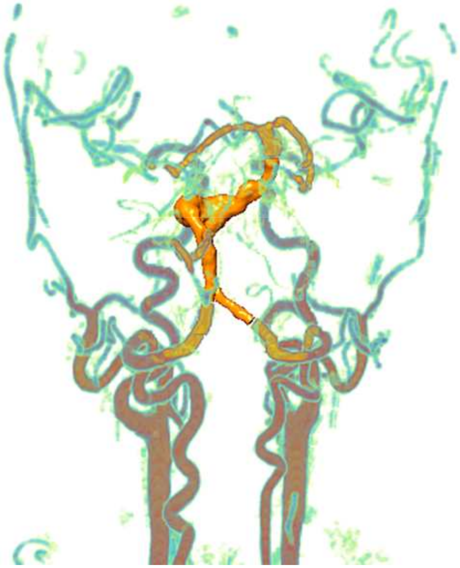
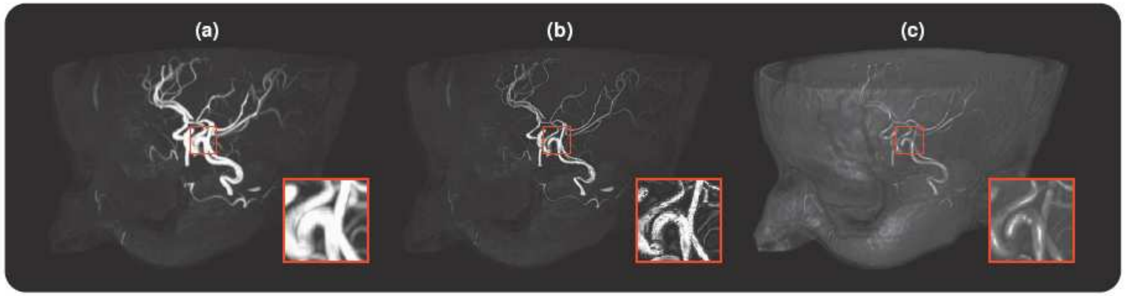
Virtual Reality and Visualization





Volume visualization

Virtual Endoscopy

Content

2D and 3D Visualization for the Exploration of Medical Image Data	(15 min.)
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	(45 min.)
Diffusion Tensor Imaging	(20 min.)
Computer-assisted Shoulder Replacement	(30 min.)
Virtual Endoscopy	(30 min.)
Virtual and Augmented Reality	(15 min.)

Medical Image Data

Regular data in an orthogonal lattice

Resolution:

- Anisotropic datasets (slice distance > distance of pixels in the slice)
- Typical: CT or MRI data: 512x512 per slice,
  80-250 slices, resolution: 12 bit per slice,
  ~ 20-50 MVoxel
- High-End: Multi-Slice CT: 1024x1024 per slice,
  up to 2000 slices (whole body scans), ~ 4000 MVoxel
- Less usual: PET, SPECT with a lower resolution

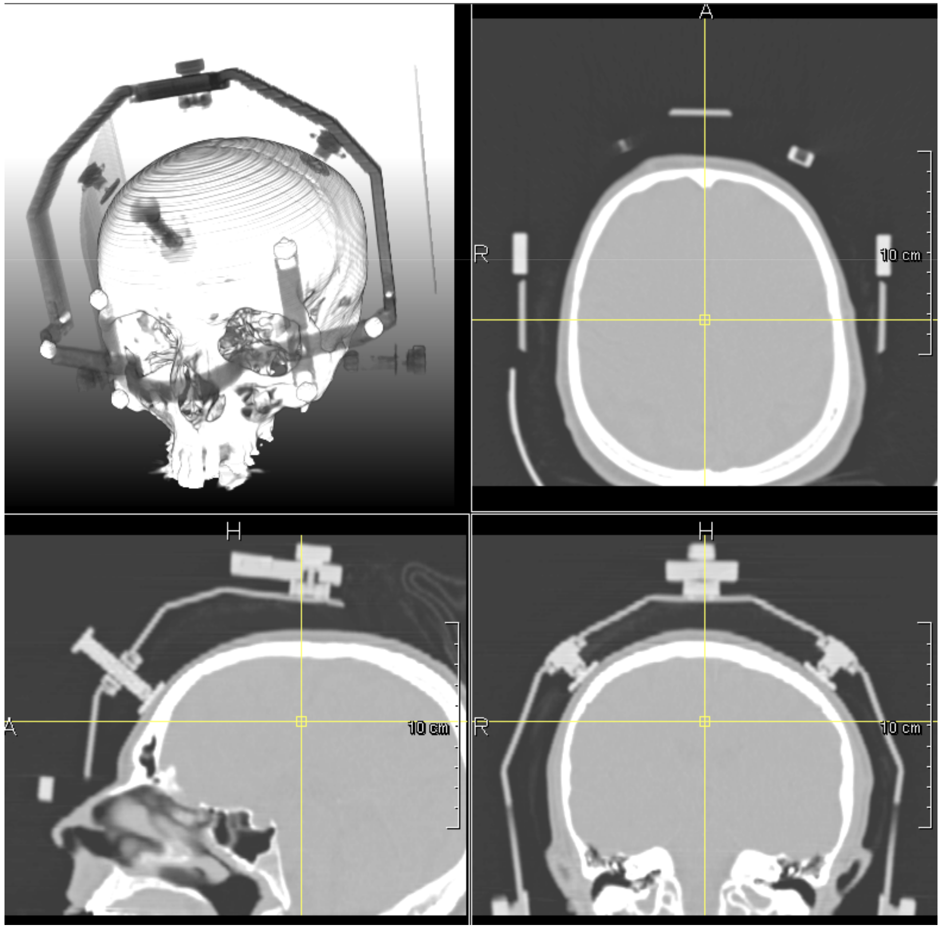
2D and 3D Visualization for the Exploration of Medical Image Data

- 3D visualizations:
  - clearly arranged, descriptive, intuitive
  - give an overview on spatial relations

- 2D visualizations:
  - are common in radiological diagnostics
  - permit the precise evaluation of structures
  - permit exact selections (for measurements, …)

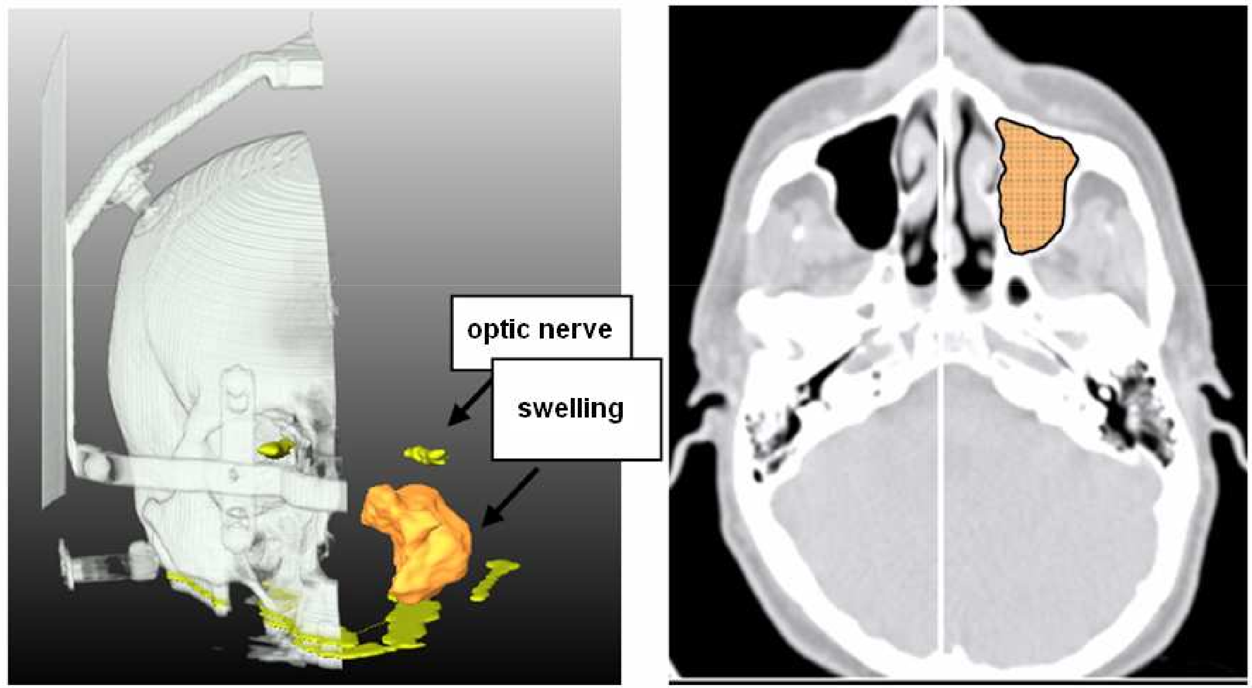
- Combination of both representations with suitable synchronizations

2D and 3D Visualization for the Exploration of Medical Image Data



- Synchronized 2D and 3D views.
- The crosshairs in one of the orthogonal 2D views can be used to select the slice displayed in the other two 2D views.
- Brightness and contrast of one view can be transferred to other views.

2D and 3D Visualization for the Exploration of Medical Image Data

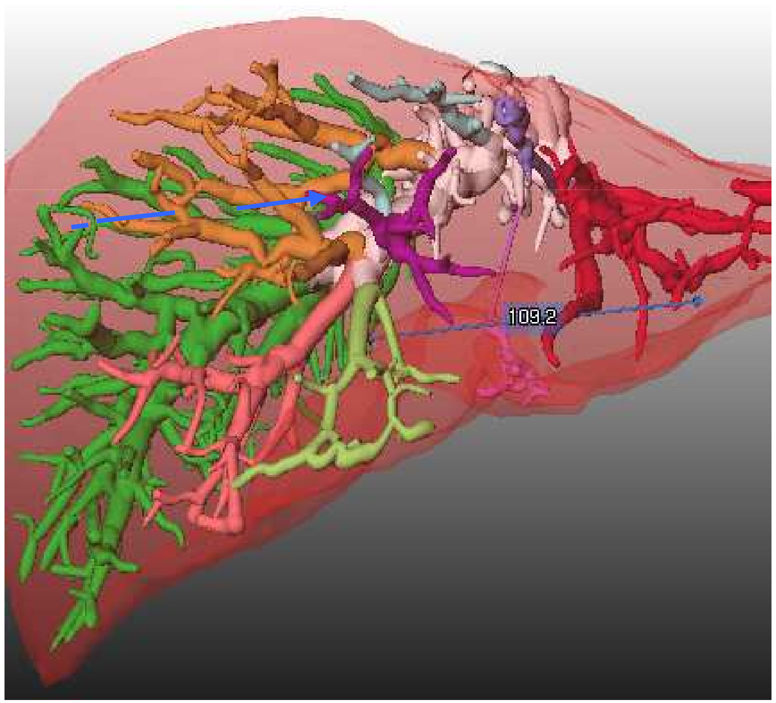


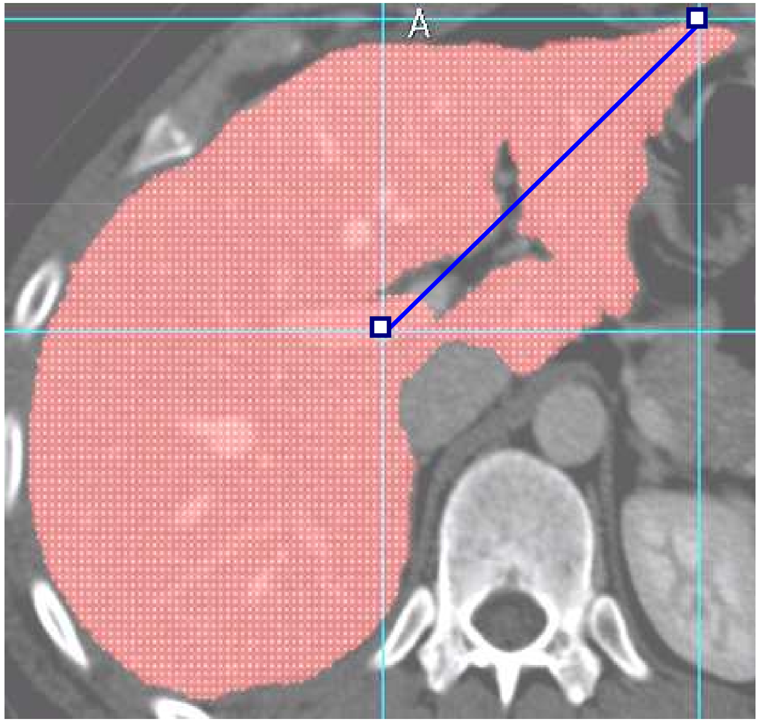
Images Dörte Apelt, MeVis Research

Planning of ENT interventions.

- 3D presentation of an ENT intervention. The relation between optic nerve and swelling is displayed, whereas a clip plane hides parts of the original data. Illustration of the swelling in the axial slice with a drawn-in clip plane**.**

2D and 3D Visualization: Measurement

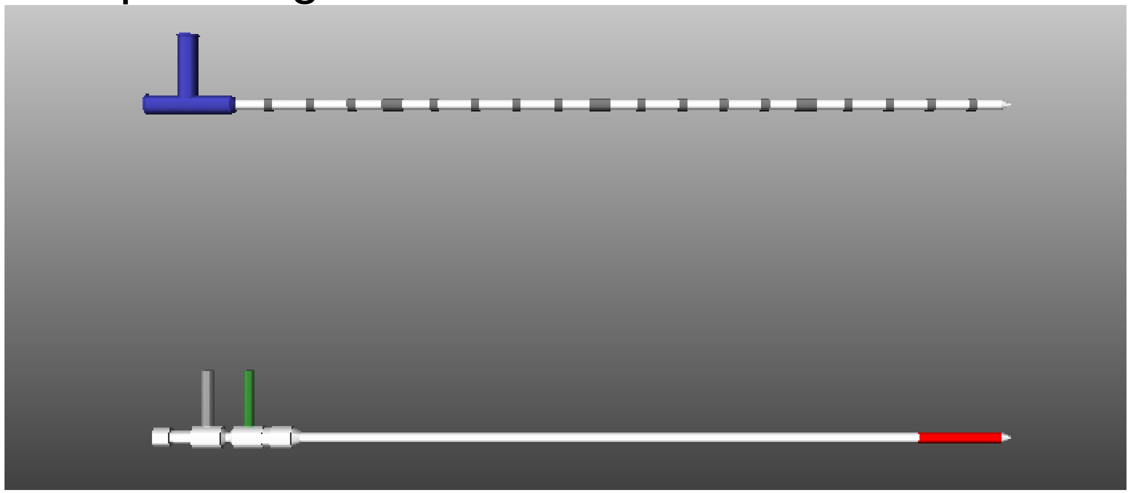




Distance measurement in 3D and 2D visualization. The endpoints of the lines can be moved in both views, whereas the respective view is adapted.

2D and 3D Visualization: Placement of Applicators

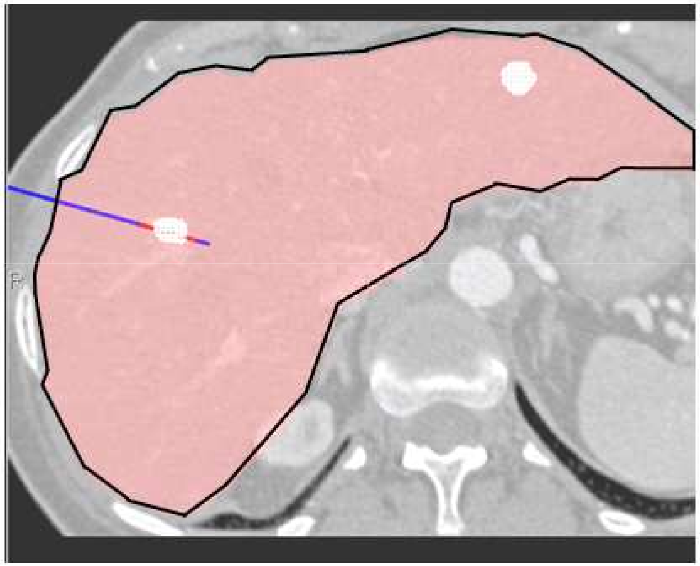
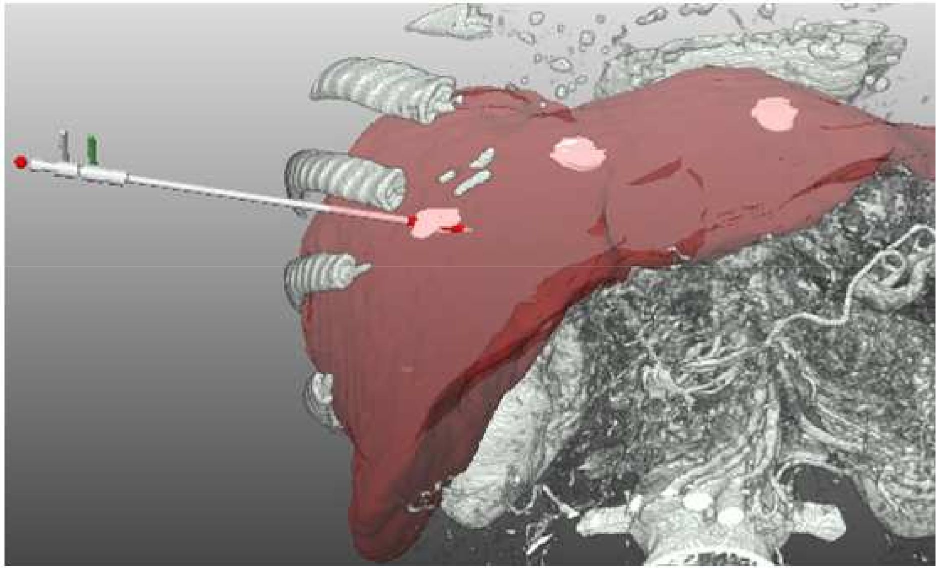
- Aims of exploration:
  - access planning of biopsies
  - planning of thermal ablations



Images Courtesy
Olaf Konrad, MeVis Research

Geometric models of high-frequency and laser applicators for the thermical treatment of liver tumors.

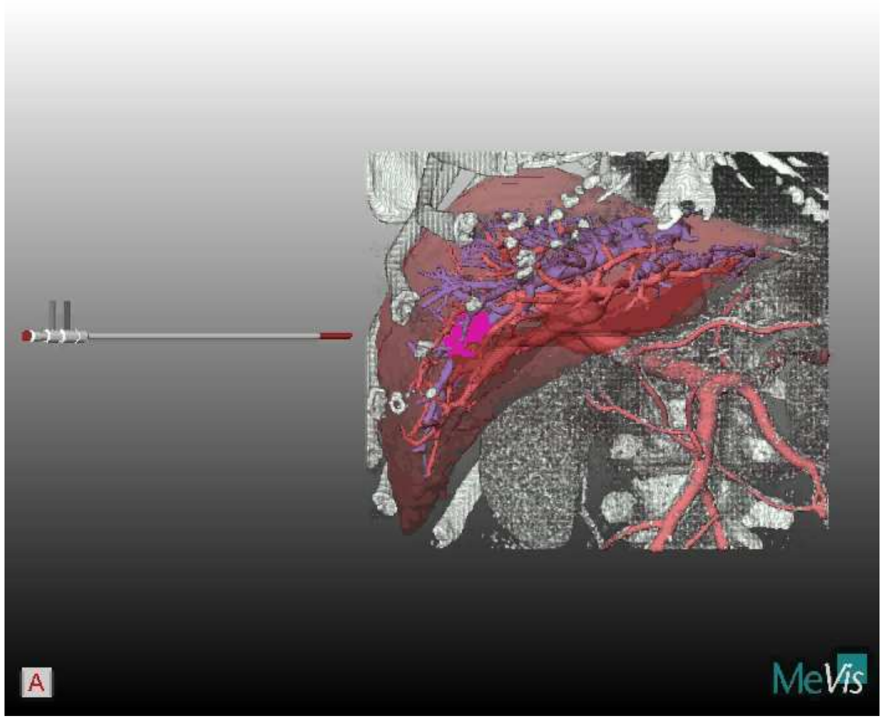
2D and 3D Visualization: Placement of Applicators

Images Courtesy Arne Littmann, MeVis Research

- Placement of the applicator into the center of a metastasis in 2D (the active zone is red).
- Placement of the applicator by means of a 3D visualization, whereas the bones are displayed as volume rendering, and the liver surface and the metastases are displayed as isosurfaces**.**

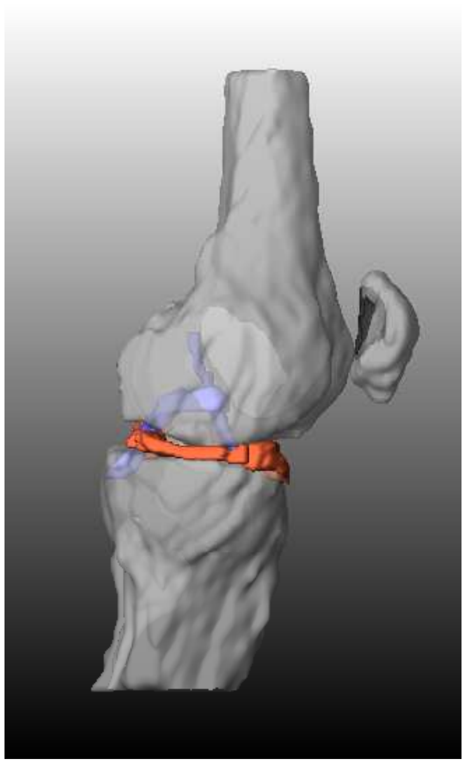
2D and 3D Visualization: Placement of Applicators

