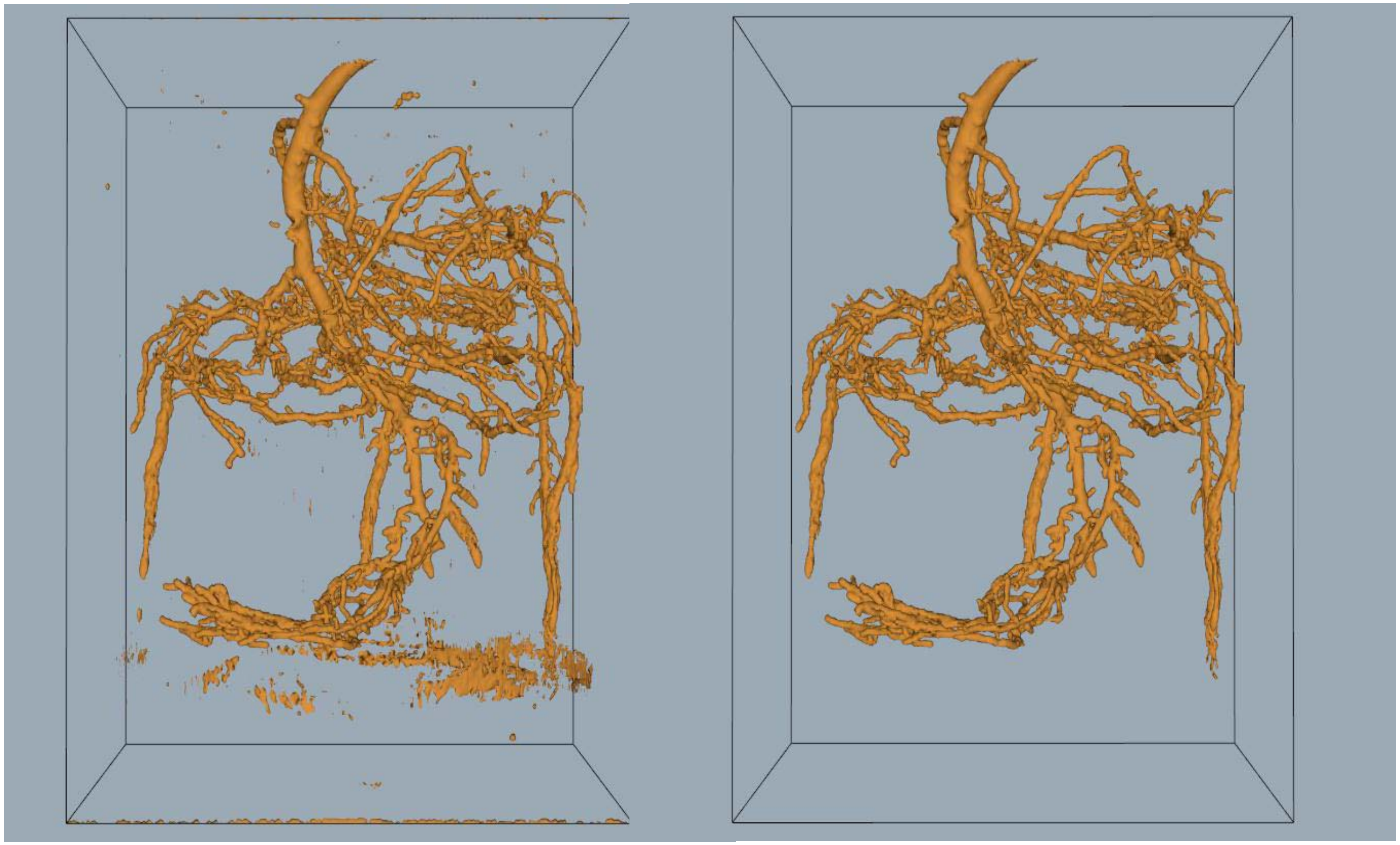
  Repeat recursively as long as there are still neighboring cells which have not been visited

- Result: all connected components
- Selection of the largest (n) component(s) according to the surface area or length of the object contour

- Connected Component Analysis. Illustration of the largest component.



- Connected Component Analysis. Illustration of the largest component.



Digitalized photograph of a pine root (Source: Schroeder et al. [1998])

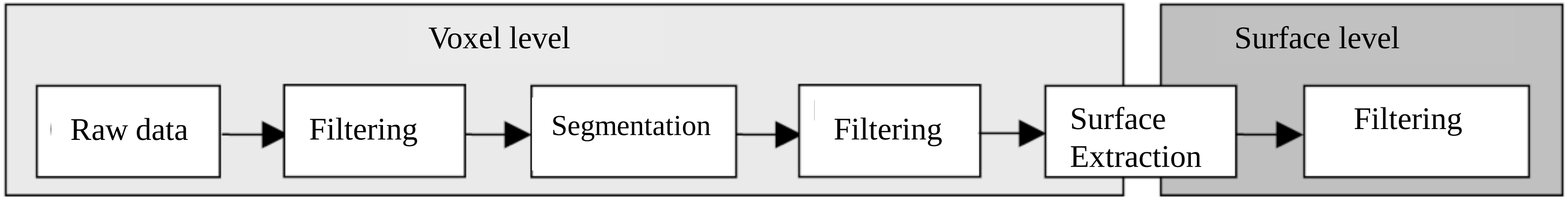
Surface Visualization: Smoothing and Noise Reduction

- General practice:
  - Interpolation of intermediate slices
  - “Manual“ smoothing
  - e.g., in vtk (vtkSmoothPolyDataFilter), itk, 3D Studio, Amira

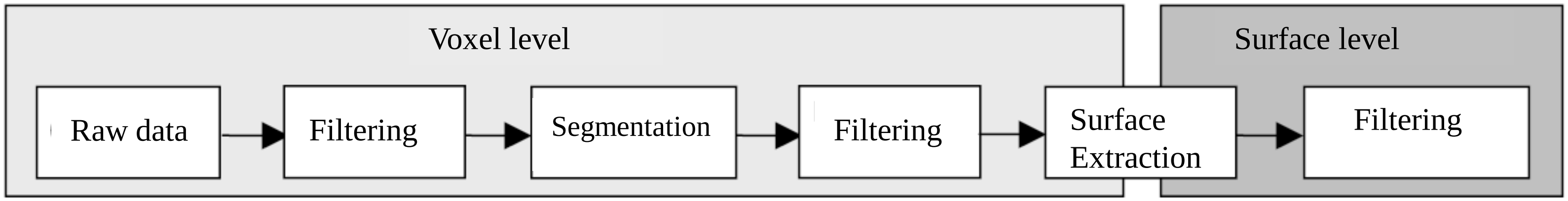
- Disadvantages
  - complex trial-and-error process
  - not reproduceable, not standardized
  - only visual control