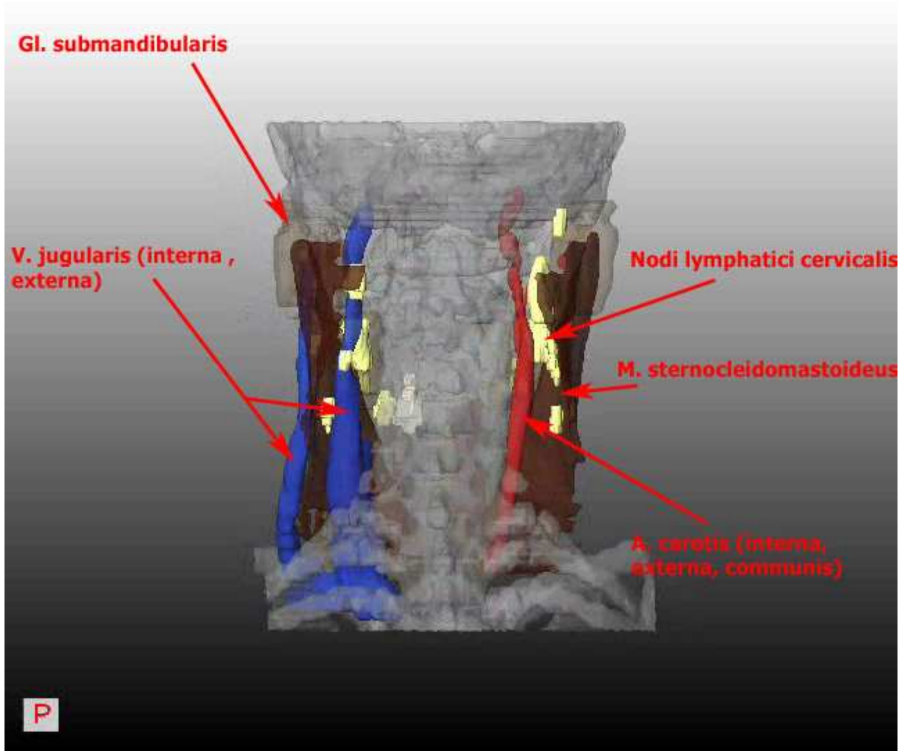


Videos from Arne Littmann, MeVis Research

Surface Visualization

Visualization of isosurfaces and segmentation results



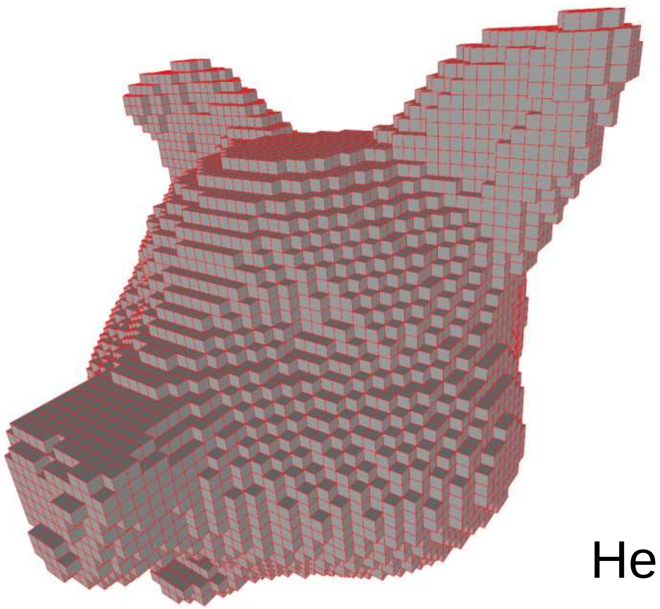


Surface Visualization: Introduction

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)

Surface Visualization: Introduction

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

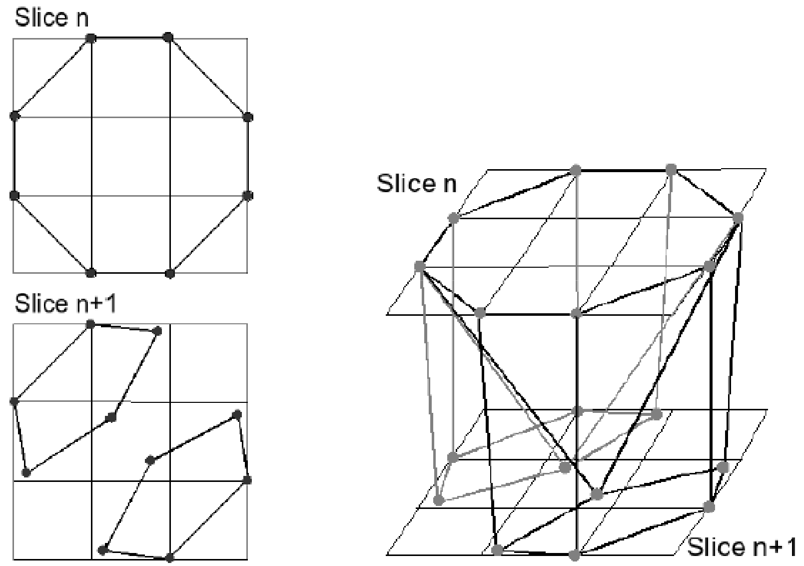
How can this be realized?

- 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)

From Contours in slices to Surfaces

Which problems need to be solved?

- *Correspondence*. (which contour of one slice belongs to a contour at the next slice)
- *Triangulation (Tiling)*. *C1* and *C2* be corresponding contours. How shall these contours be connected through triangulation nets?
- *Branching problem*. If the number of contours in one slice *Sn* is different to the number of contours in the neighbor slice *Sn+1*.



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

From Contours in slices to Surfaces

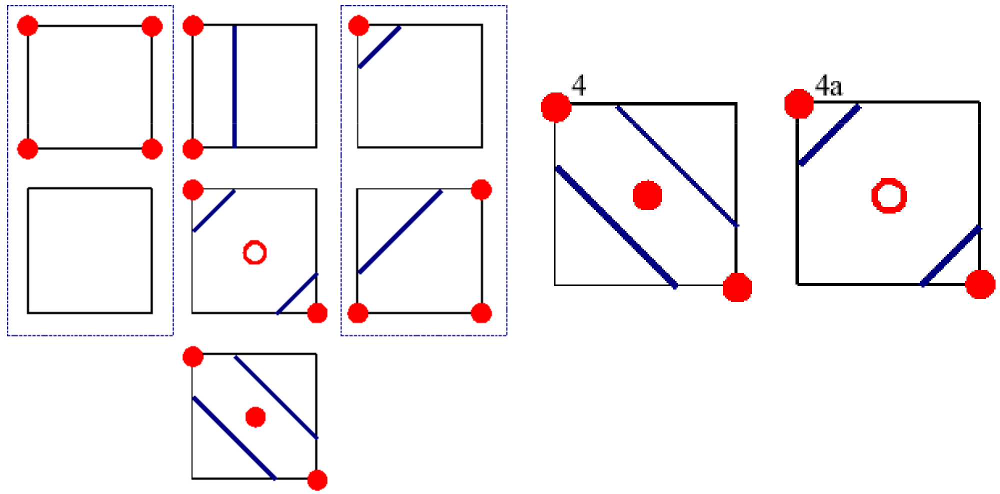
- *Correspondence problem*. Comes up, if the following applies:

  The contours *C1* (*Sn)* and *C1* (*Sn+1)* belonging of object *C1* do not overlap themselves, and the number of contours belonging to one object is > *1* in *Sn* and/or *Sn+1.*

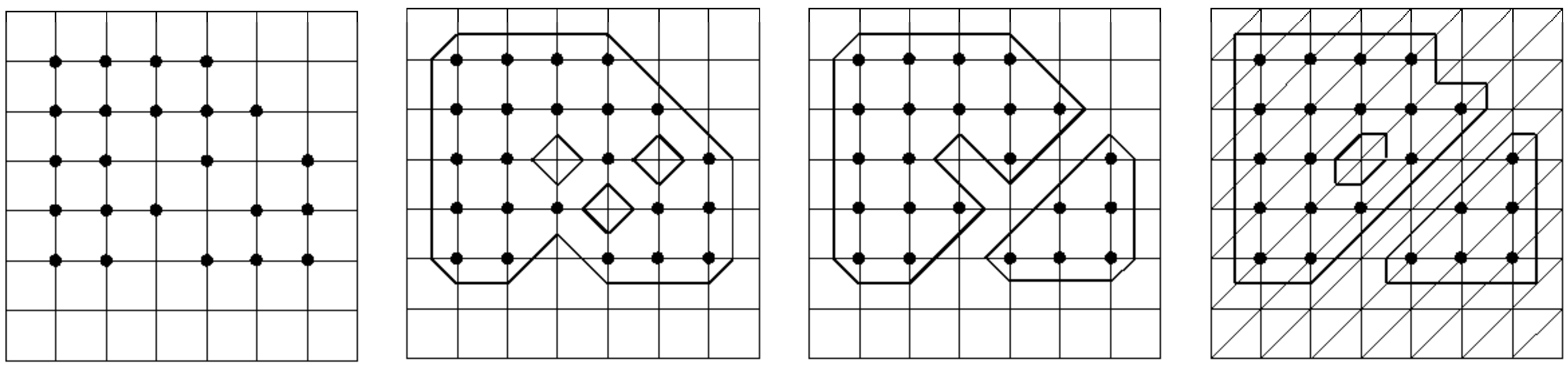
- What does Marching Cubes?
  - An overlapping of contours in neighbored slices is assumed.
  - Limit of this assumption? In case of a large slice distance or thin objects which proceed diagonal to the slices.
  - If the requirements are not fulfilled, separate surfaces are generated.
- In such cases, correct solutions are complex.
  - Interpolation of intermediate slices often helps.

Surface Visualization: Marching Cubes

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



- Ambiguity:

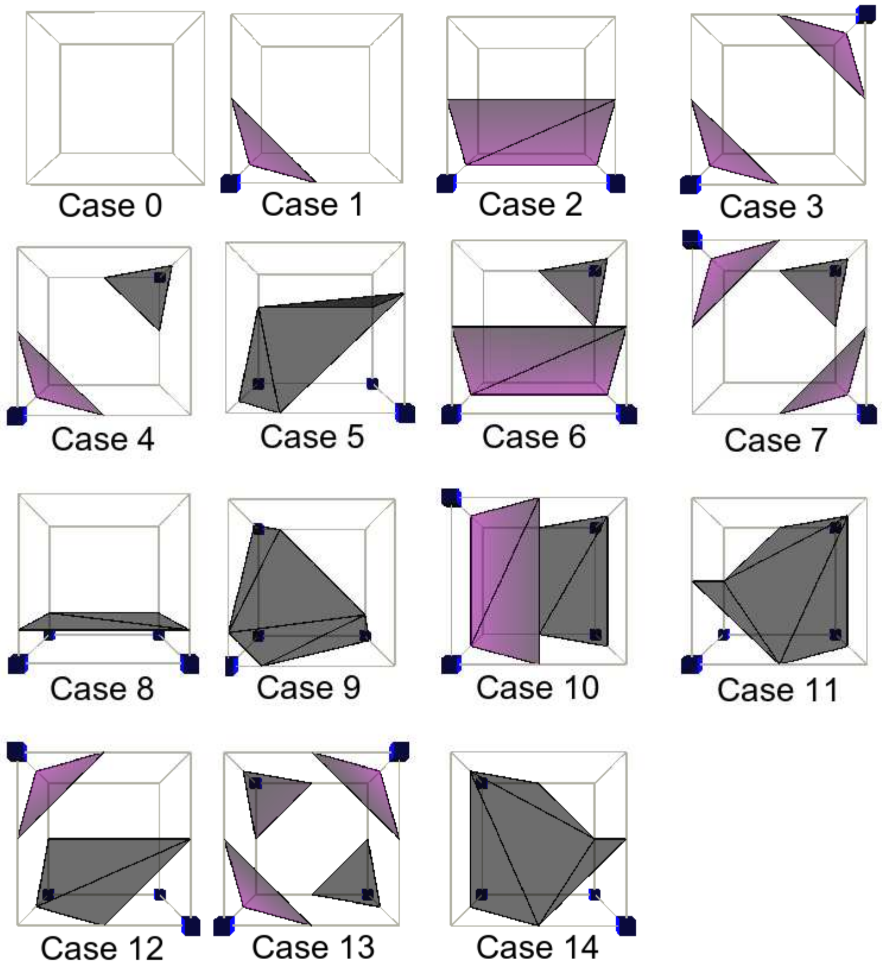


Surface Visualization: Marching Cubes

- Extension to 3D:
- there are 14 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.



Surface Visualization: Marching Cubes

Marching Cubes

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

Procedure:

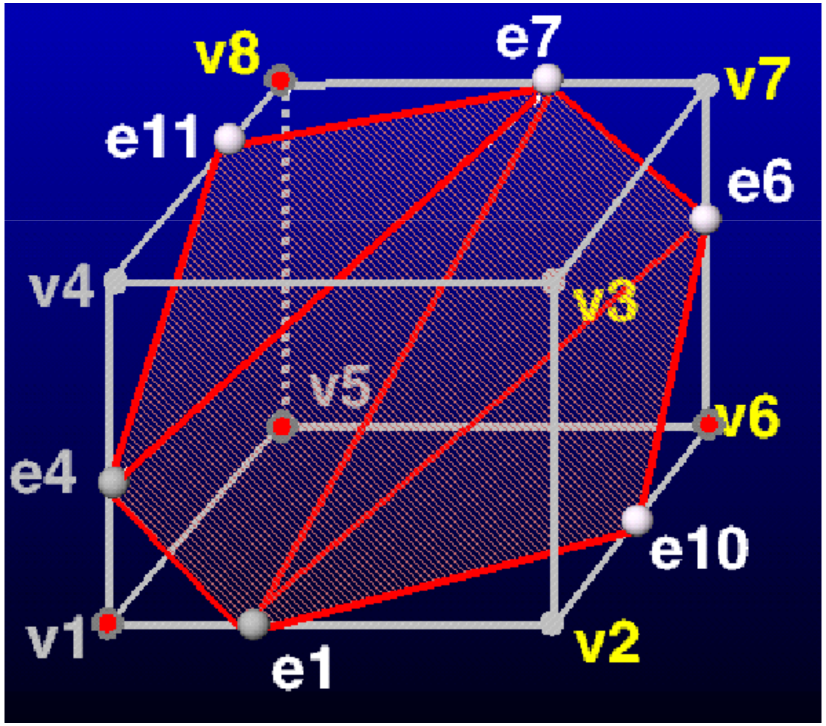
1. Consider cells from 4 voxels of the slice *k* and 4 voxels of the slice *k+1*
2. Check out which vertices are lying above the threshold value, create an index
3. Determine the involved edges
4. Determination of points at these edges through linear interpolation
5. Connection of these points to create triangles

Indirect Volume Visualization: Isosurfaces

Marching Cubes
Step 2:
v_1, v_5, v_6, v_8 – above,
v_2, v_3, v_4, v_7 – below
Index: 1000 1101

Step 4: Linear interpolation
Example: determination of e_1 to the edge (v_1; v_2)
$e_1 = v_1 + (\text{isoval} - f(v_1)) / (f(v_2) - f(v_1)) * (v_2 - v_1)$

Step 5: Triangles
(e_4, e_7, e_{11}) (e_1, e_7, e_4)
(e_1, e_6, e_7) (e_1, e_{10}, e_6)



© Alexandre Telea

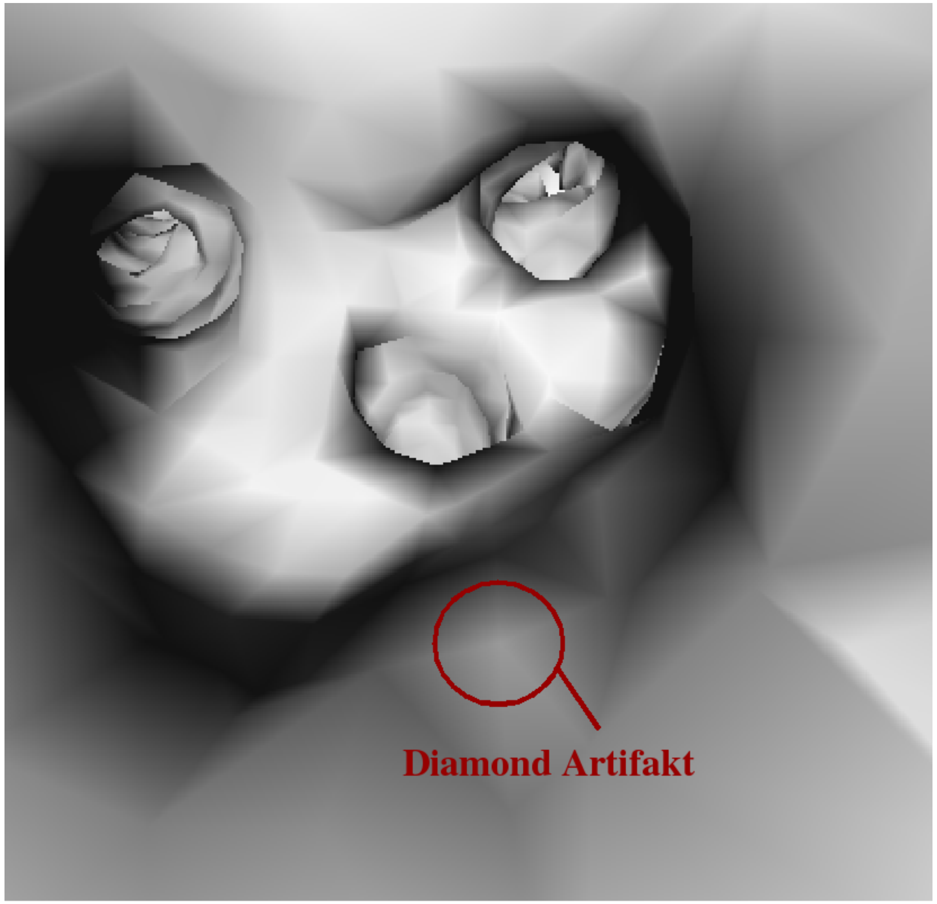
Surface Visualization: Marching Cubes

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

Surface Visualization: Marching Cubes

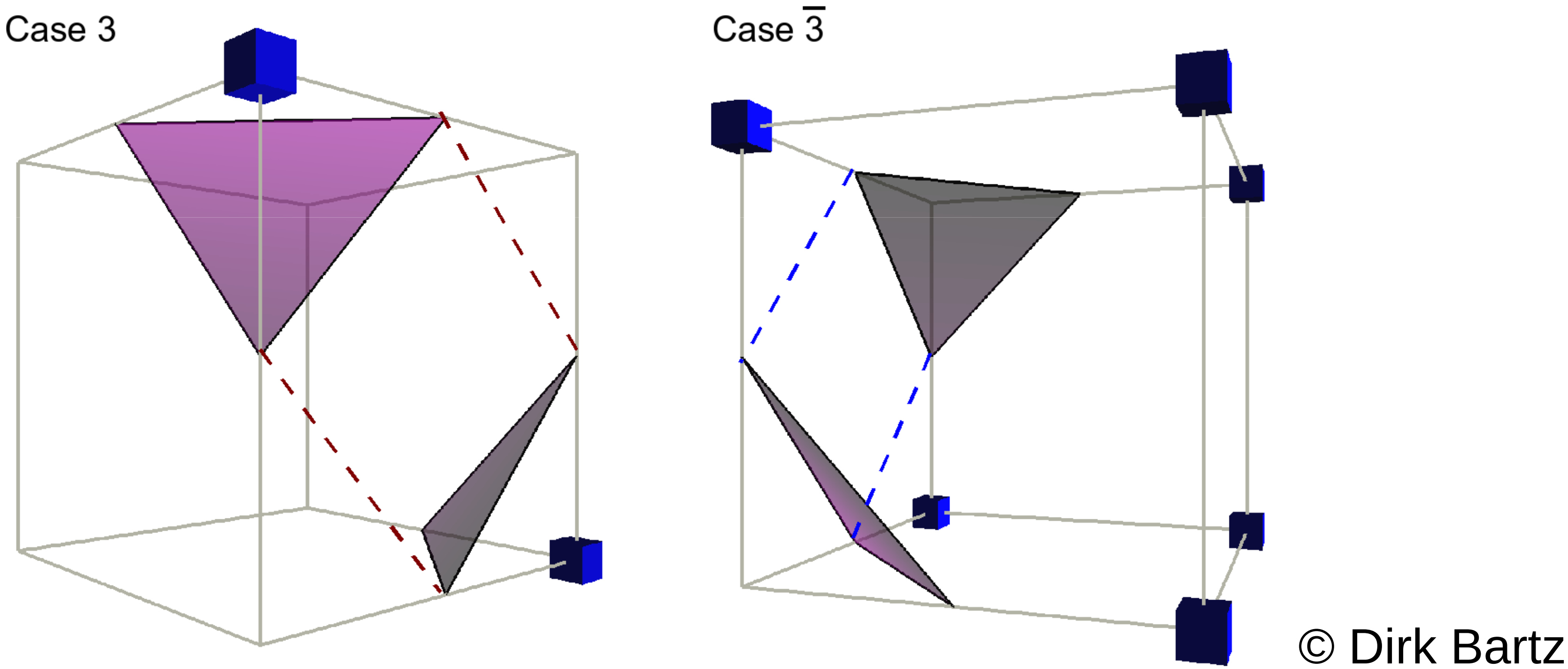
Quality problems through linear interpolation and Gouraud shading



Virtual bronchoscopy

© Dirk Bartz

Surface Visualization: Marching Cubes



© Dirk Bartz

- Holes in the surface arise, if, for the neighbored cells, once the decision is made to divide the intersections and once the decision is made to connect them.

Surface Visualization: Marching Cubes

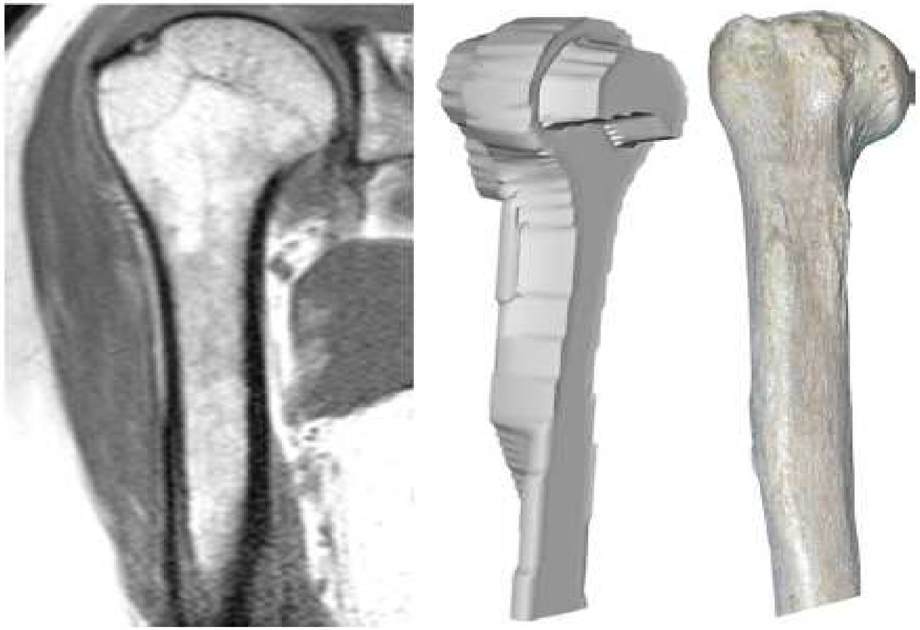
- How can this inconsistency be corrected?
  - Interpolation of points at the interface. The state of this point (above/below) is decisive (Nielsen, Hamann [1991])
  - Usage of the complete case list (Schröder et al. [1998])
  - Decomposition of the cells into tetrahedrons (Shirley, Tuchman [1990])

- 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])

Surface Visualization: Smoothing and Noise Reduction

Problem:

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



MR data, 3D visualization, picture

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*

Surface Visualization: Smoothing and Noise Reduction

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 are still neighbored cells z_n of *z* which contribute to the surface and are not "visited" yet,

add z_n to the component *k* and mark it as "visited".

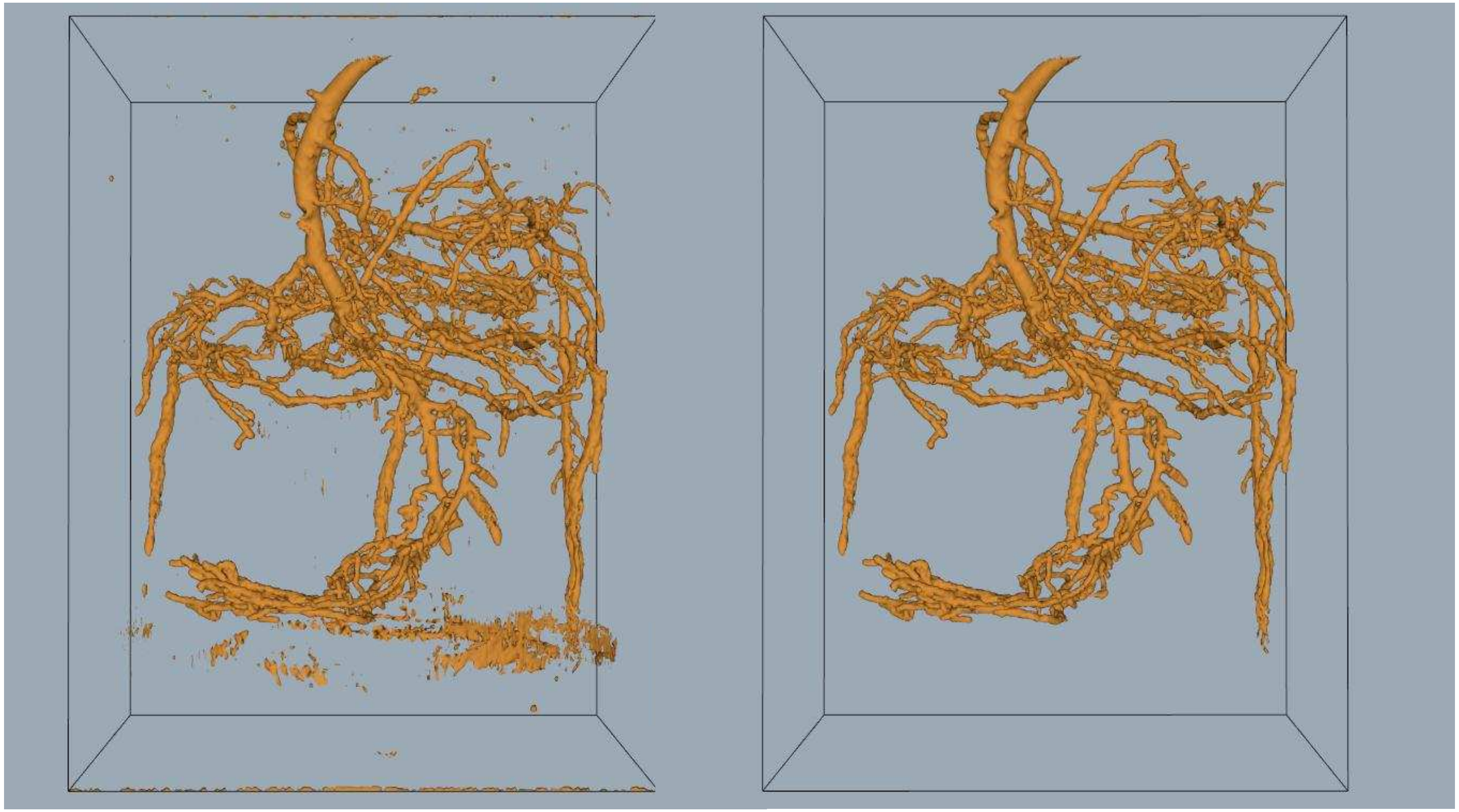
Continue recursively as long as there are still cells which are neighbored and not visited yet.

Result: all connected components

Selection of the largest (n) component(s) according to the surface area or length of the object contour

Surface Visualization: Smoothing and Noise Reduction

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

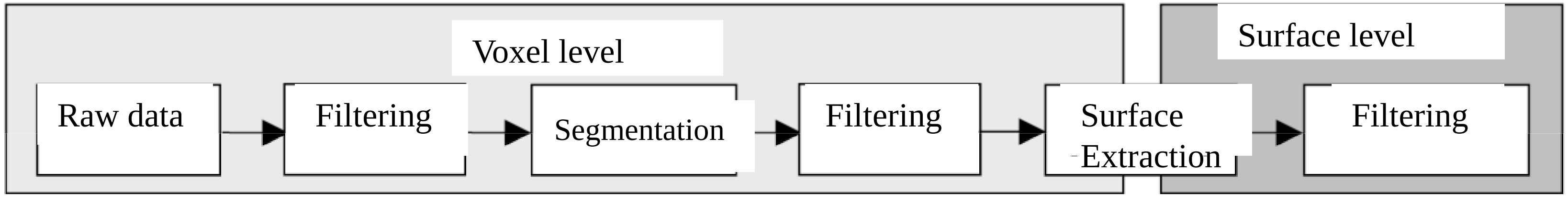
  e.g., in vtk (vtkSmoothPolyDataFilter), itk, 3D Studio, Amira

Disadvantages

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

Surface Visualization: Smoothing and Noise Reduction

Extraction of surfaces



Long-term goal:

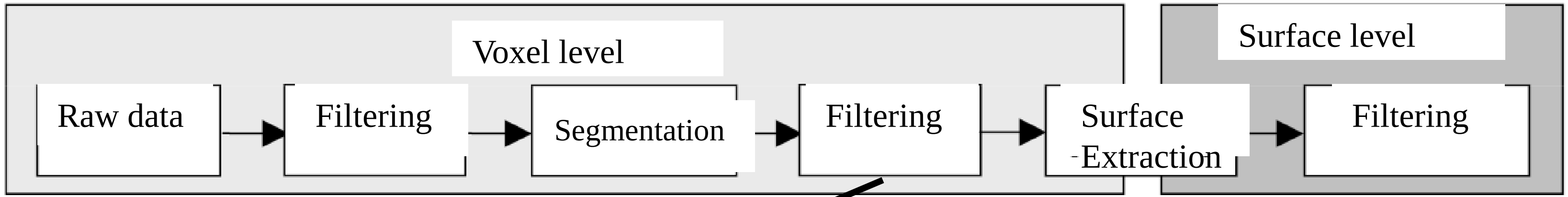
Pipeline of algorithms for the post-processing of segmentation results (e.g., closure of holes), surface generation and subsequent smoothing

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)

Surface Visualization: Smoothing and Noise Reduction

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



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

Source: Neubauer et al., IEEE Visualization 2004

- First of all, erosion and modification:

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

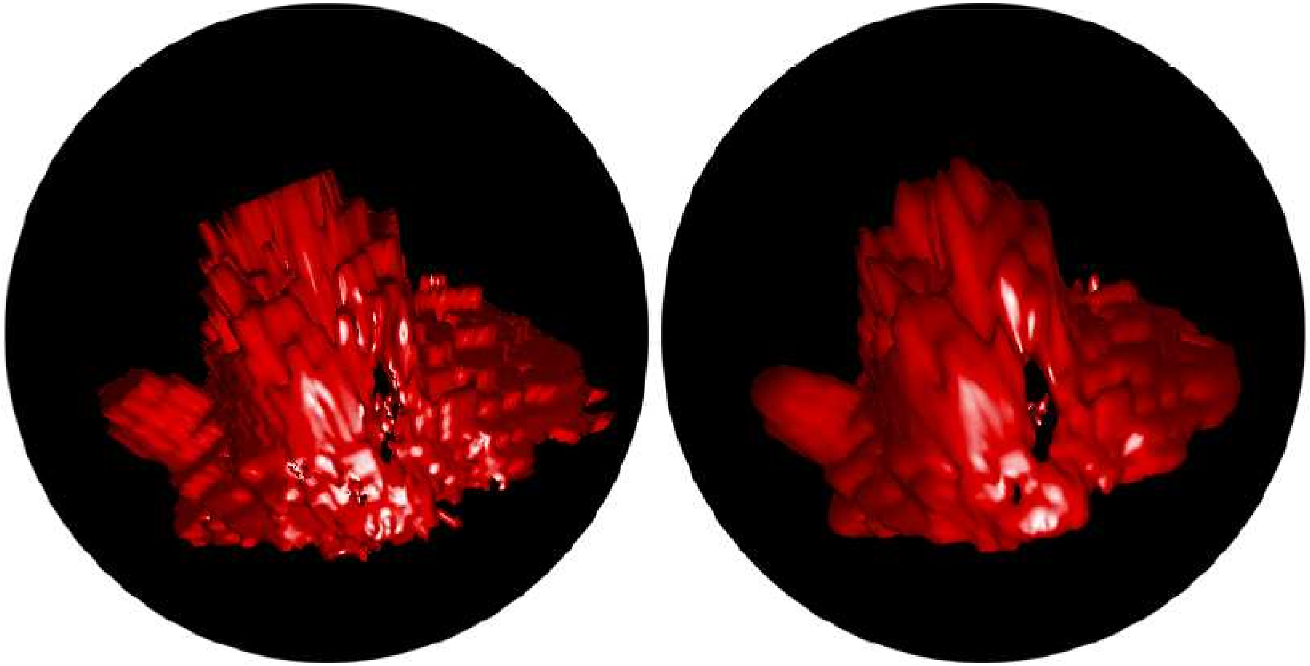
- Afterwards, twice dilatation and modification:

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

- d Eucl. Distance, v_ref = 50

Surface Visualization: Smoothing and Noise Reduction

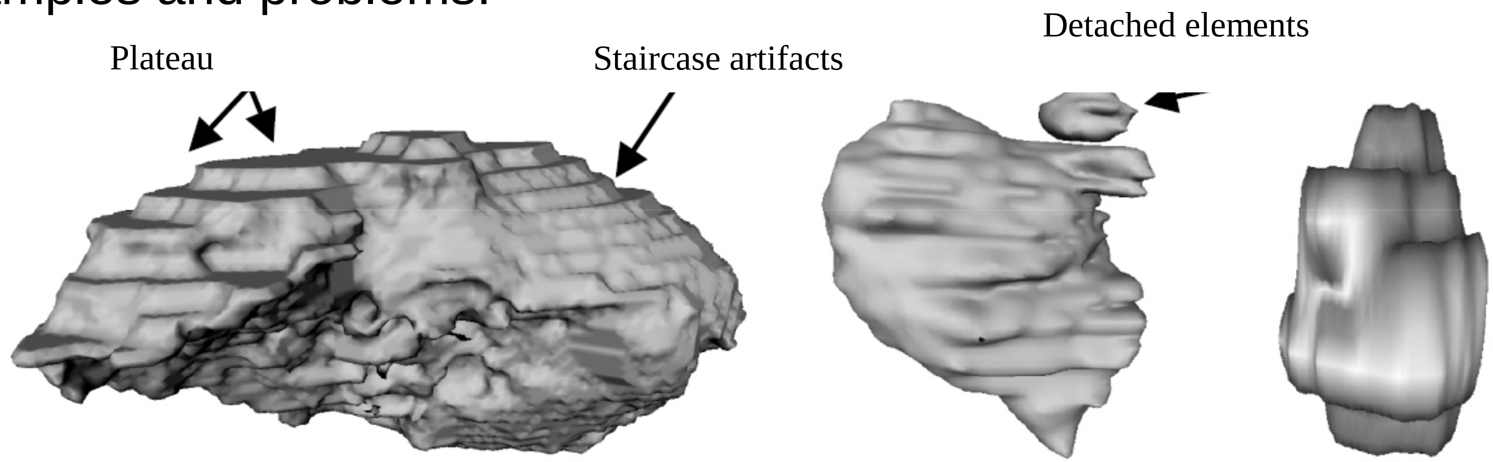
- Smoothing of the segmentation result through morphological methods

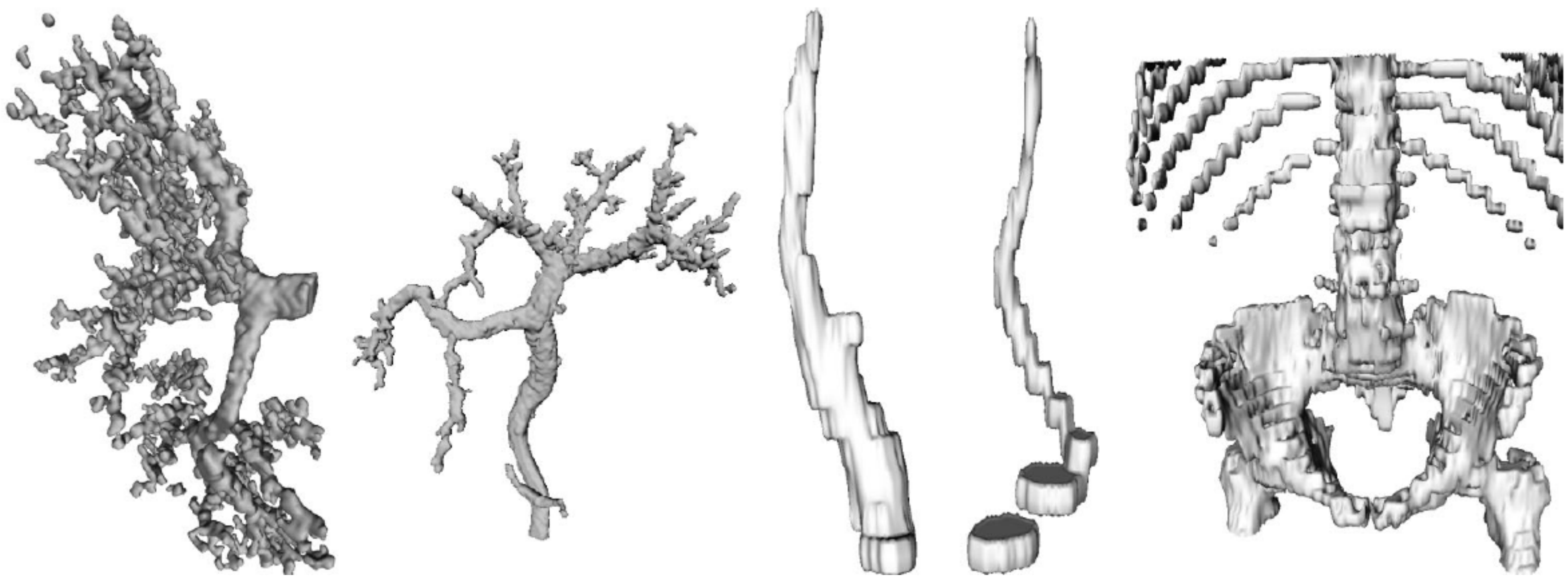


Source: Neubauer et al., IEEE Visualization 2004

Smoothing of Polygonal Surfaces

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

Smoothing of Polygonal Surfaces: Requirements

Analog to the smoothing of image data:

- Elimination of high frequency noise at the receipt of features

  Measures/Evaluation:

  - curvature plots, total curvatures

- Speed
- Accuracy

  Measures:

  - slight distances between the original surface and the smoothed surface
  - volume maintenance

Smoothing of Polygonal Surfaces

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

Direct neighbors

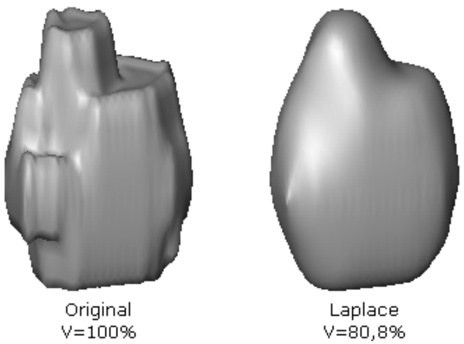
Second order neighbors

Smoothing of Polygonal Surfaces: Laplace Smoothing

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

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

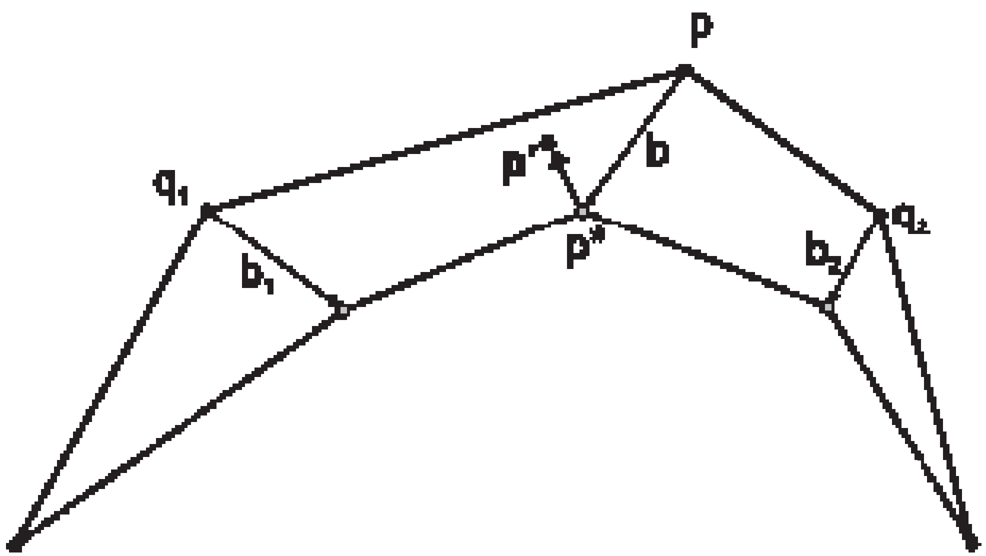
- Realized in vtk (vtkSmoothPolyDataFilter), …
- Simple, fast realization
- Causes strong (uncontrolled) shrinkage and the favored smoothness is often only achieved through total smoothing of minor features



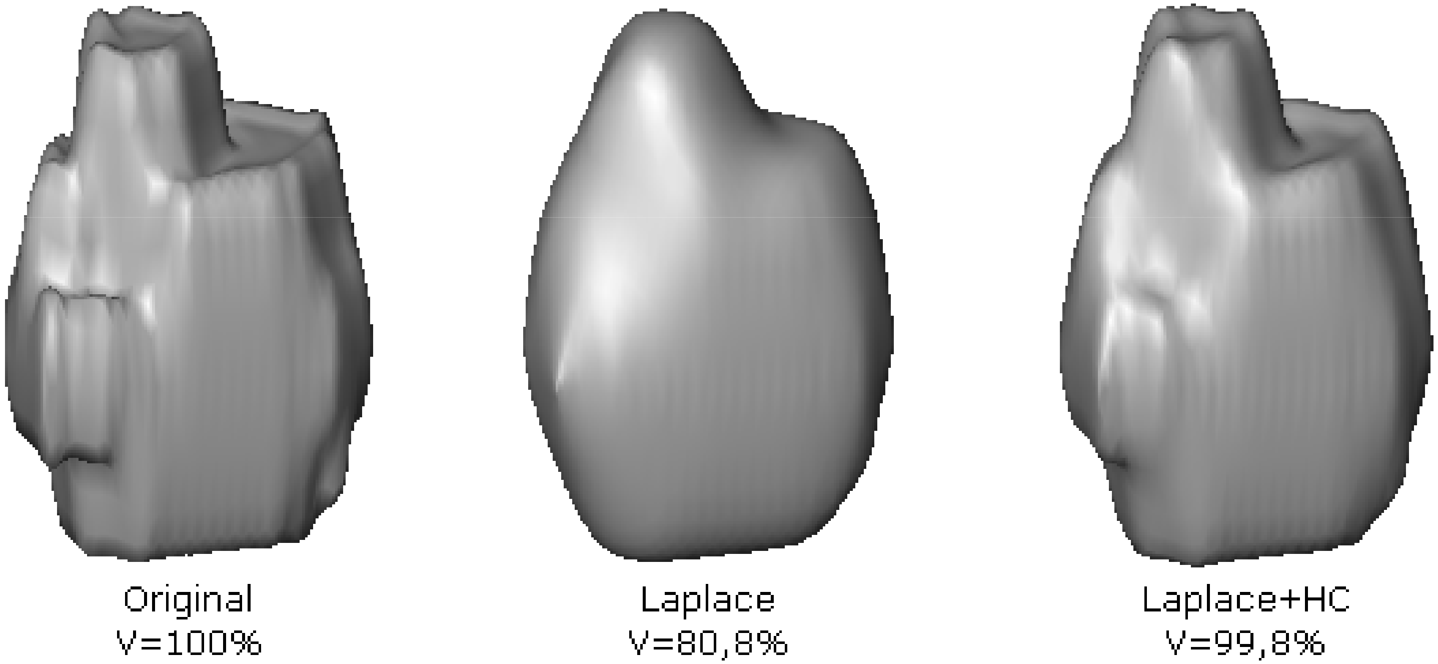
smoothing with α = 0.5 and 20 iterations

Smoothing of Polygonal Surfaces: Laplace Smoothing with Correction

- 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?