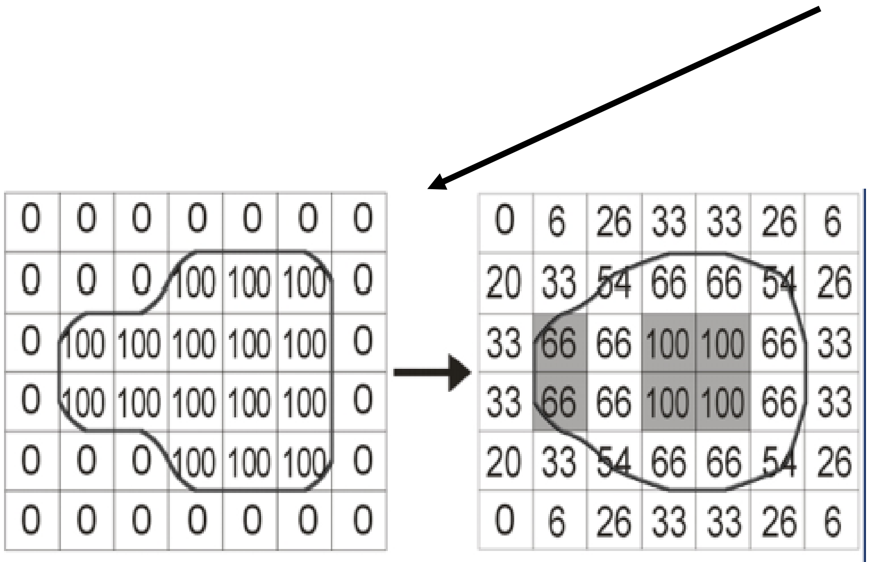
- Long-term goal:
  - Pipeline of algorithms for the post-processing of segmentation results (e.g., closure of holes), surface generation and subsequent smoothing
- Adaptation of the respective procedures to
  - the class of anatomic structure (e.g., tumor, organ, …)
  - imaging or segmentation parameters (e.g., slice distance, model-based segmentation)

Extraction of surfaces



- Smoothing of the segmentation result through smoothing filters (e.g., Gauss) or morphologic methods





Source: Neubauer et al., IEEE Visualization 2004

- First of all, erosion and modification:

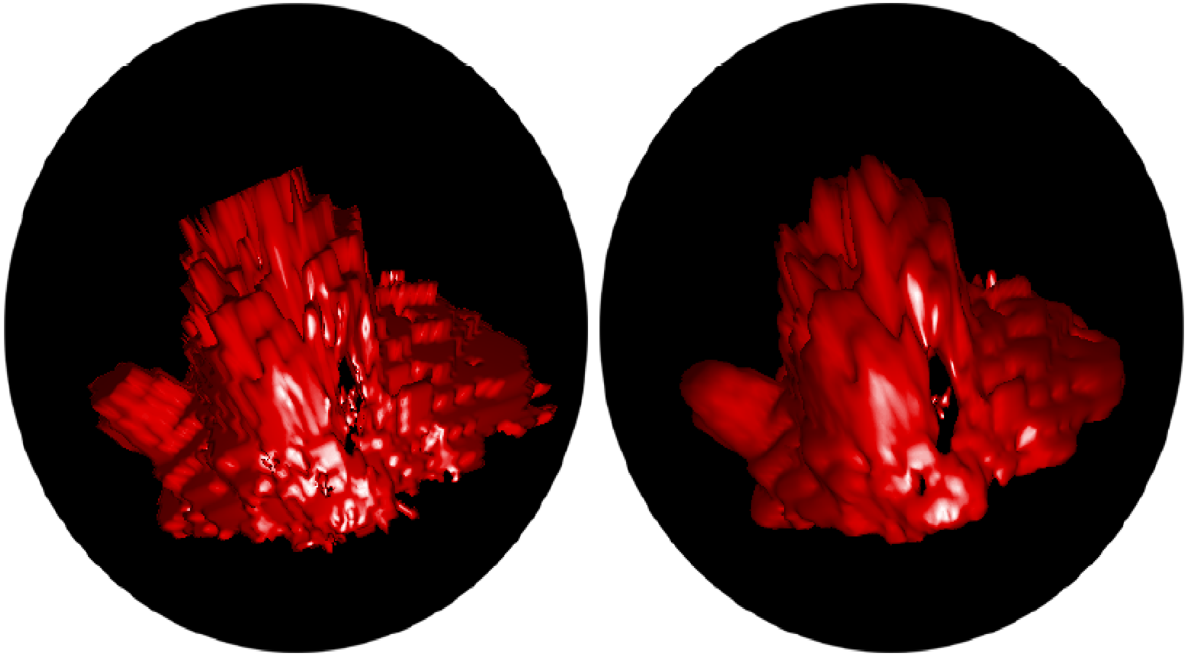
$$v = v_2 - (v_2 - v_1) * \frac{1}{3}$$

- Afterwards, twice dilatation and modification:

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

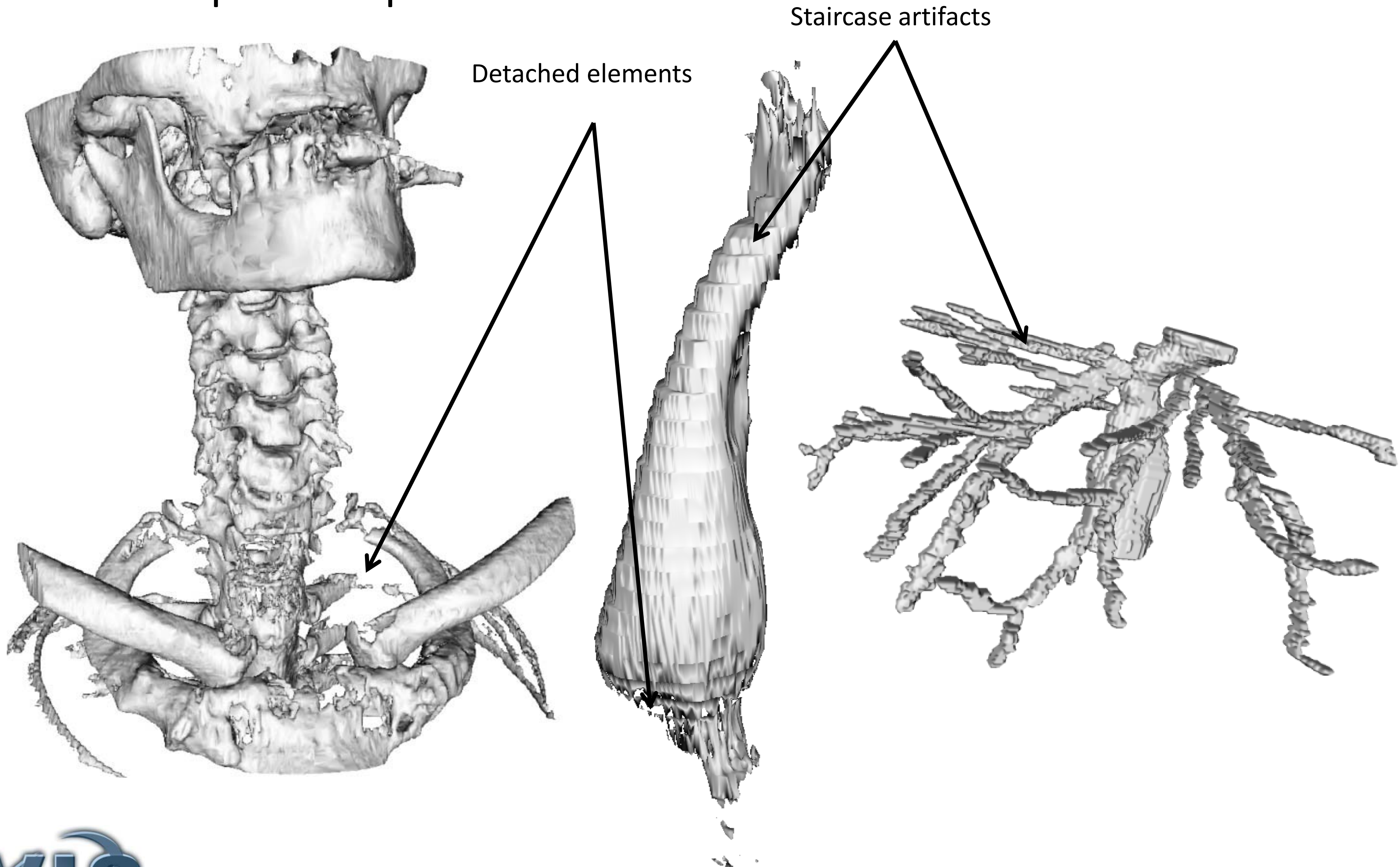
- d Eucl. Distance, v_ref = 50

- Smoothing of the segmentation result through morphological methods



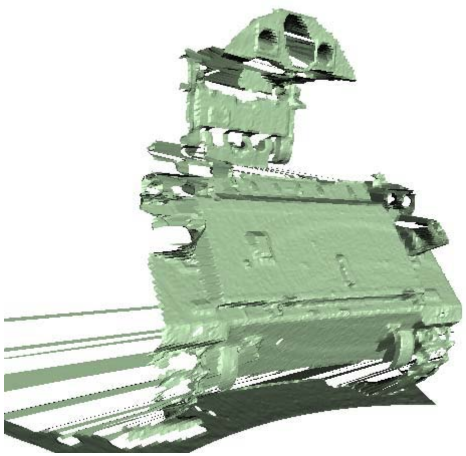
Source: Neubauer et al., IEEE Visualization 2004

- Examples and problems:



Smoothing of Surfaces

- Large amount and diversity of methods
- Very often an academic procedure: smoothing of artificial noise test data
- Clear application in the CAD area and for the smoothing of models which have been acquired with the laser scanner.
- CAD area: preservation of sharp (orthogonal) edges with preferably optimal smoothing of planar areas
- Medical surface models: barely sharp edges, curvatures are partly changing very fast, "large" models



Source: Tasdizen, 2003, Proc. of 3-D Imaging and Modeling

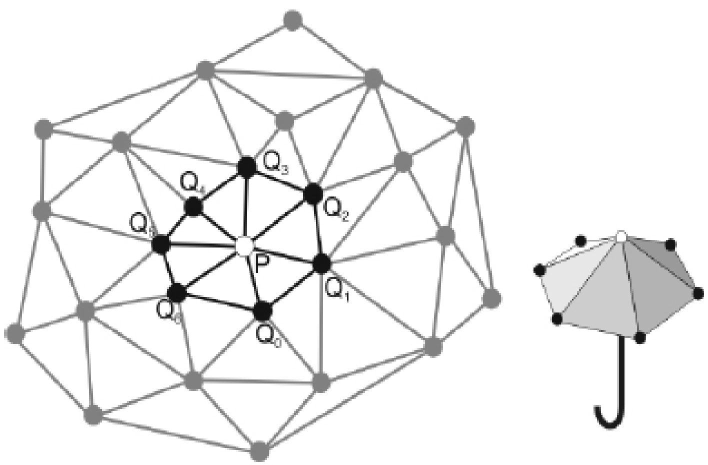
Smoothing of Polygonal Surfaces: Requirements

- Analog to the smoothing of image data:
  - Elimination of high frequency noise at the receipt of features
  - Evaluation:
    - **Curvature plots, total curvatures**
    - **Speed**
    - **Accuracy**

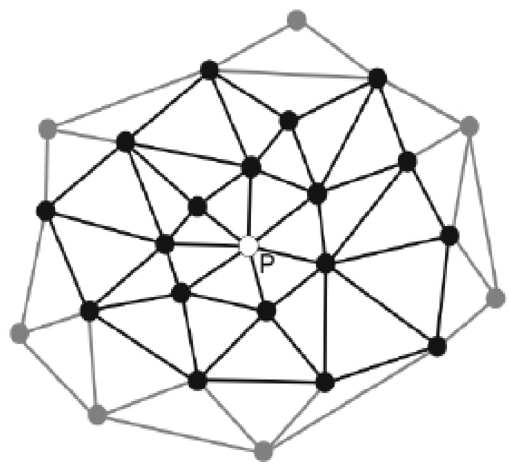
- Measures:
  - Distances changes between the original surface and the smoothed surface
  - Volume preservation

Smoothing of Polygonal Surfaces

- Iterate over all vertices and replace each vertex through a weighted average from its former value and the vertices from the neighborhood
- Which neighborhood?
  - vertices in a specific distance (Euclidean distance)
  - vertices which are connected to the current vertex (directly or through a path of length n) (topological distance)
  - Typical: vertices in the topological distance of 1 or 2



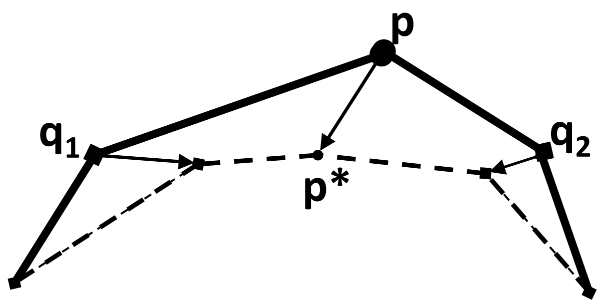
Direct, 1st order neighbors



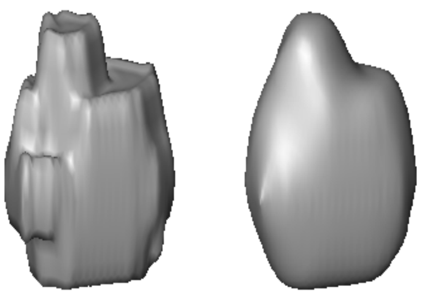
2nd order neighbors

- Considers the points q_i in the topological distance of 1
- Parameter: smoothing factor α and number of iterations

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

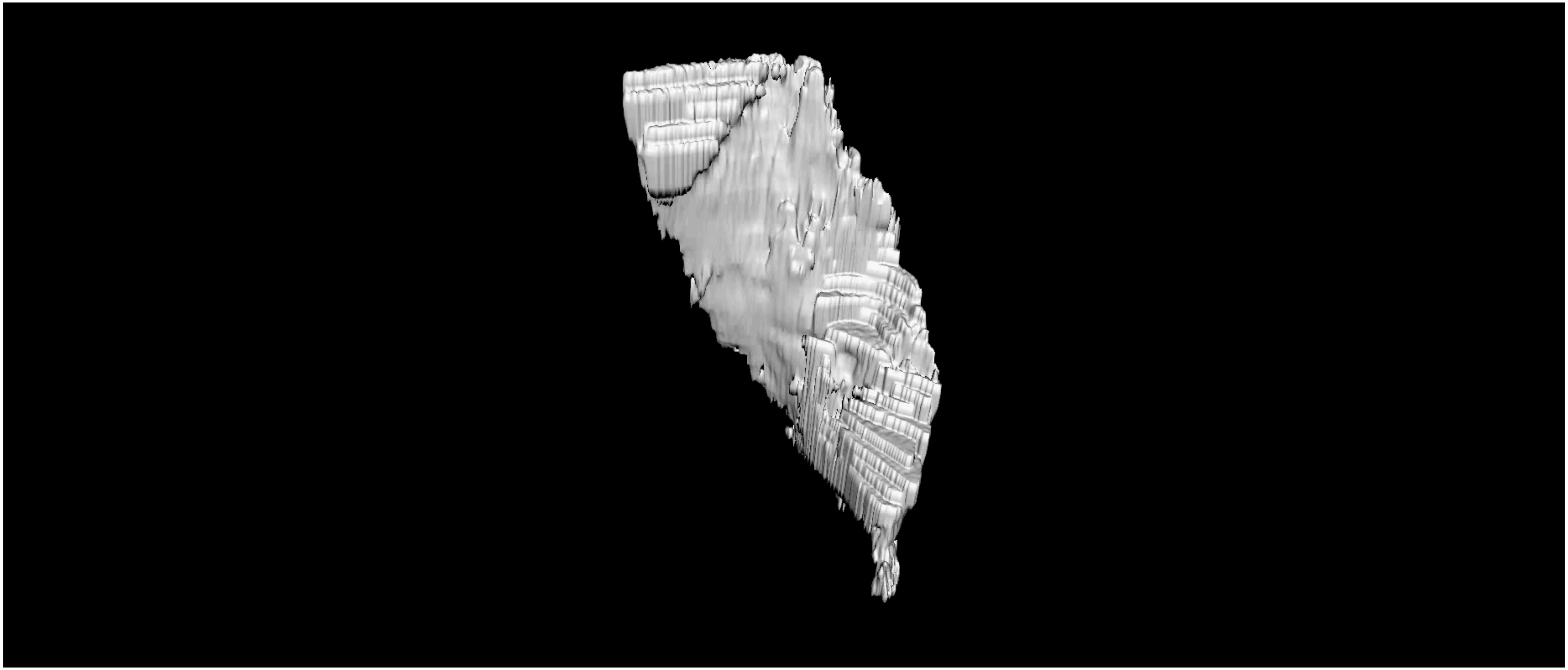


- Simple, fast realization (e.g., in vtkSmoothPolyDataFilter)
- Causes strong (uncontrolled) shrinkage and the favored smoothness is often only achieved through total smoothing of minor features