Smoothing of Polygonal Surfaces: Laplace Smoothing with Correction



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

Smoothing of Polygonal Surfaces: Low-pass Filtering

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

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

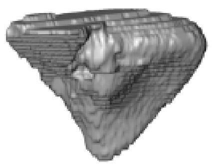
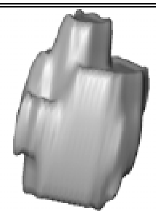
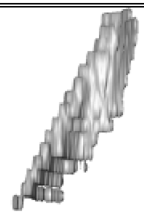
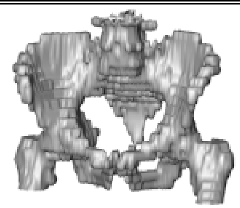
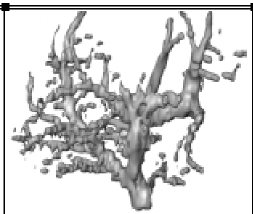
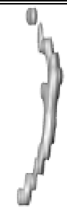
- Filtering: usually 1/n (all neighbors have the same influence; like Laplace)
- Selection of *μ:* a bit smaller than *α*
- Default: - *μ* = *-1.02 α* (Taubin, 1995)

Smoothing of Polygonal Surfaces: Comparison of Elementary Methods

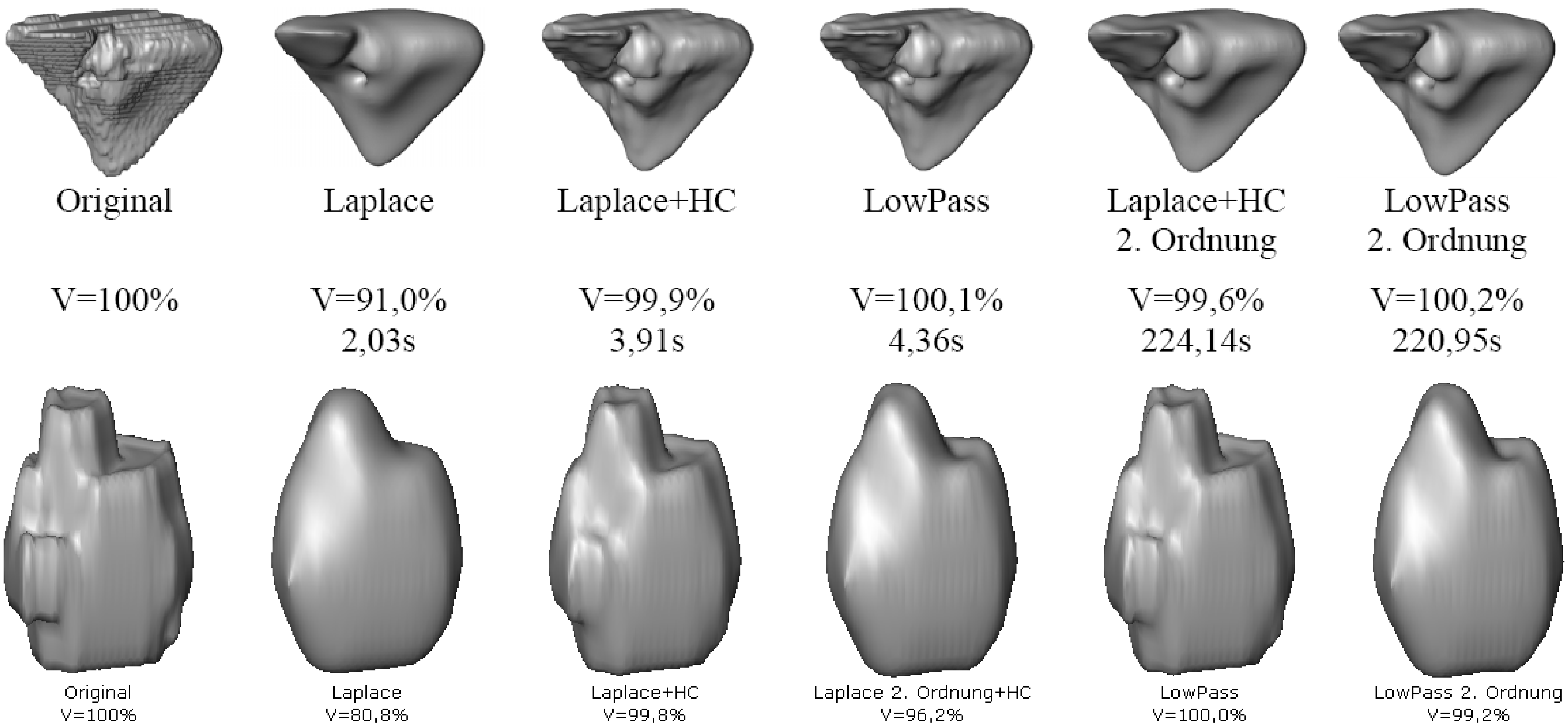
Criteria: Quality, volume maintenance (measurement in Amira), run time

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)

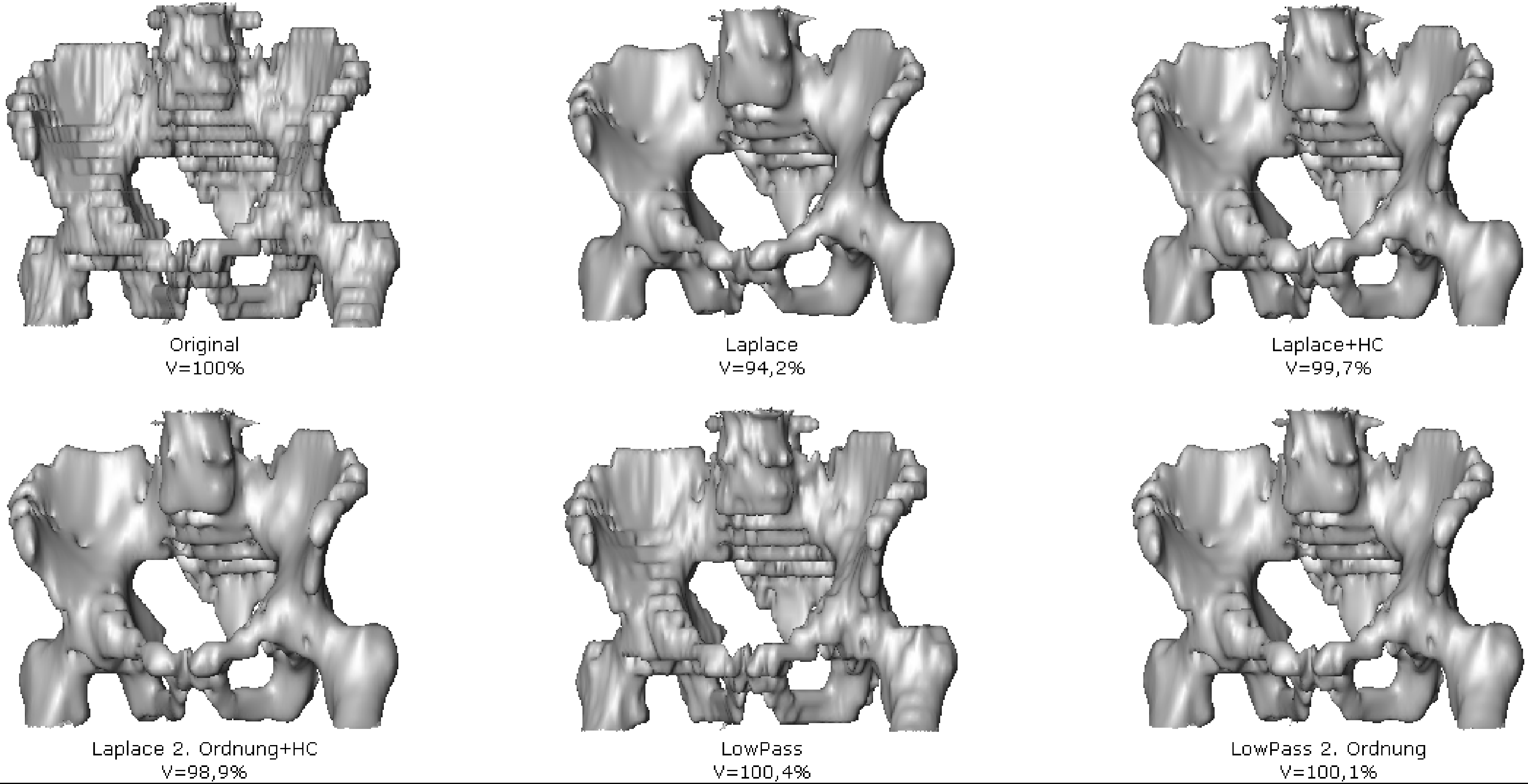
	 Leber	 Lymphknoten	 Kopfwendemuskel	 Beckenknochen	 Gefäßbaum	 Halsschlagader
Faces	37.148	3.412	9.616	53.930	23.236	1.956
Vertices	18.576	1.708	4.804	27.211	11.820	982
Voxel	1.696.250	1.664	101.035	430.318	96.807	16.404

Smoothing of Polygonal Surfaces: Comparison of Methods



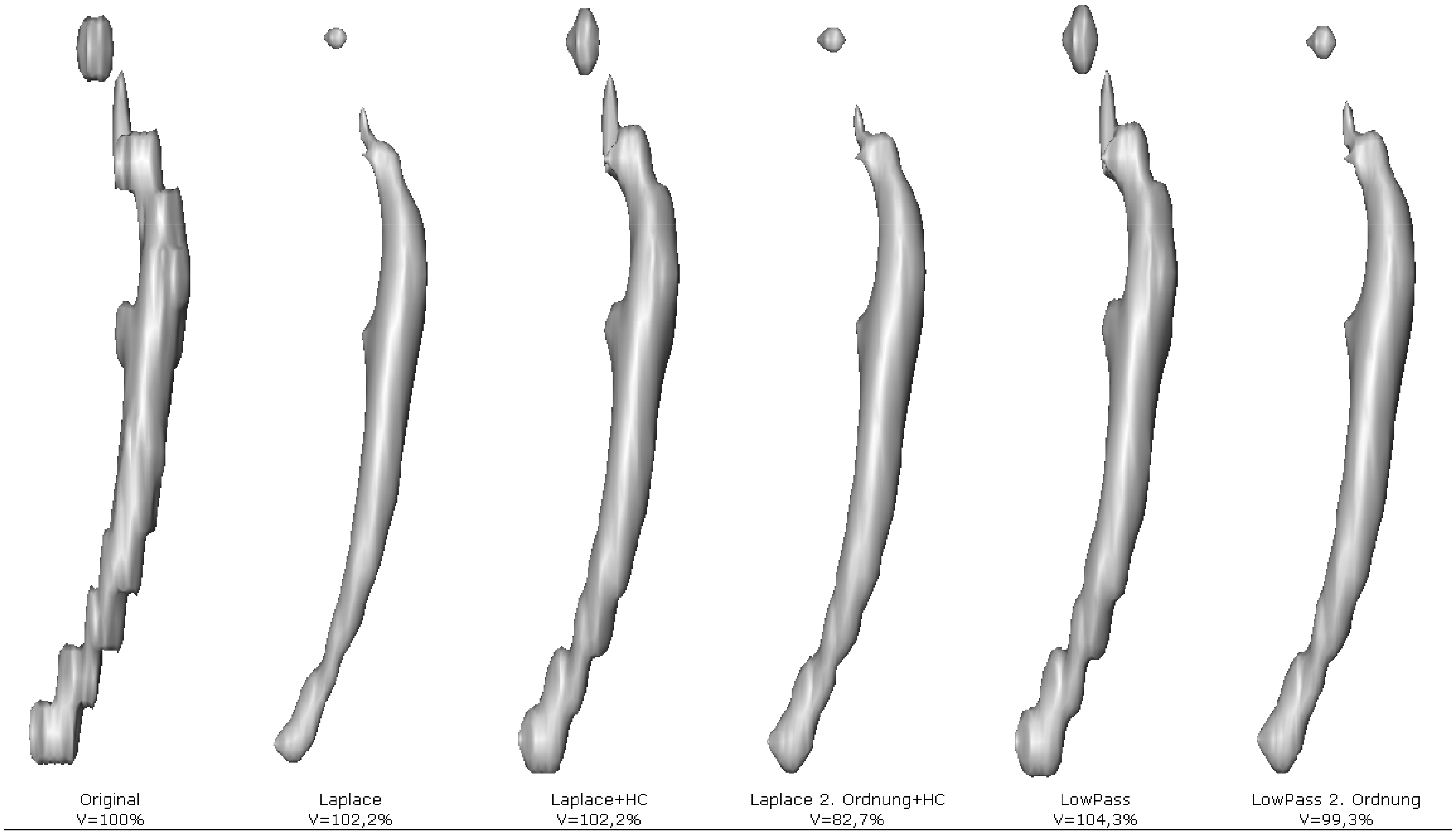
Smoothing factor: 0.5, 20 iterations

Smoothing of Polygonal Surfaces: Comparison of Methods



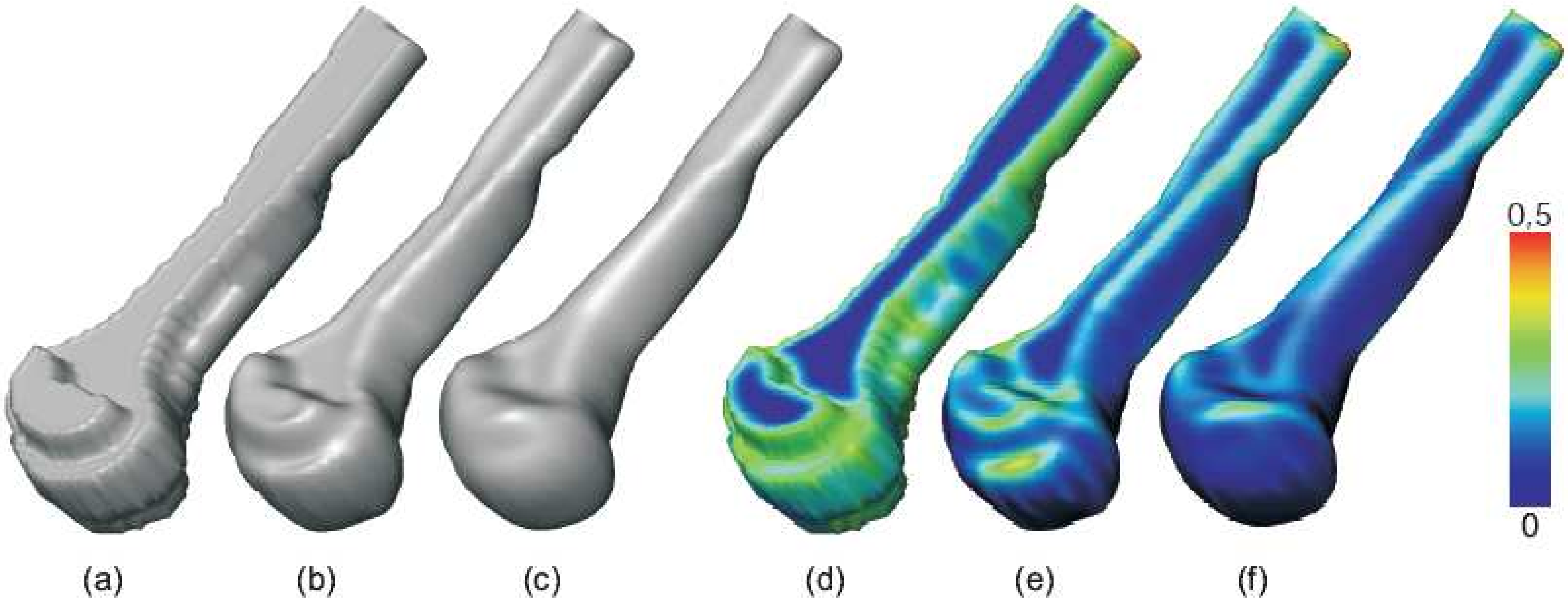
All images with smoothing factor 0.5 and 10 iterations

Smoothing of Surfaces: Comparison of Methods



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

M. Desbrun, M. Meyer, P. Schröder, and A. Barr (1999). “Implicit Fairing of Irregular Meshes Using Diffusion and Curvature Flow”. In Proc. of ACM SIGGRAPH, pp. 317–324, 1999

GT. Herman and HK. Liu (1979). „Three-dimensional Display of Human Organs From Computed Tomograms“, Computer Graphics and Image Processing, 9(1):1–21

D. Meyers, S. Skinner, K. Sloan (1992). „Surfaces from contours“, ACM Transactions on Graphics, Vol. 11(3), pp. 228-258

A. Neubauer, S. Wolfsberger, M. Forster, L. Mroz, R. Wegenkittl, and K. Bühler (2004). STEPS - An Application for Simulation of Transsphenoidal Endonasal Pituitary Surgery. In Proc. of IEEE Visualization, pp. 513–520, 2004

Will Schroeder, Ken Martin, and Bill Lorensen. The Visualisation Toolkit. Kitware, 3rd edition, 2001.

Gabriel Taubin (1995). „A Signal Processing Approach to Fair Surface Design“, *SIGGRAPH*, pp. 351-358, 1995

G. Nielson and B. Hamann (1991). The Asymptotic Decider: Removing the Ambiguity in Marching Cubes. In Proc. of IEEE Visualization, pp. 83–91, 1991.

P. Shirley and A. Tuchman (1990). A Polygonal Approximationm to Direct Scalar Volume Rendering. In Proc. of San Diego Workshop on Volume Visualization, pp. 63–70, 1990.

Surface Visualization: References

R. Bade, J. Haase, and B. Preim (2006). „Comparison of Fundamental Mesh Smoothing Algorithms“, *Simulation and Visualization*, pp. 289-304

All 864 measurements:

http://wwwisg.cs.uni-magdeburg.de/cv/projects/LST/smoothing/

J. Vollmer, R. Mencel, and H. Müller (1999). „Improved Laplacian Smoothing of Noisy Surface Meshes“. In *Proc. of Eurographics*, pp. 131–138, 1999.

J. Wilhelms and A. van Gelder. Octrees for Faster Isosurface Generation. ACM Transactions on Graphics, 11(3):201–227, 1992

Yagou et al., Mesh Smoothing Via Mean and Median Filtering, *Geometric Modelling and Processing*, 2002, pp. 124-131

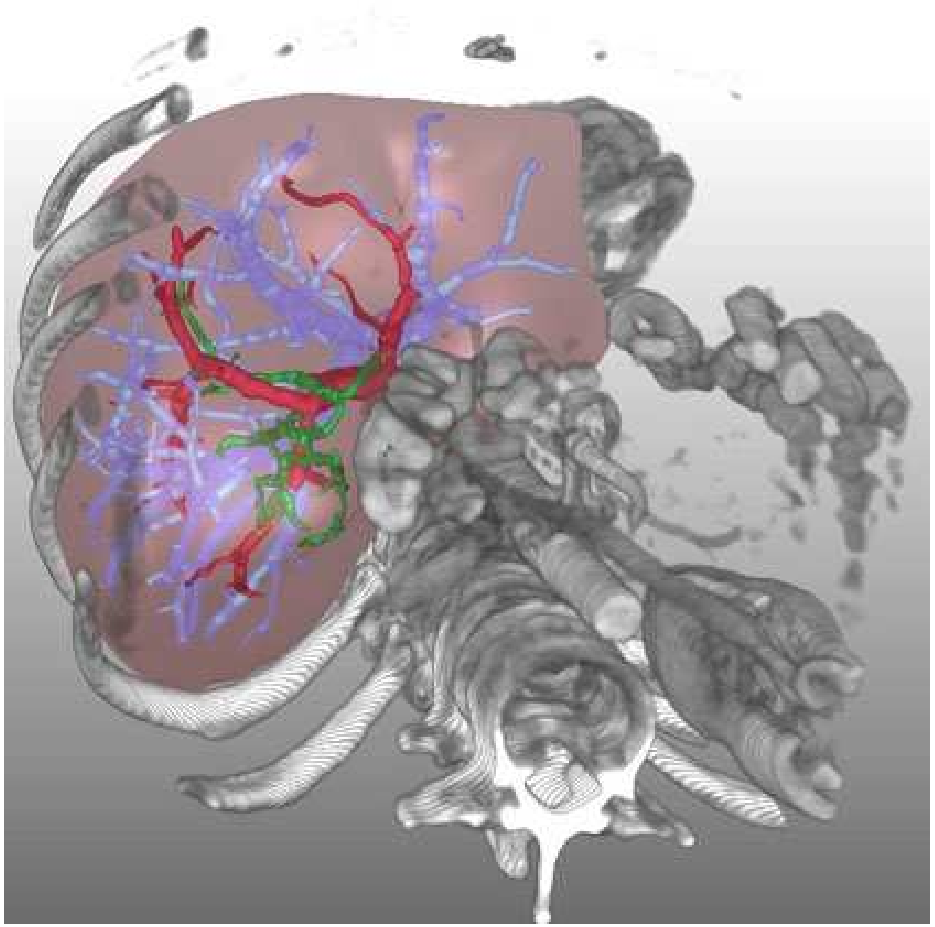
Overview:

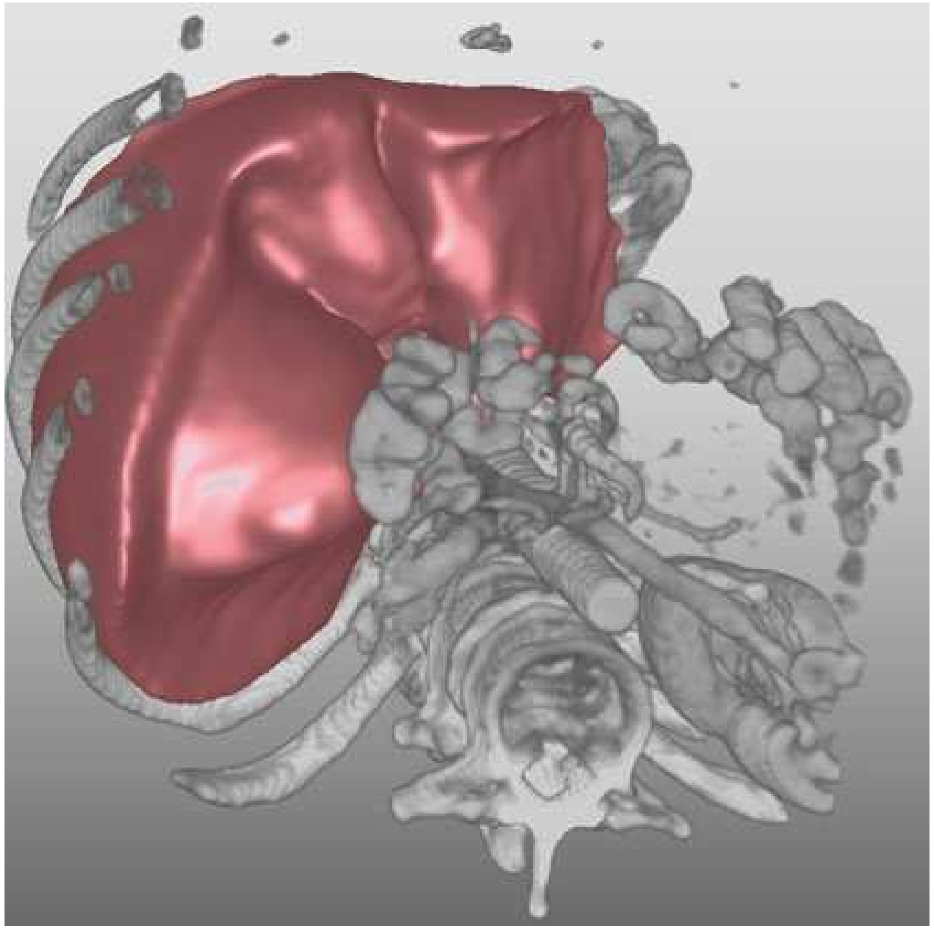
Gabriel Taubin. „Geometric Signal Processing on Polygonal Meshes“, *Eurographics, State of the Art-Report*

http://mesh.caltech.edu/taubin/publications/taubin-eg00star.pdf

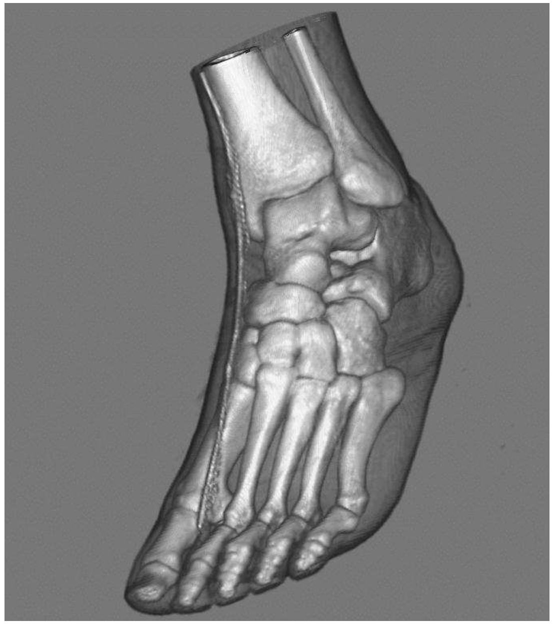
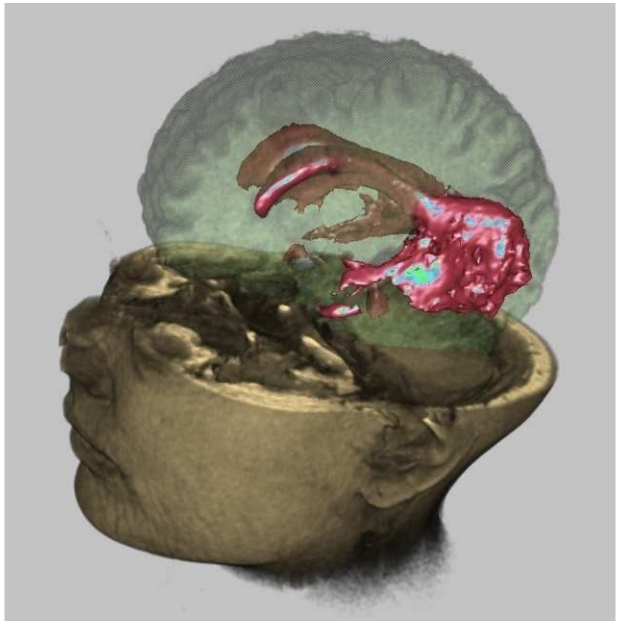
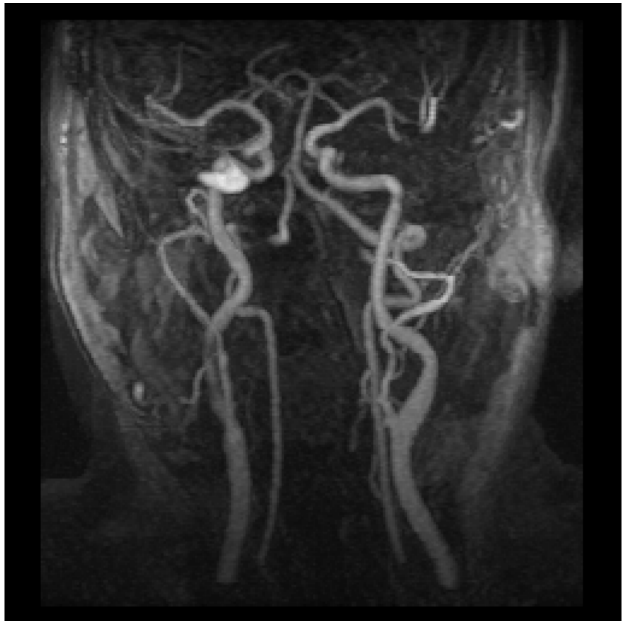
Surface Visualization: Examples

- Embedding of segmented objects (isosurfaces, strongly smoothed) into the anatomic context (DVR)





Direct Volume Visualization

Direct Volume Visualization: Structure

Direct Volume Visualization

- Introduction
- Image-based Volume Visualization
- Texture-based Volume Visualization
- Projection Methods

Direct Volume Visualization: Introduction

Requirements:

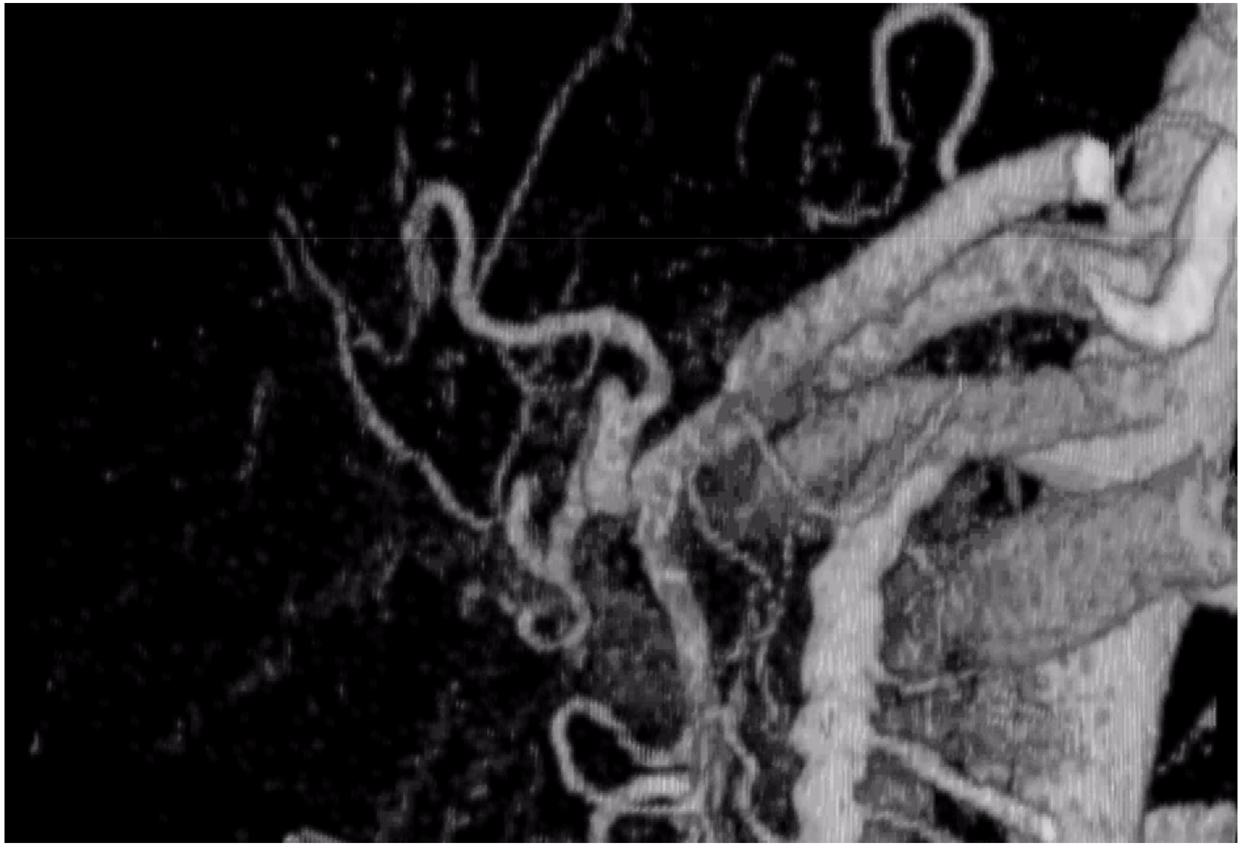
- detailed visualization of the original data (relevance for diagnostic and therapeutic purposes)
- Good rendition of the spatial relations (visual cues like shadows, highlights, depth cueing)
- Easy parameterization, ideally good defaults for all parameters
- High presentation speed
- Integration of surface and volume data (*hybrid rendering*)

Direct Volume Visualization: Introduction

DVR procedure for medical visualization:

- *Image-based procedures* which (re)trace a ray for each pixel in the scene and compound the colors/the grey value from the hit voxels (*back to front*), weighted with transparency
- *Object-based procedures* which sample the voxels and determine how the voxels contribute to the image (*front to back*), and (splatting, Westover [1990], Hanrahan [1991])
- *Texture-based procedures* which use a 3D texture memory and hardware support for the texture mapping.

Direct Volume Visualization: Introduction



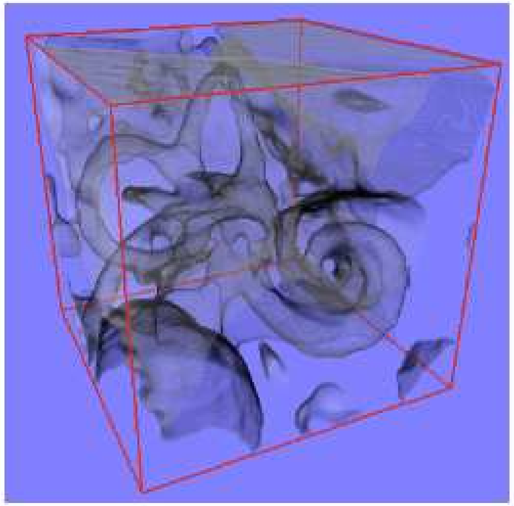
Volume rendering to evaluate liver vessels, Video by Christoph Wald, Lahey Clinic Boston

Direct Volume Visualization: Introduction

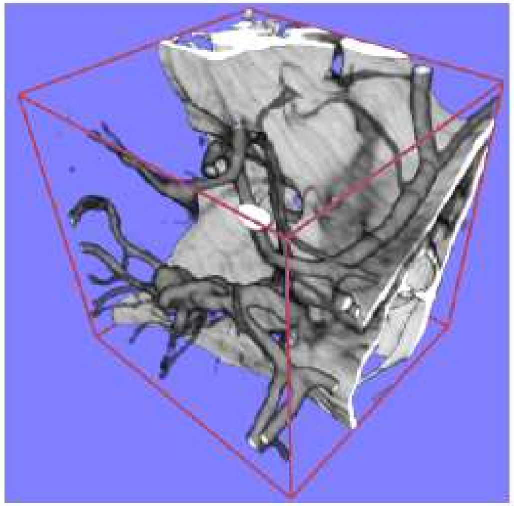
Examples:

Inner ear with HRCT: matrix: 512x512, thickness: 1 mm,
slice dist: 0.5 mm, 64 slices, resolution: 0.12 mm

Intracranial vessels, CTA: 512x512x256, resolution: 1 mm,
thickness: 1 mm



CT Inner Ear Detail
1 MB (128 x 128 x 64)



CTA Aneurysma Detail
2 MB (128 x 128 x 128)

What is typical?
- Many transparent or semi-transparent voxels

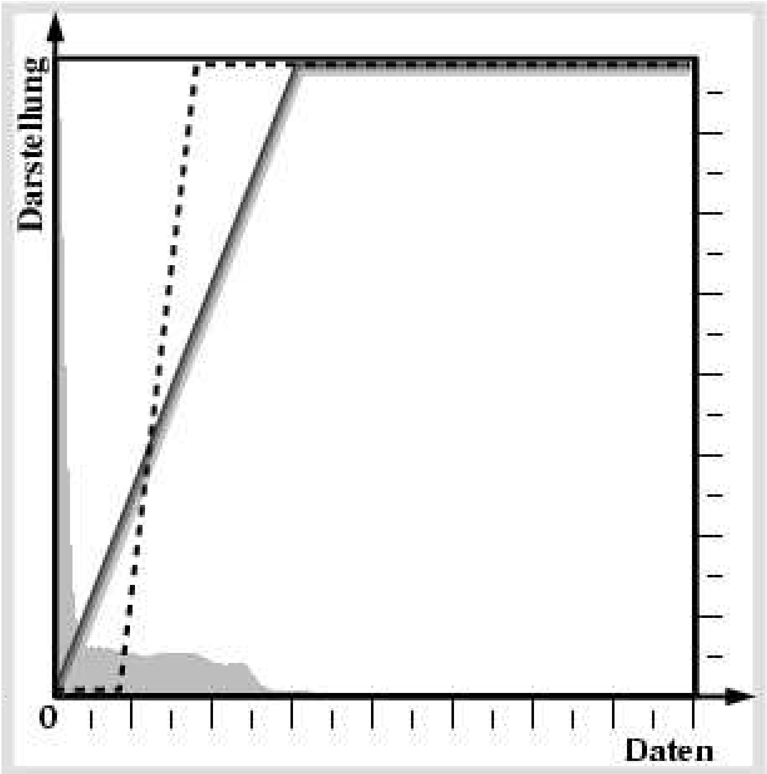
How is this specified?
- Through an appropriate transfer function

Source: Rezk-Salama, 2002

Direct Volume Visualization: Introduction

Setting of TFs for grey values and transparency (very often a linear function).

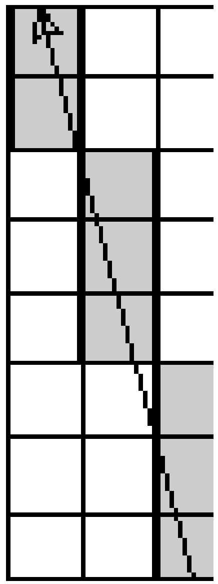
Histogram displayed as context in a graphic editor.



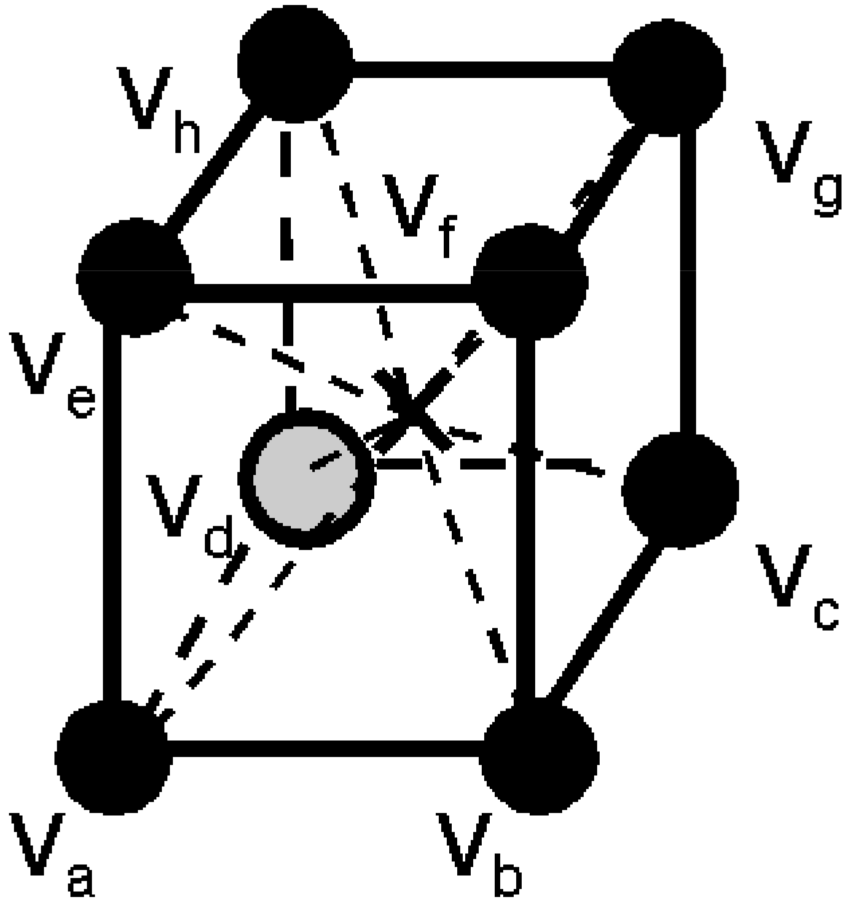
Source: Hastreiter, 1999

Direct Volume Visualization: Image-based Methods

- Pursuit of rays in the scene (ray casting)
- Per sampling point:
  - Rounding up to the next voxel (nearest neighbor)
  - Trilinear interpolation from the 8 surrounding voxels



Direct Volume Visualization: Image-based Methods



Trilinear interpolation

I(x): Intensity/density at the point x

$$
\begin{aligned}
I(V_p) = & \; I(V_a)\,(1-x_p)\,(1-y_p)\,(1-z_p) \\
& + I(V_e)\,(1-x_p)(1-y_p)\,z_p \\
& + I(V_b)\,(x_p)\,(1-y_p)\,(1-z_p) \\
& + I(V_f)\;x_p\,(1-y_p)\,z_p \\
& + I(V_c)\;x_p\,y_p\,(1-z_p) \\
& + I(V_g)\;x_p\,y_p\,z_p\,+ \\
& + I(V_d)\,(1-x_p)\,y_p\,(1-z_p) \\
& + I(V_h)\,(1-x_p)\,y_p\,z_p
\end{aligned}
$$

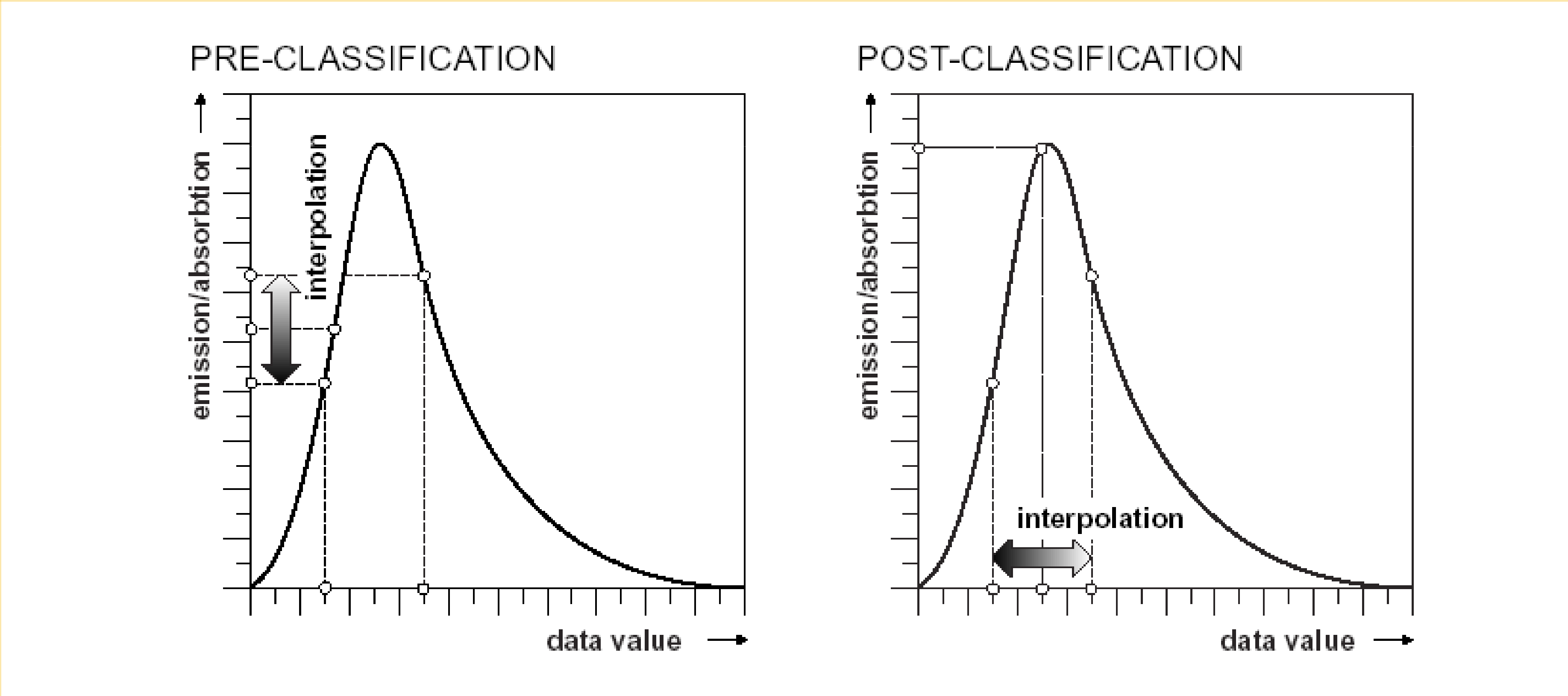
Direct Volume Visualization: Image-based Methods

Interpolation and application of the transfer function

- 1st variant: Application of the TF (classification) to all vertices near the filter (result: RGBA quadruple) and afterwards (tri)linear interpolation of these quadruples (p*re-classification*)
- 2nd variant: Interpolation of the intensity values from the data (e.g., Hounsfield Units) and afterwards application of the transfer function to the interpoled result (*post-classification*)

Problem of the first variant: Color perception is non-linear in RGB and interpolation for up to 4 channels. But this variant is very often supported through hardware lookup tables.