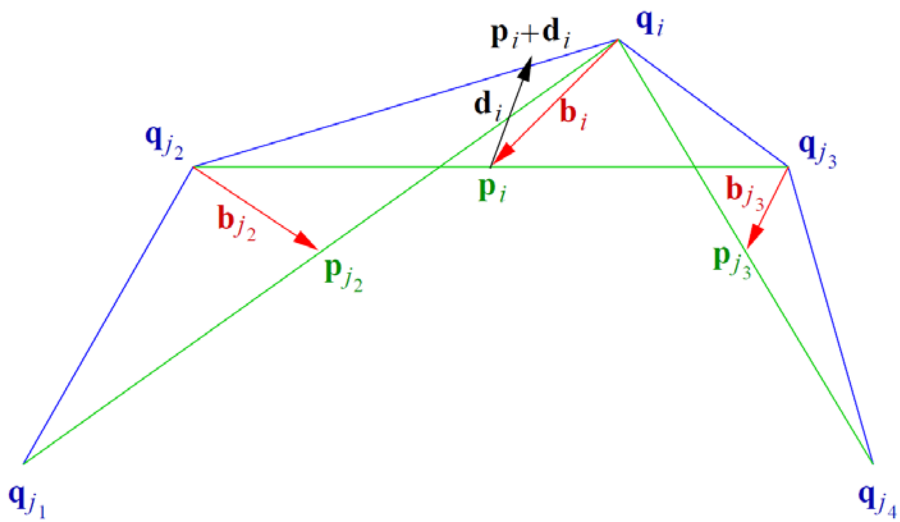


smoothing with α = 0.5 and 20 iterations

- Parameters: 20 Iterations (repeatedly), λ = 0.5



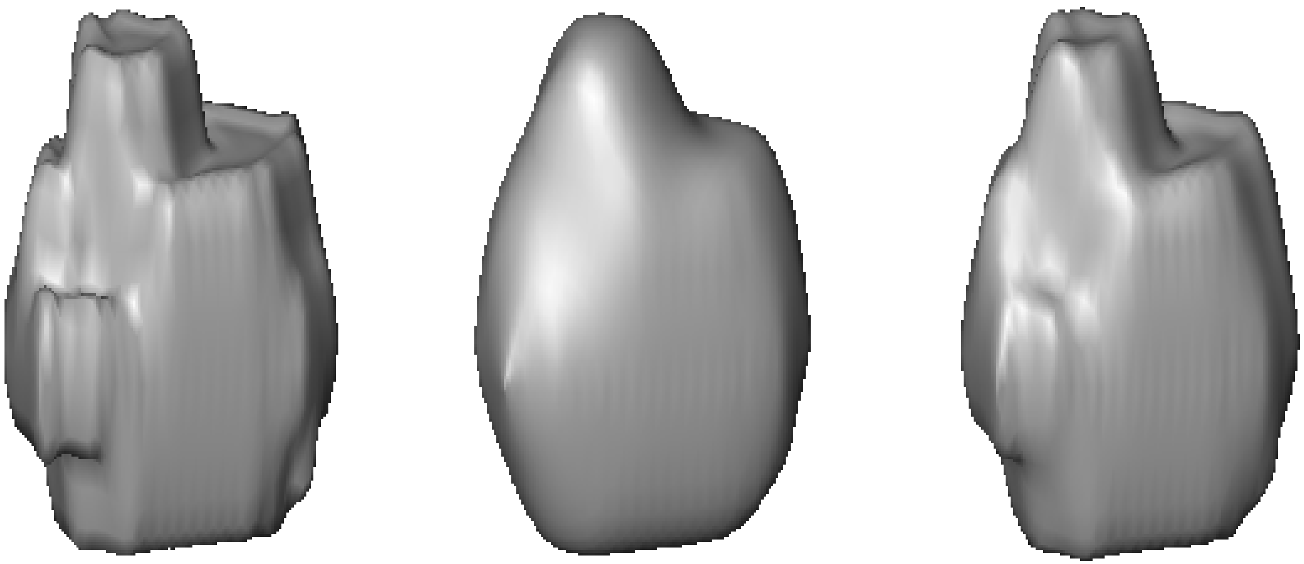
- Correction to maintain the volume
- In each step, modified nodes are shifted back about a certain value (the average of all shiftings in the considered surrounding)
- Additional parameters:
  - How strong is the shifting in direction to the original point?
  - How is the shifting of the neighbors considered?



Example: Laplace+HC

Source: Vollmer et al., Eurographics 1999

Smoothing of Polygonal Surfaces: Laplace Smoothing with Correction



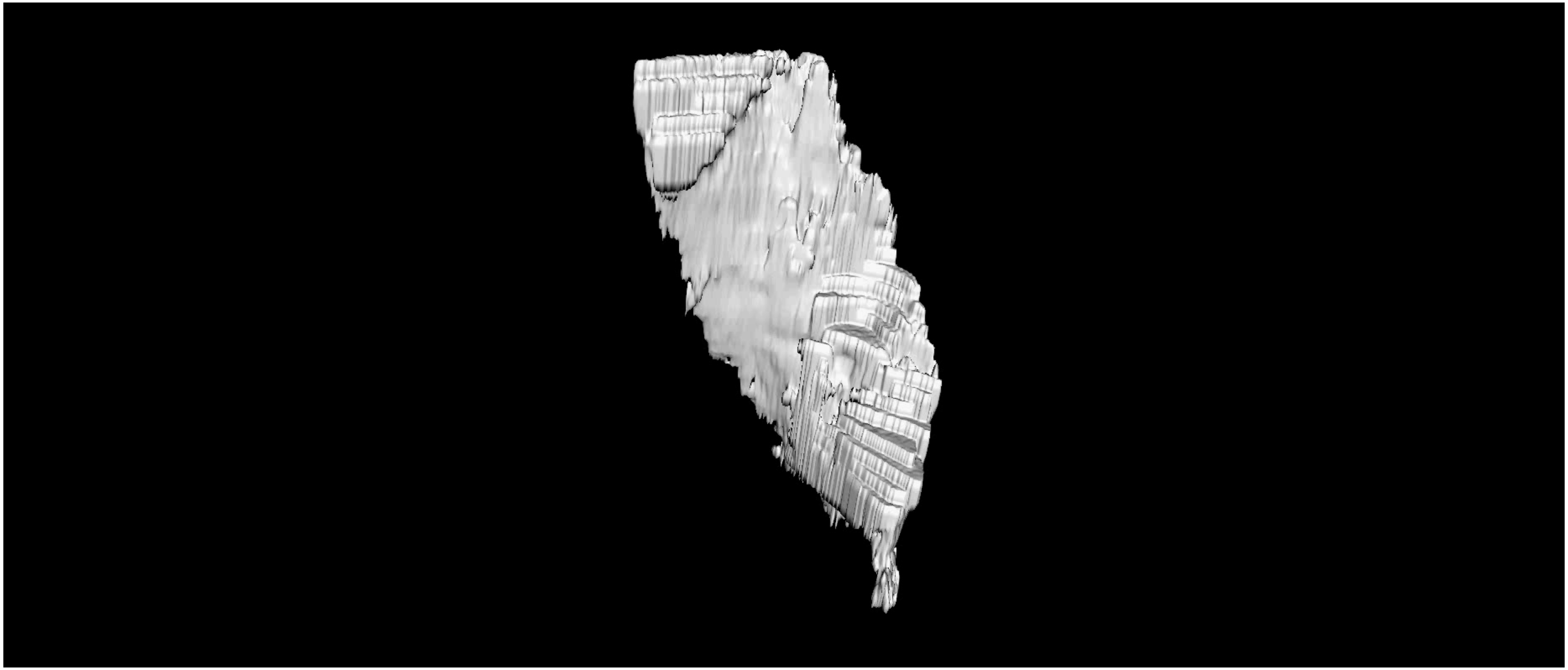
Original
V=100%

Laplace
V=80,8%

Laplace+HC
V=99,8%

Literature: Vollmer et al., „Improved Laplacian Smoothing of Noisy Surface Meshes“, Eurographics, 1999

- Parameters: 20 Iterations (repeatedly), λ=0.0, β=0.5

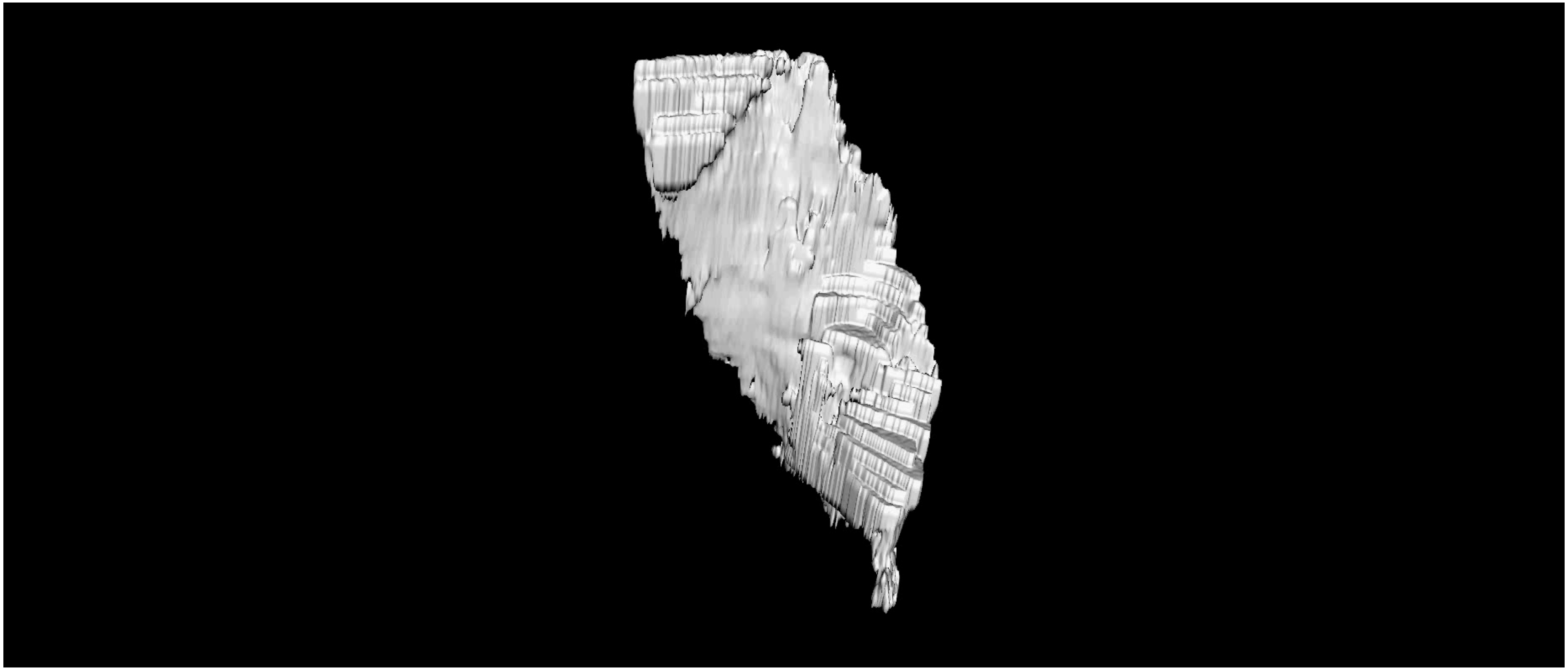


- Alternating implementation of two filters similar to Laplace with different factors α and μ

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

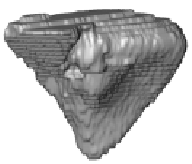
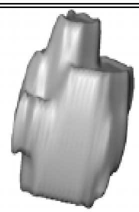
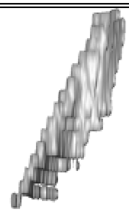
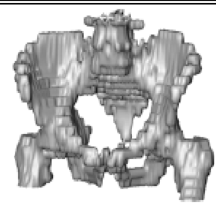
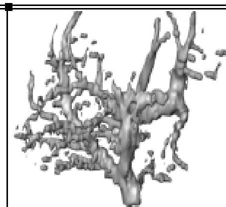
- Selection of μ: a bit smaller than α
- Default: - μ = -1.02 α (Taubin, 1995)