Direct Volume Visualization: Image-based Methods

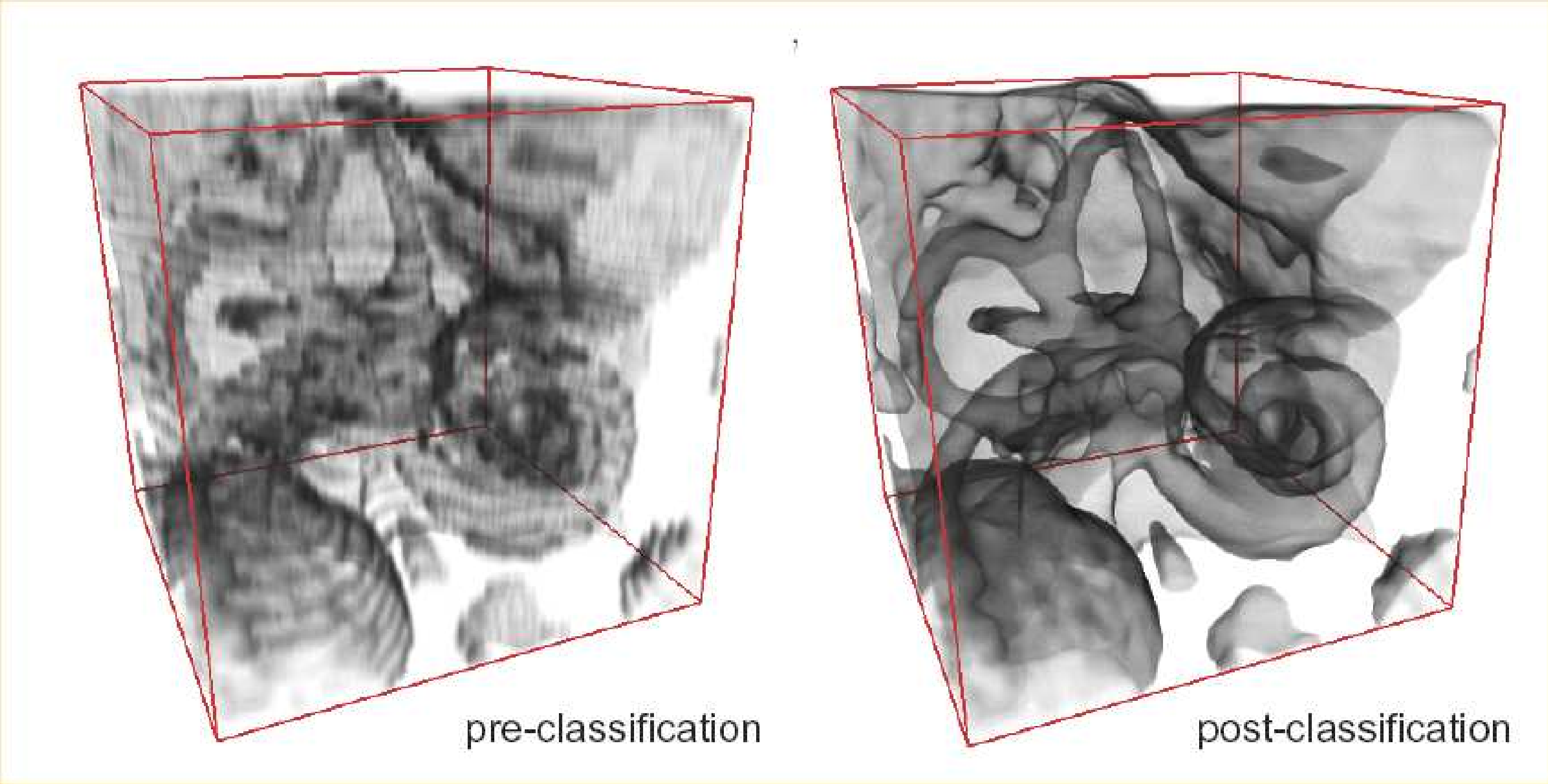


A late application of the TF is more precise!

Source: Rezk-Salama, Dissertation, 2002

Direct Volume Visualization: Image-based Methods

Interpolation and application of the transfer function



Source: Rezk-Salama, 2002

Direct Volume Visualization: Image-based Methods

Basic algorithm ray casting:

for y_i = 1 to ImageHeight
    for x_i = 1 to ImageWidth
      for z_i = 1 to RayLength
          foreach x_0 in ResamplingFilter (x_i, y_i, z_i)
            foreach y_0 in ResamplingFilter (x_i, y_i, z_i)
              foreach z_0 in ResamplingFilter (x_i, y_i, z_i)
                add contribution of Voxel [x_0, y_0, z_0] to ImagePixel [x_i, y_i]

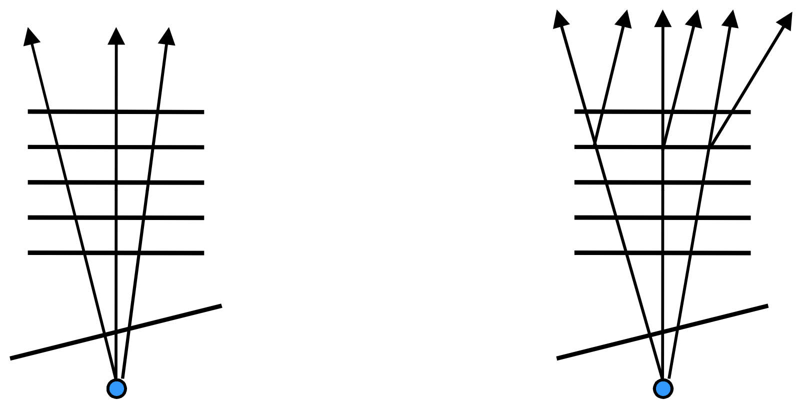
The resampling filter corresponds to the interpolation (often 2x2x2 values)

Problem: The volume is not traversed in the order in which it lies in the memory. Often, voxels which are not in the cache or in the central memory, are required.

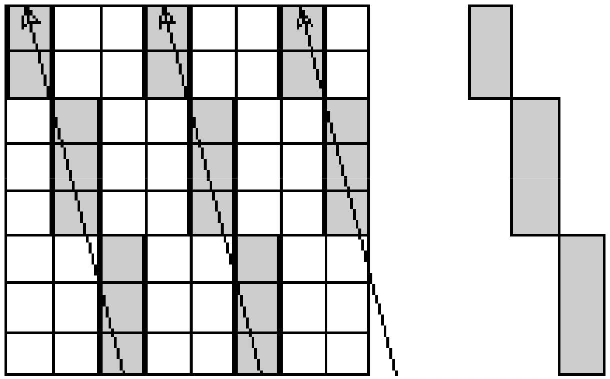
Direct Volume Visualization: Image-based Methods

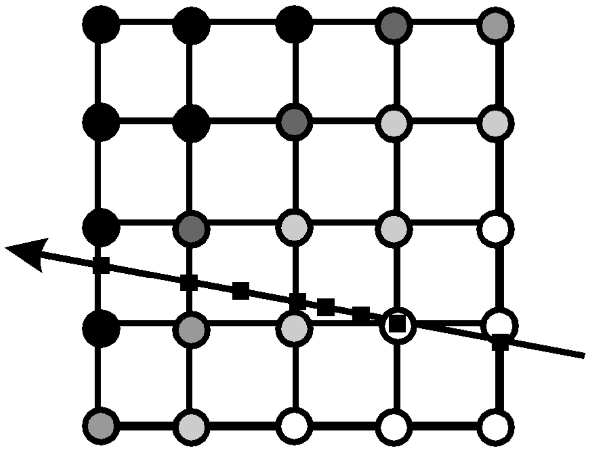
- Problem: consistent sampling of the volume in case of perspective projection (diverging rays)
- Possible solution:
  - Splitting of the rays
  - The ray integrates a broader area for slices that are further away

Image plane



Direct Volume Visualization: Image-based Methods



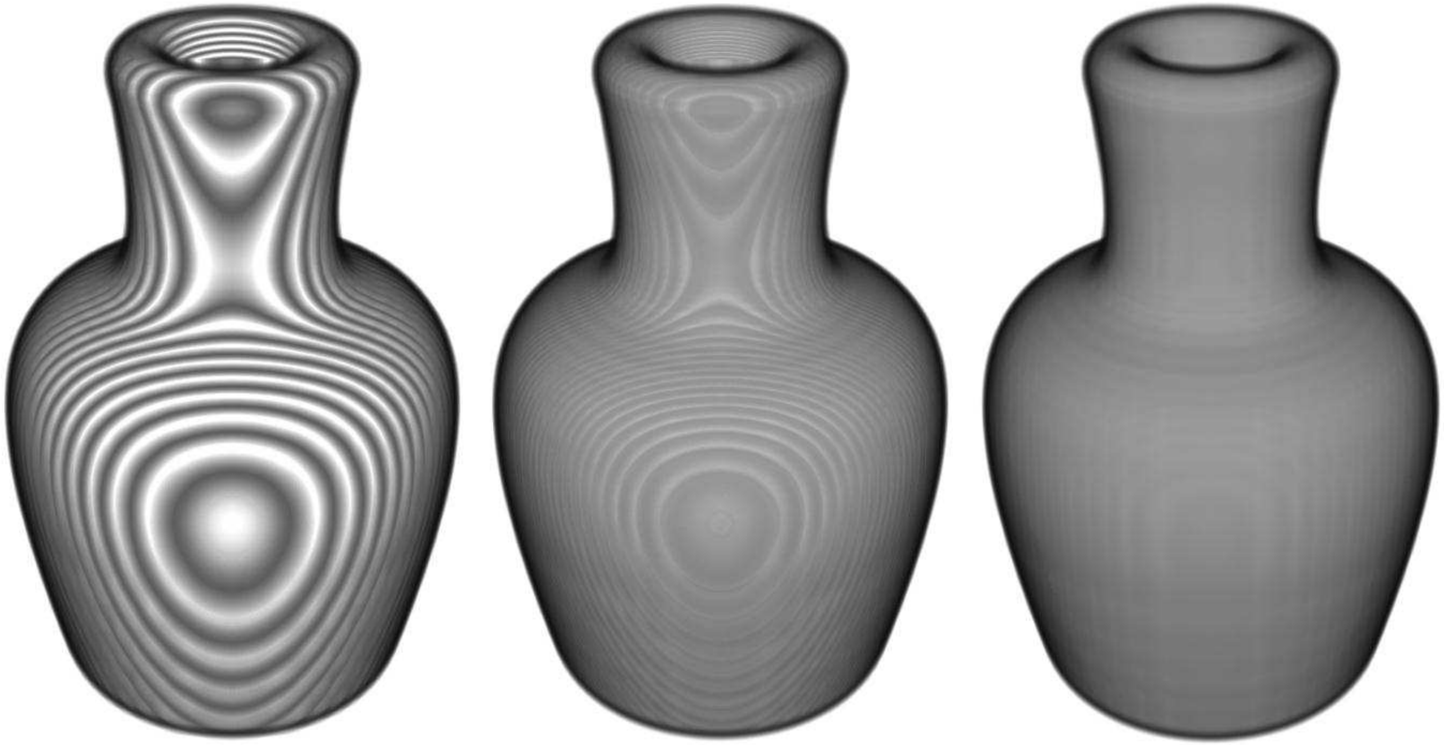


Methods of acceleration

- Ray templates in case of parallel ray casting (Yagel et al. [1992])
- Early ray termination (e.g., at 95% opacity, acceleration approx. factor 2) (Levoy [1990])
- Adaptive ray sampling (increase of the sampling rate in very transparent areas or with increasing distance) (Danskin, Hanrahan [1992])

Direct Volume Visualization: Image-based Methods

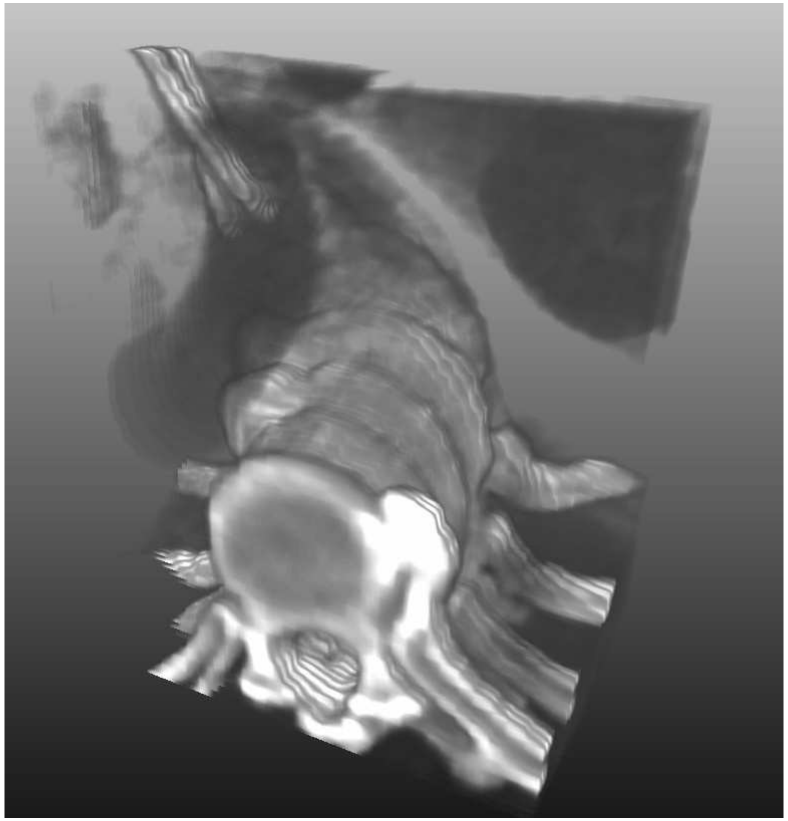
Influence of the sampling rate on alias effects (increment: 2.0 voxel, 1.0 voxel, 0.1 voxel), (© Schroeder et al. [1998])

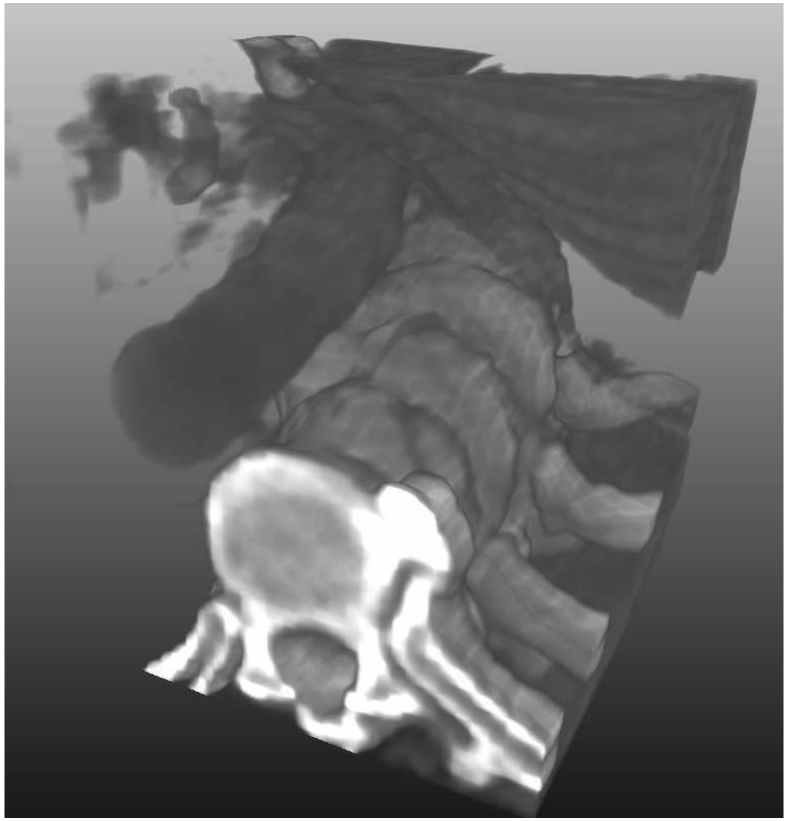


Suggestion: increment < 0.5 voxels (according to the sampling theorem: sampling at least with the double frequency which is present in the discrete data).

Direct Volume Visualization: Image-based Methods

Influence of the sampling rate on alias effects
(increment: 1.0 voxel, 0.2 voxels)





Direct Volume Visualization: Texture-based Methods

Volume Definition

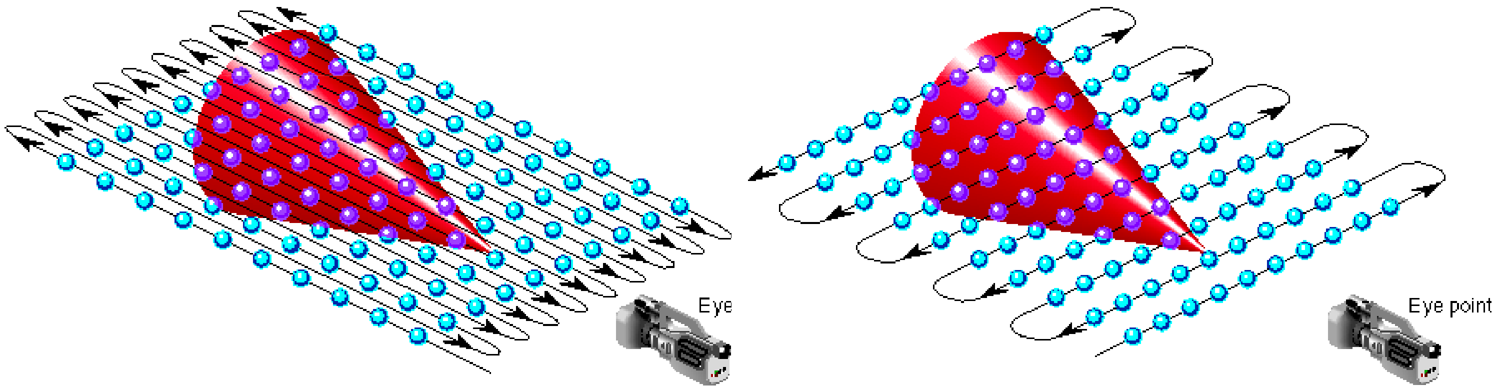
- The volume is loaded into the 3D texture memory.
- Application of a (hardware-based) lookup table, in which the data can be scaled and shifted and be mapped to RGBA values (transformation into an internal format)
- If volume > texture memory
  - partition of the volume into bricks
  - overlapping of the brick ends for a correct interpolation at the edges

Direct Volume Visualization: Texture-based Methods

Basic Approach:

- The volume is cut through equidistant planes
- Textured polygons are generated for each slice plane. They are drawn from back to front and overlaid semi-transparently.
- If volume > texture memory
  - sorting of the blocks according to the distance

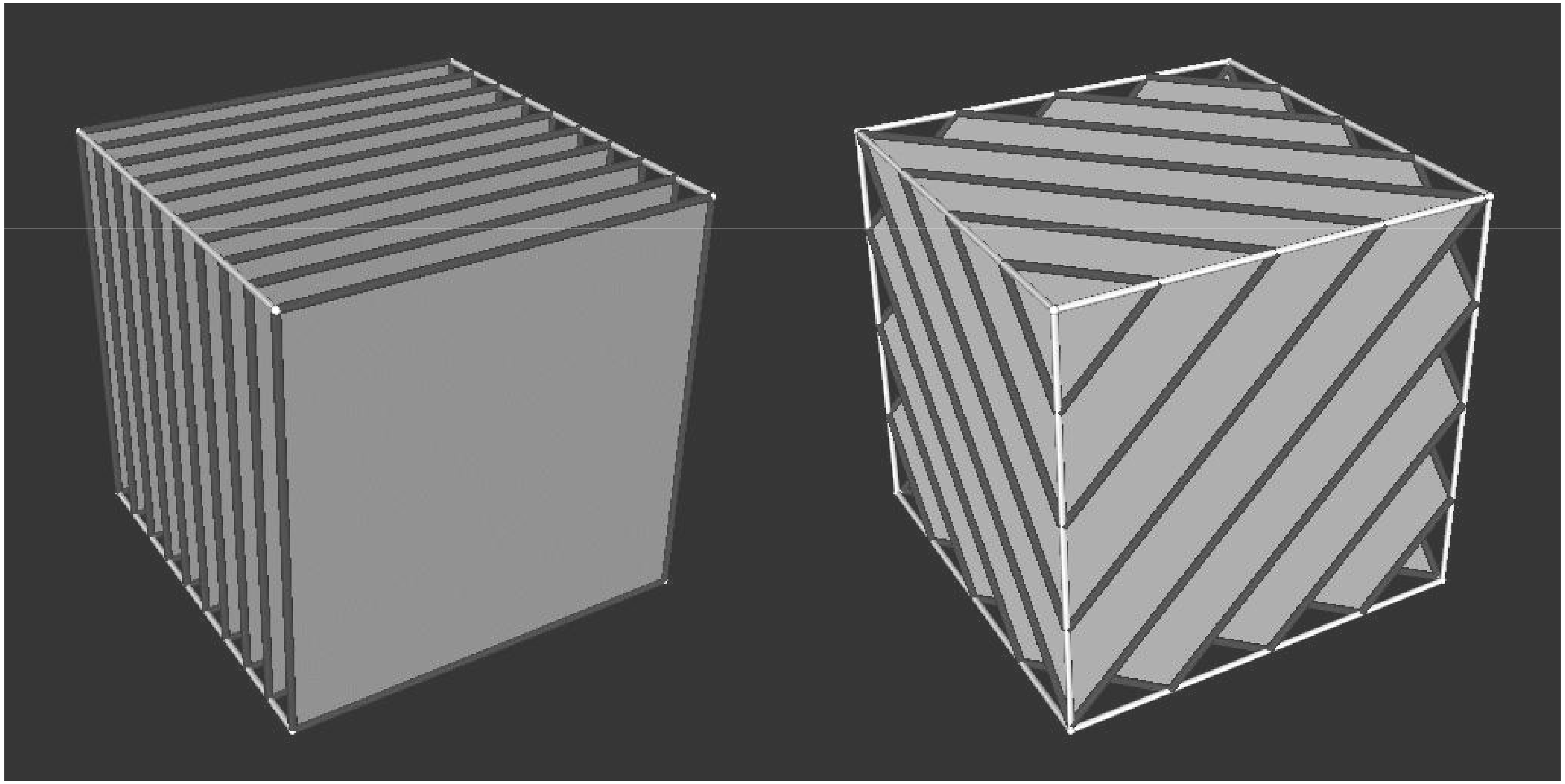
Direct Volume Visualization: Texture-based Methods