- Parameters: 20 Iterations (repeatedly), $\lambda=0.5$, $\mu=-0.52$

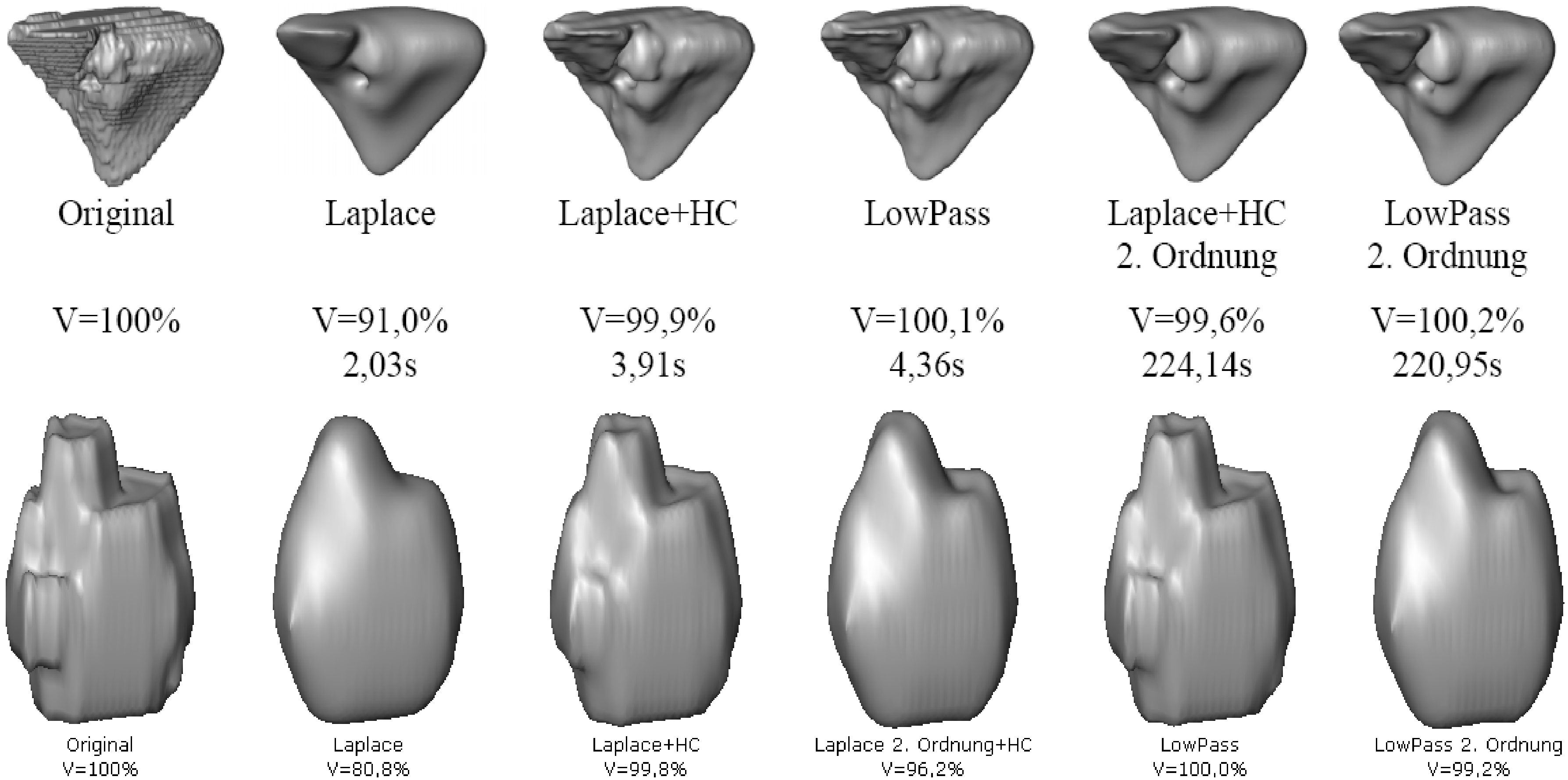


Smoothing of Polygonal Surfaces: Comparison of Elementary Methods

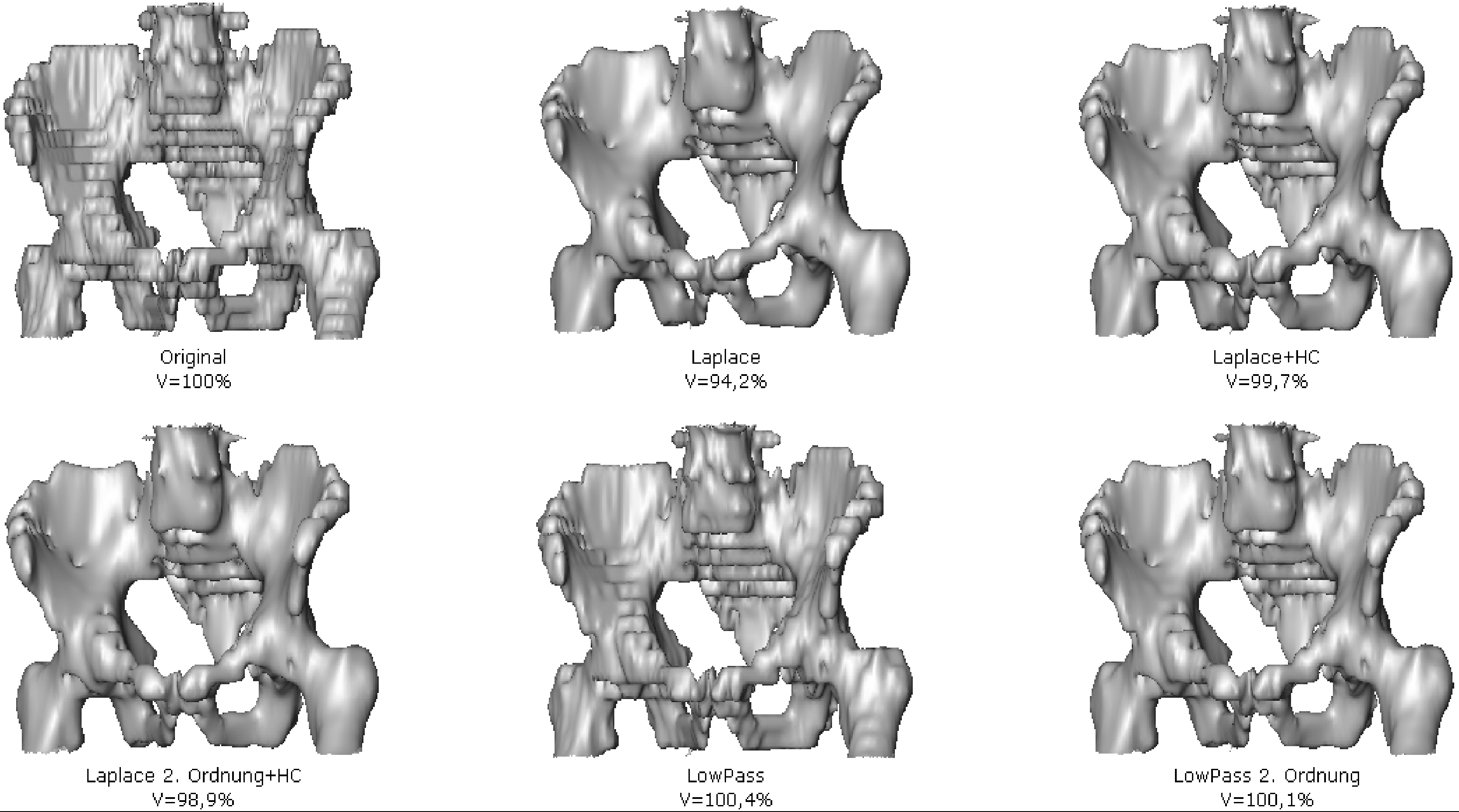
- Criteria: Quality, volume preservation
- Methods/parameters:
  - Laplace, Laplace with correction, Low-pass
  - Different iteration steps: 5, 10, 20, 50
  - Different weighting factors: 0.05, 0.1, 0.3, 0.5, 0.7, 0.9
  - Different neighborhood: 1, 2 (topological)

	 Leber	 Lymphknoten	 Kopfwendemuskel	 Beckenknochen	 Gefäßbaum	 Halsschlagader
Faces	37.148	3.412	9.616	53.930	23.236	1.956
Vertices	18.576	1.708	4.804	27.211	11.820	982
Voxel	1.696.250	1.664	101.035	430.318	96.807	16.404

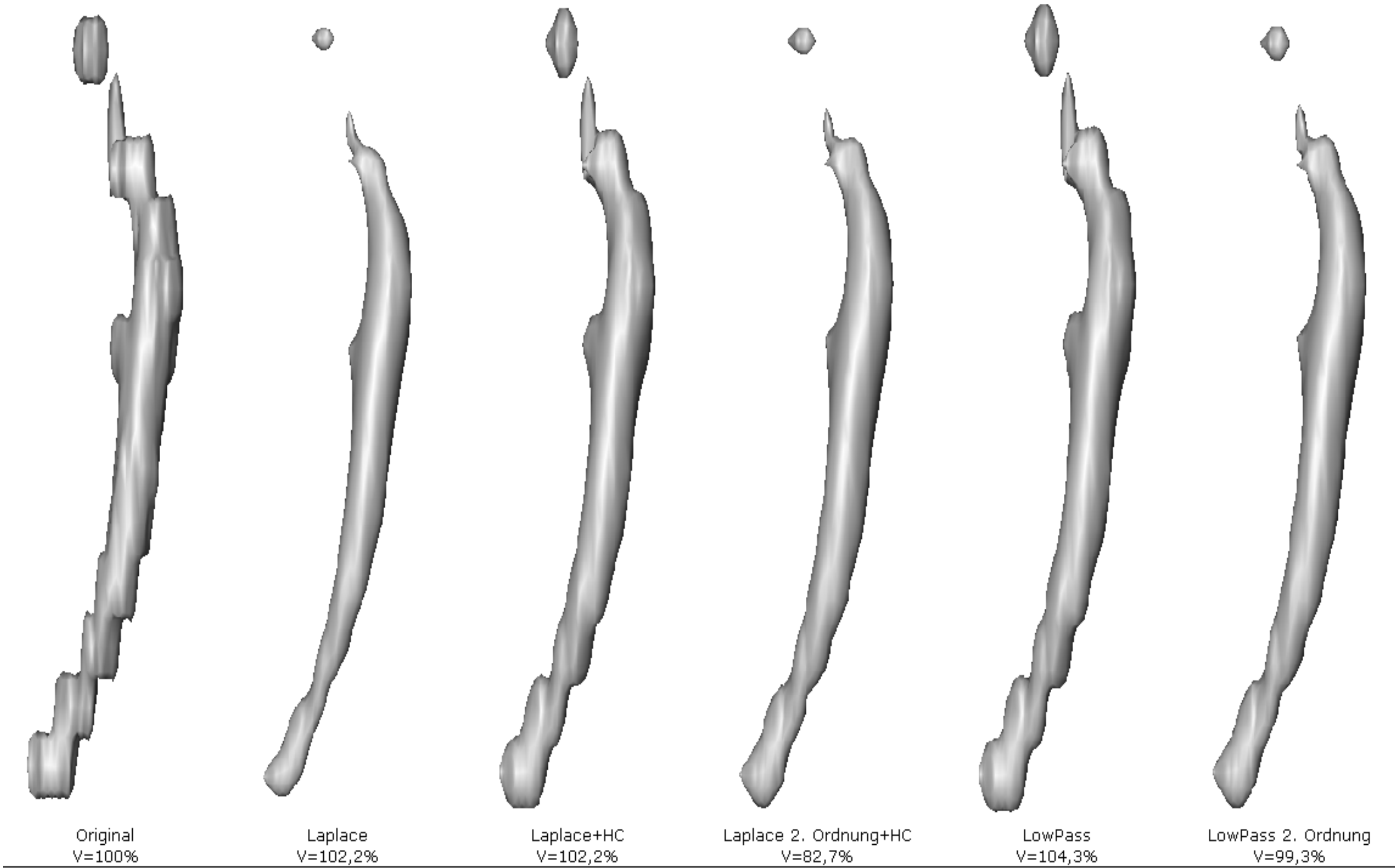
Smoothing of Polygonal Surfaces: Comparison of Methods



- All images with smoothing factor 0.5 and 10 iterations

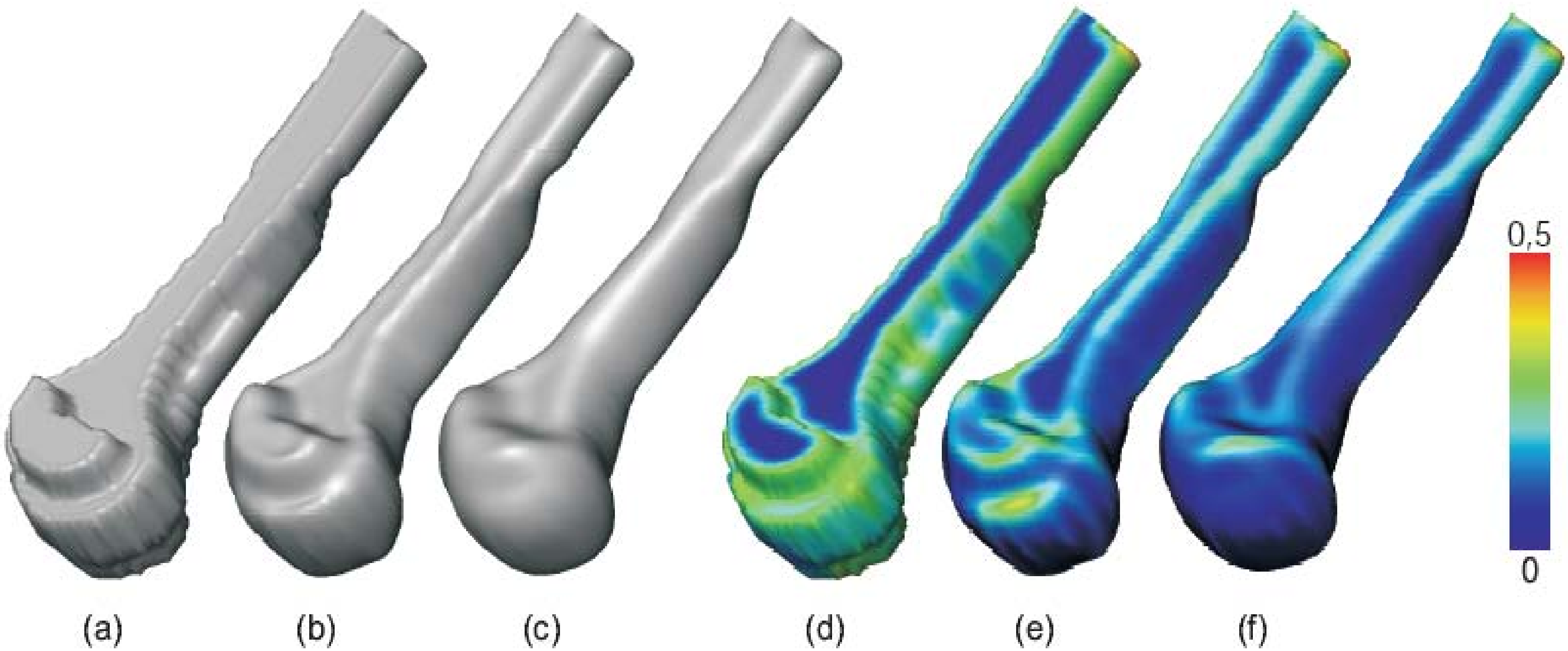


- Carotid artery: Smoothing factor: 0.7 and 10 iterations



Smoothing of Surfaces: Comparison of Methods

- Original, low-pass filtering with one neighborhood and extended neighborhood as well as the corresponding curvature values.



Smoothing of Polygonal Surfaces: Recommendations

- A low-pass filter is the best solution for all object classes.
- For smaller objects
  - Topological neighborhood of the size 2, 20-50 iterations, weighting: 0.7
- For flat or larger objects, especially with poblem points:
  - Topological neighborhood: 1, approx. 20 iterations
- For elongated, branching objects:
  - No really good filter (-> Vessel Visualization part will provide appropriate methods)
  - Low-pass filter with topological neighborhood of 1, weighting factor: 0.5 and 10 iterations

Surface Visualization: References

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Surface Visualization: References

- R. Bade, J. Haase, and B. Preim (2006). „Comparison of Fundamental Mesh Smoothing Algorithms“, *Simulation and Visualization*, pp. 289-304
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- Embedding of segmented objects (isosurfaces, strongly smoothed) into the anatomic context (DVR)