Source: Silicon Graphics

Comparison of the procedures of the image-based volume visualization (ray casting, left) and of texture based procedures (right)

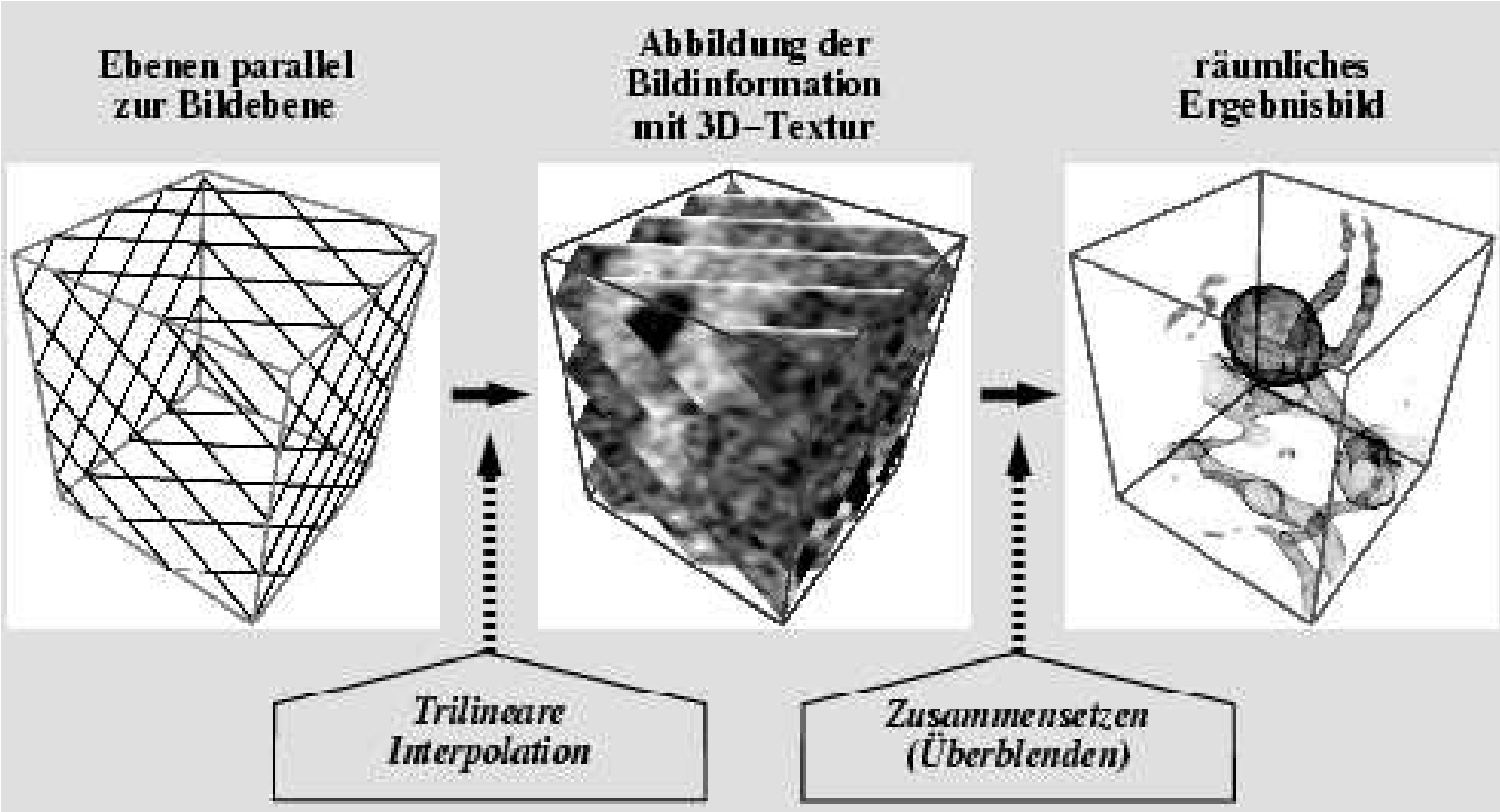
Direct Volume Visualization: Texture-based Methods



Source: Silicon Graphics

2D texture mapping and 3D texture mapping with sectional planes which proceed parallel to the view plane. (viewport-parallel)

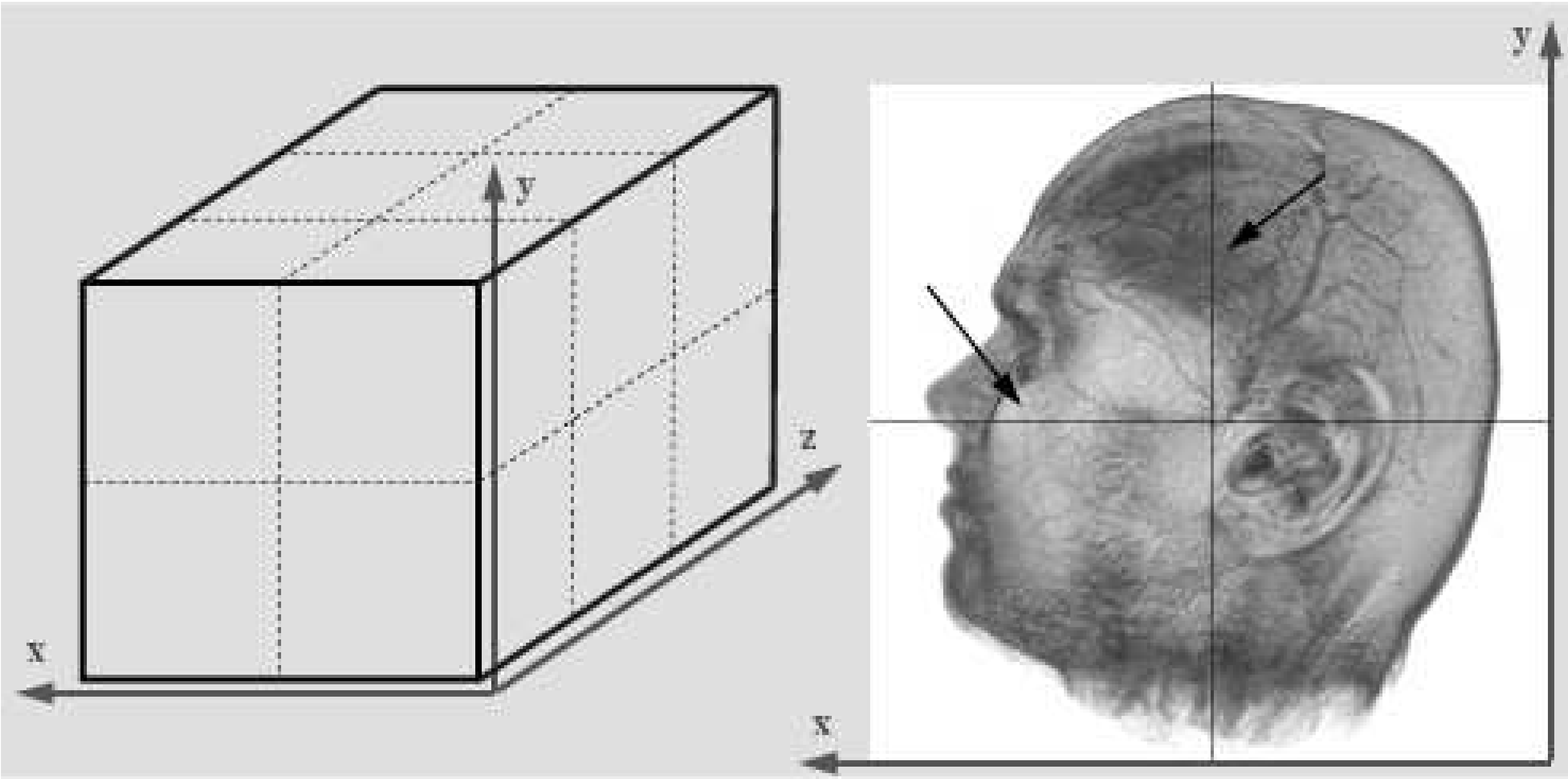
Direct Volume Visualization: Texture-based Methods



Procedure for the use of 3D textures
(© Peter Hastreiter, University of Erlangen)

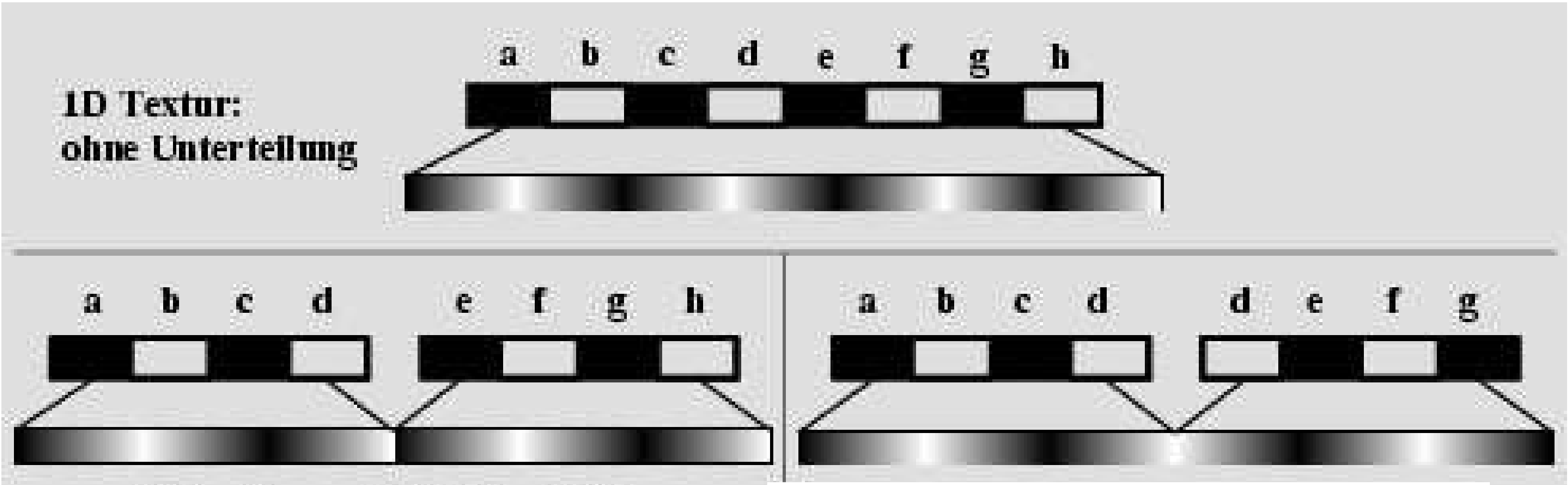
Direct Volume Visualization: Texture-based Methods

Division of the volume into bricks, artifacts (black stripes) in case of non-observance of the boundaries (© Peter Hastreiter, University of Erlangen)



Direct Volume Visualization: Texture-based Methods

Division into bricks. Thus, the data overlap about one voxel in each dimension and continuous transitions raise at the boundaries.



Wrong Subdivision

Correct Subdivision

© Peter Hastreiter, University of Erlangen

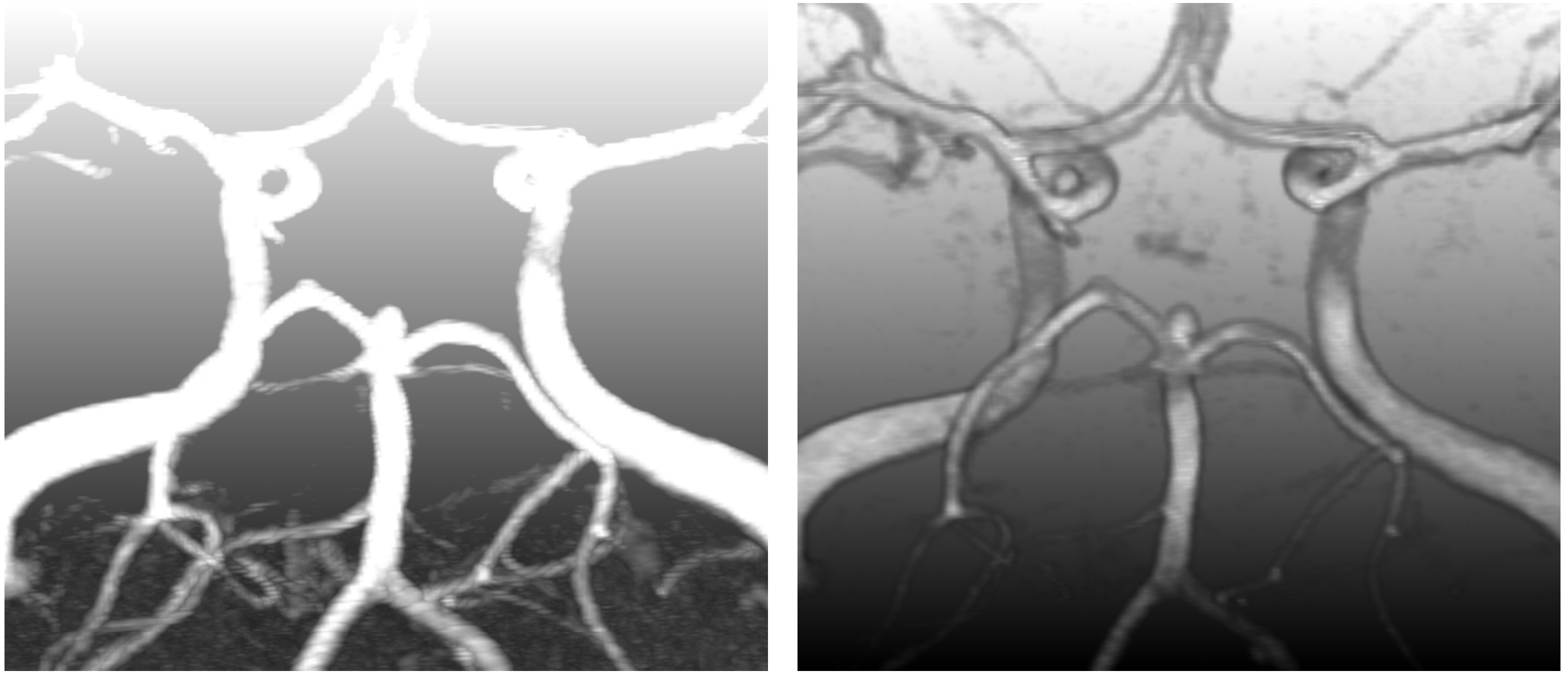
Direct Volume Visualization: Projection Methods

Average Projection	Average of all hit voxels per ray	Simulation of x-ray projections
Maximum (minimum) Intensity Projection (M(m)IP)	Brightest and (darkest) voxel hit per ray	Illustration of vessels, noise-added data
Closest Vessel Projection (Zuiderveld [1995])	First hit voxel per ray above a threshold	Illustration of vessels

Direct Volume Visualization: Projection Methods

MIP (Data: MR angiography)

Direct Volume Visualization: Projection Methods



Comparison of MIP and DVR, cerebral vessels, purpose: diagnosis of aneurysms (Data: MR angiography, Prof. Terwey, Bremen)

Direct Volume Visualization: Projection Methods

Restriction of the data on which a MIP is applied:

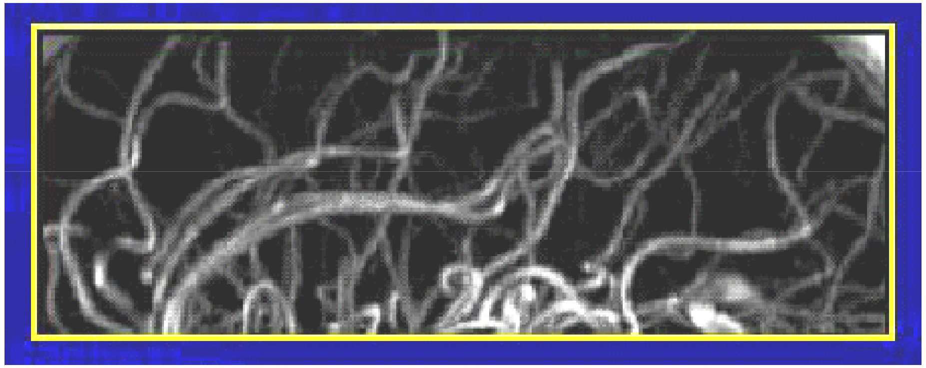
(1) Remove certain structures which disturb the MIP interaction.

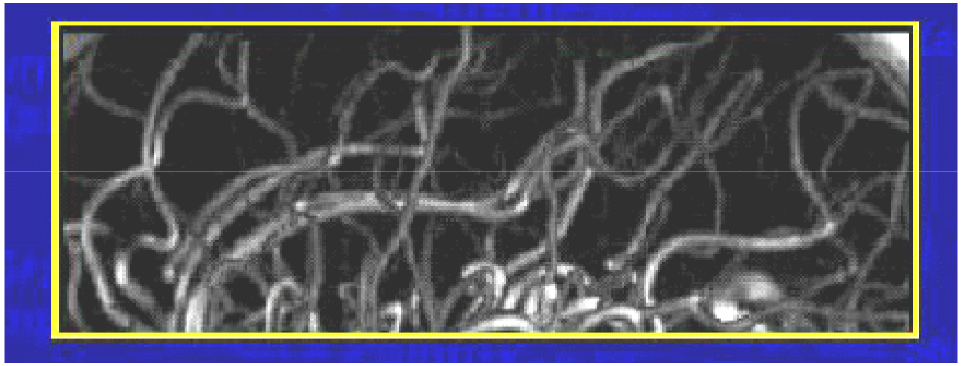
Example: Removal of bones (interactively by placing a seed point and Region Growing).

(2) Apply the MIP to a certain partial volume.

Example: MIP illustration in a segmented organ for the selective evaluation of this organ

Direct Volume Visualization: Projection Methods





MIP and CVP of brain vessels (© Karel Zuiderveld)

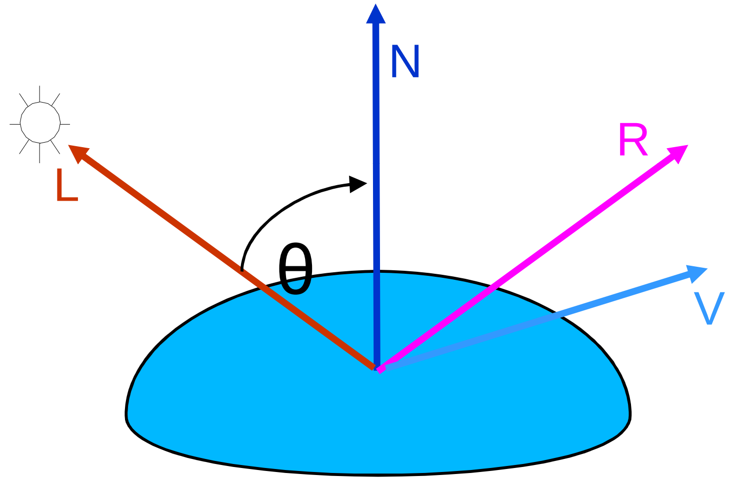
To evaluate spatial relations, movies with rotations of MIP and CVP in a central perspective are often used.

Direct Volume Visualization: Projection Methods

Thin-Slab-MIP

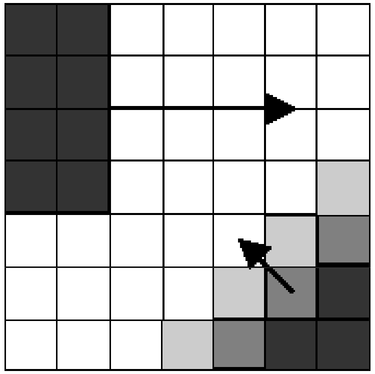
Direct Volume Visualization: Lightning

- Angle of incidence θ: angle between *L* and *N* (determines the diffuse reflection)
- Reflection angle *r*: angle between *R* and *N*.
- Angle *Φ* between *V* and *R* determines the intensity of the incident light.
- If *V* = *R* (respectively *Φ* =0), the light is reflected maximal to the viewer.



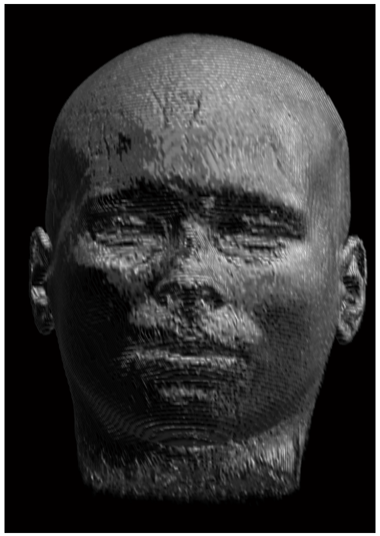
L-Light Vector
N-Surface normal
R-Reflected Light Vector
V-View Vector

Direct Volume Visualization: Lightning



- Approximation of the surface normal by calculating the gradient (grey level gradient shading, Source: Höhne and Bernstein [1986])
- Problem: Memory requirements:4 Byte * 3 per voxel
- Indirect storage of the normals as indices in a field of normalized vectors (rounding)

  → Discretization of the normal in a gradient lookup table

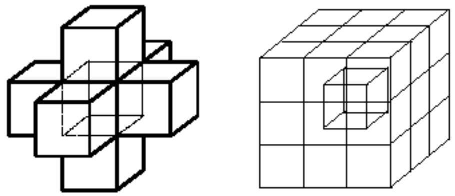


- Illuminated illustration of an MRT data set
  (high sampling rate and trilinear interpolation)

Problems:

- High noise sensibility (possibly smooth gradients) or ignore small gradients (use the threshold value)
- No consideration of the gradient strength

Direct Volume Visualization: Shading



Common variants of gradient estimation:

(1) central differences (6 neighbors):

$$\nabla V(X) = (\partial V/\partial x, \partial V/\partial y, \partial V/\partial z)$$

$$\nabla V(x_i, y_j, z_k) = (\tfrac{1}{2}\ (V(x_{i+1}, y_j, z_k) - (V(x_{i-1}, y_j, z_k)),$$
$$(\tfrac{1}{2}\ (V(x_i, y_{j+1}, z_k) - (V(x_i, y_{j-1}, z_k)),$$
$$(\tfrac{1}{2}\ (V(x_i, y_j, z_{k+1}) - (V(x_i, y_j, z_{k-1}))\ )$$

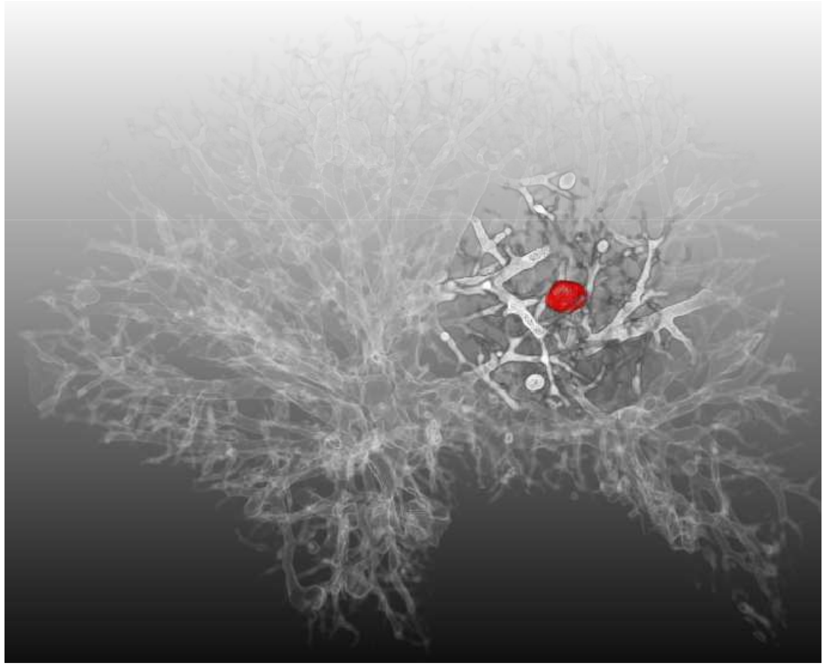
(2) Gradient estimation of from the 26 neighbors (weighting according to the distance from the central voxel)

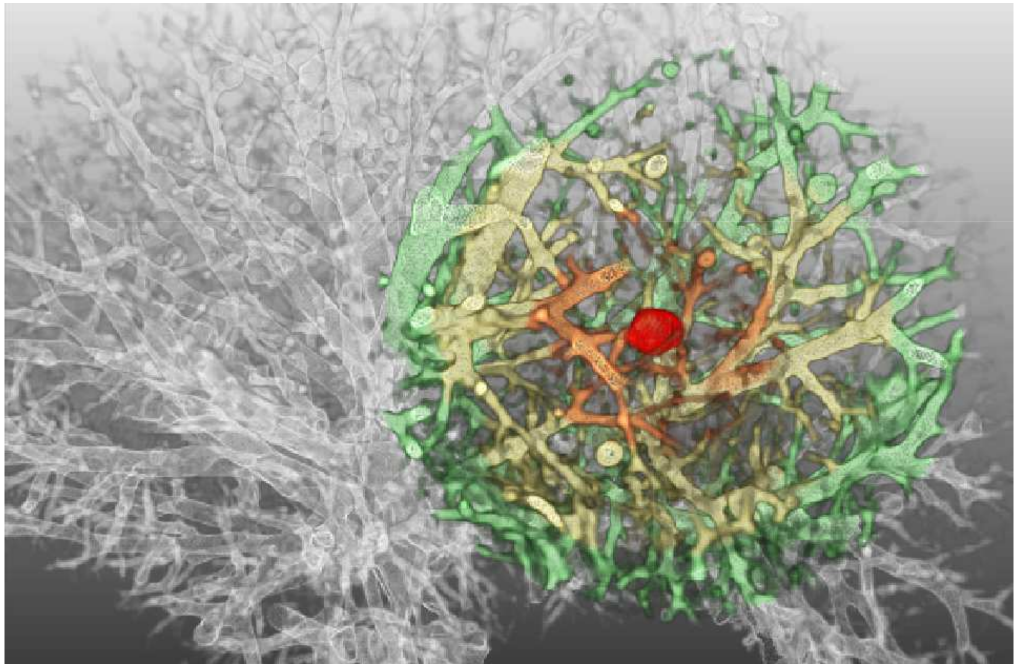
(3) Gradient calculation, not from direct neighbors, but from $x_{i+2}, x_{i-2}, y_{i+2}, y_{i-2}, z_{i+2}, z_{i-2},$

The second variant is more complex than the first one, but qualitatively better.

Problems: treatment of boundaries, line structures

Direct Volume Visualization: Tagged VR





Tappenbeck [2006]

Segmentation: Tumor

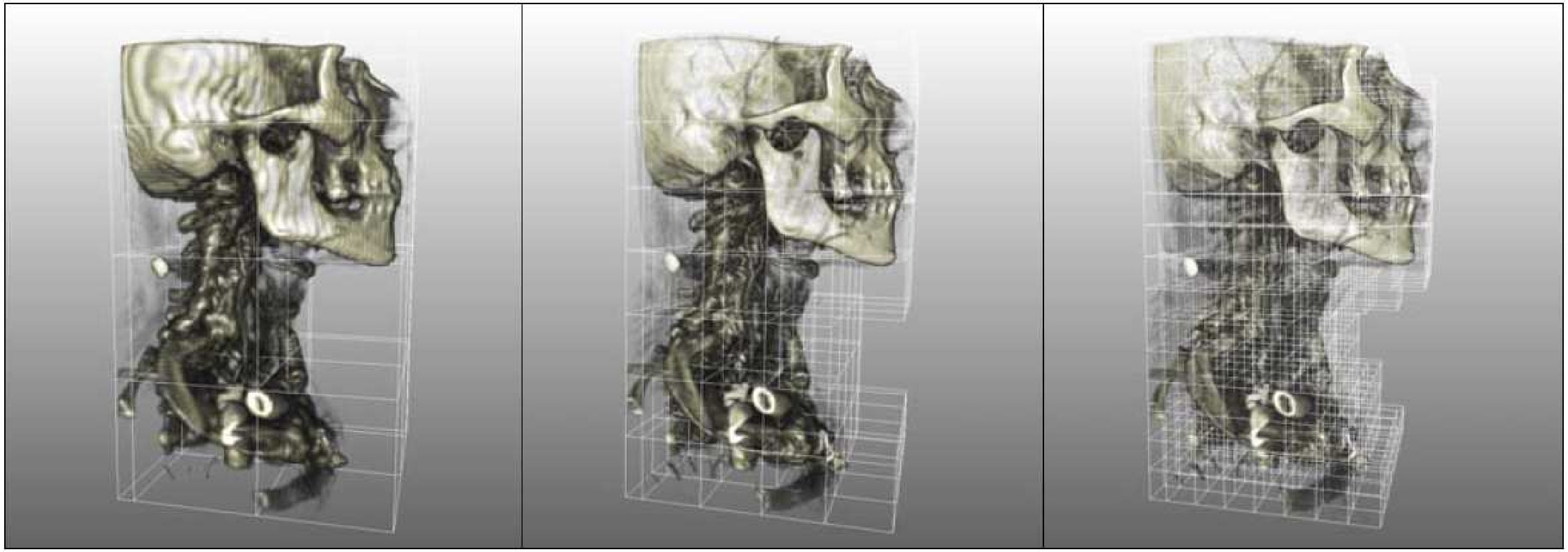
Visualization: Distance-based TFs (distance to tumor mapped to opacity and color)

Direct Volume Visualization: Hierarchical Methods

- Goal: restrict rendering to visible portions and/or importance
- Typical data structure: Octree
- Node size, 16x16 …. 64x64
- Requires resampling, e.g. by means of a rank filter
- Overlap of the nodes for correct interpolation (1 voxel)
- Moderate additional memory load

Direct Volume Visualization: Hierarchical Methods

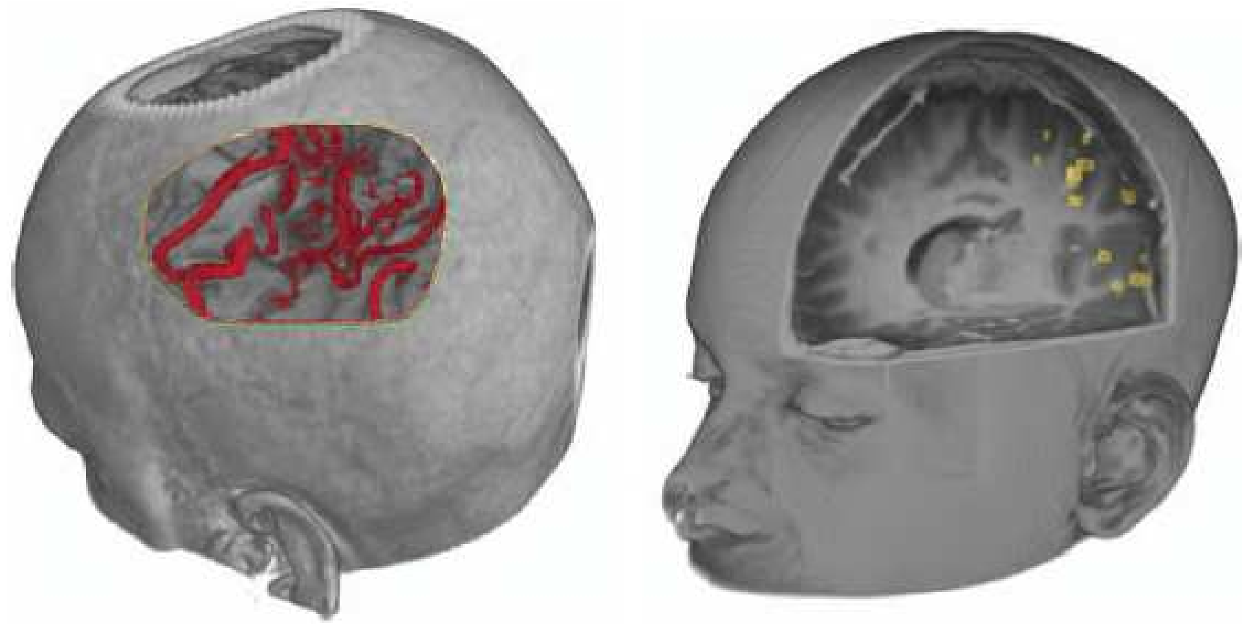
- Octree nodes are rendered back to front
- Order of nodes depends on the viewing direction
- Lower resolution may be used for interactive rendering



Link [2006]

Multivolume-Rendering

- **Integration of multiple volumes**
- **Registration of the datasets**
- **With advanced acquisition, such as PET/CT direct overlay**

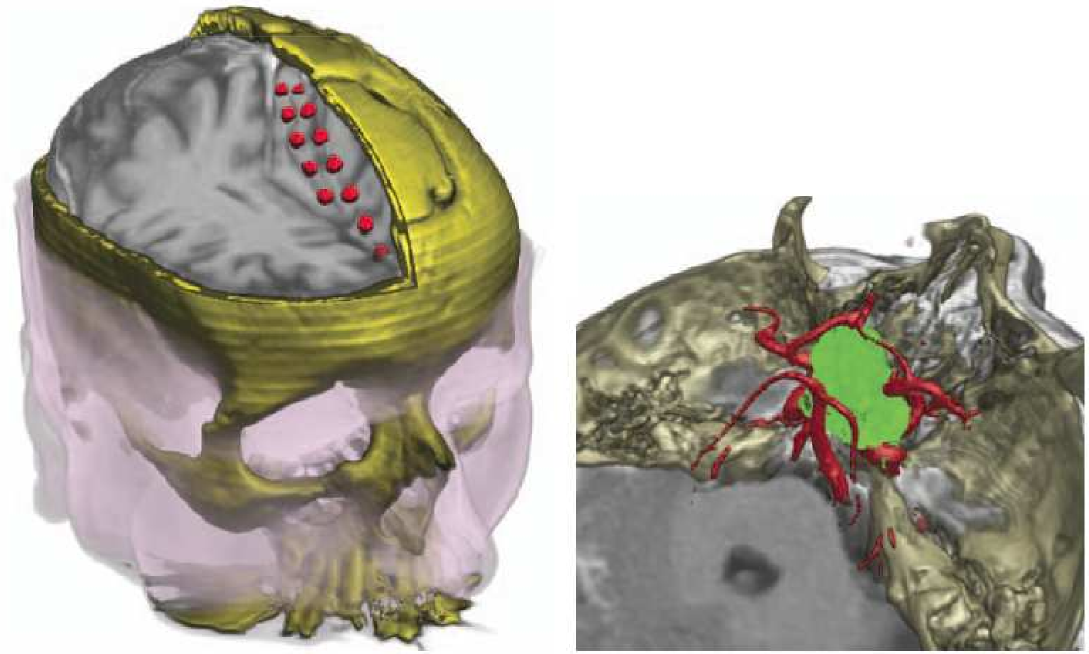


Fusion of MRI- and DSA data (left)

Fusion of MRI and fMRI activation data. Beyer [2007]

Multivolumerendering

- **Challenges: Performances and correct depth-sorting**



(a) (b)

CT and MR data for visualization of implanted electrodes for epilepsy surgery.
CT, MR and MRA data for tumor resection planning. Beyer et al., 2007

Direct Volume Rendering: Combining MIP and DVR

Goal:

To provide expressive volume rendering which is easily parameterized, like MIP

Idea:

Modify the MIP scheme by analyzing *each* maximum along the viewing ray

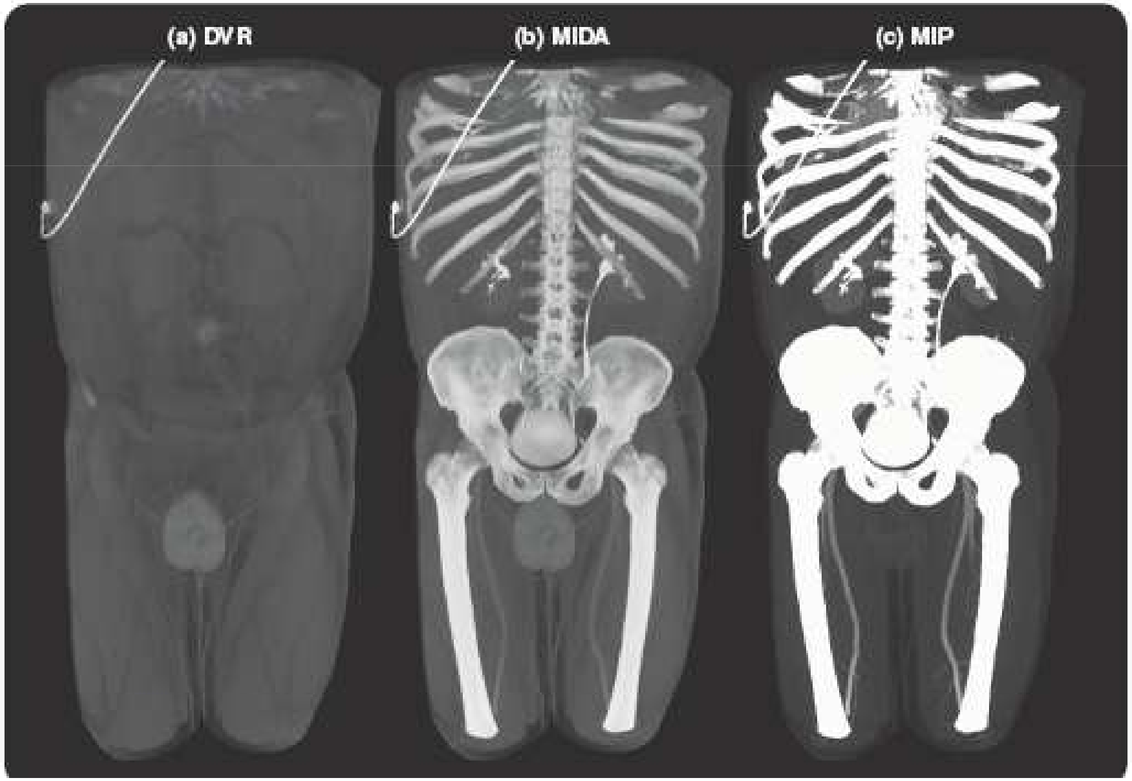
Each Maximum contributes to the intensity in a way proportional to the difference to the previous maximum

Application:

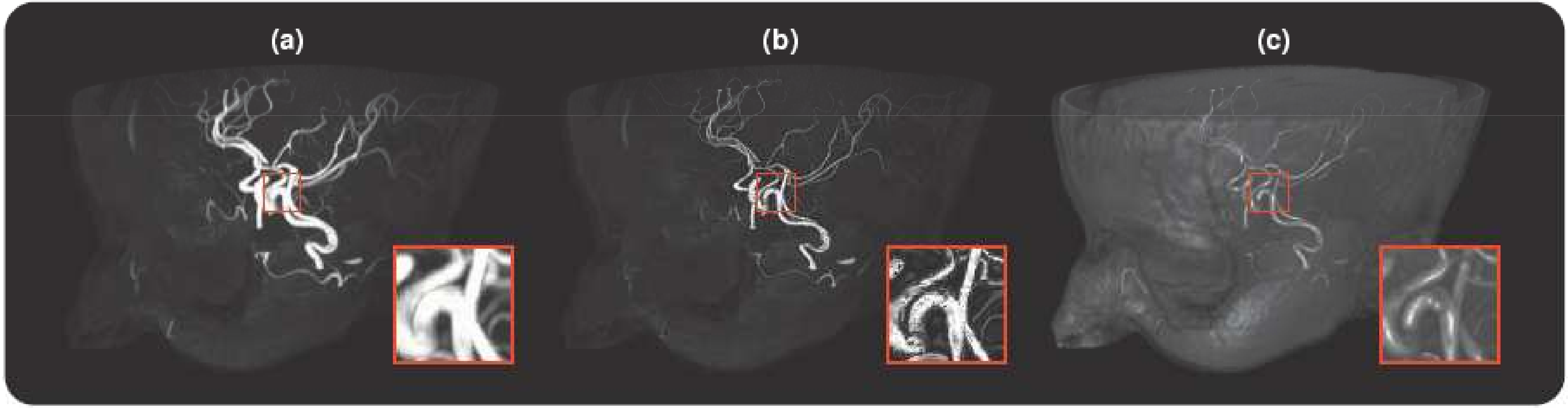
Broadly applicable, strong effects for vascular structures

- **Bruckner, et al. [2009]**

Direct Volume Rendering: Combining MIP and DVR

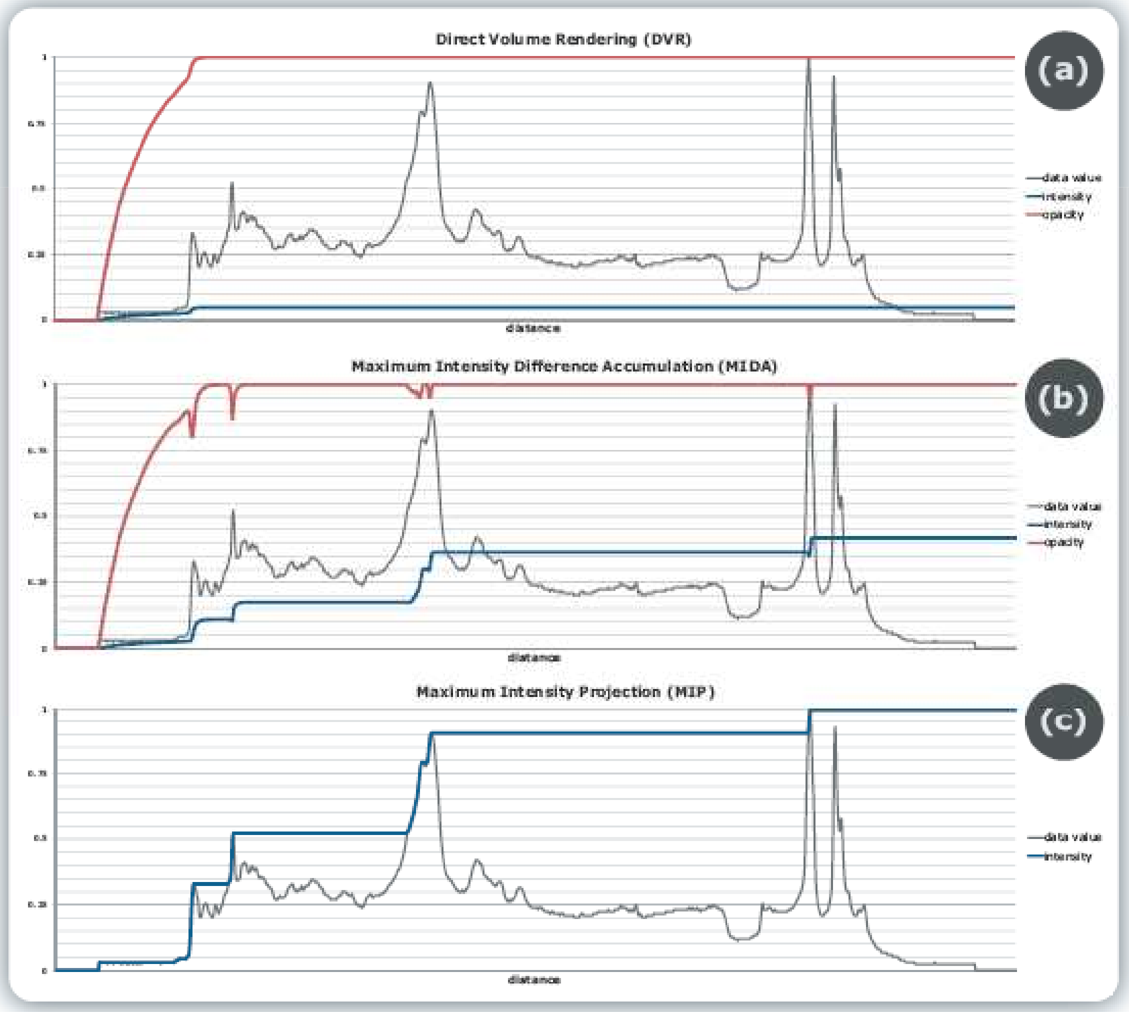


Comparison of DVR, MIDA and MIP [Bruckner/Gröller, 2009]



Cranial MRI angiography rendered using (a) MIP without shading, (b) MIP with gradient-based shading, and (c) MIDA with gradient-based shading. [Bruckner/Gröller, 2009]

Direct Volume Rendering: Combining MIP and DVR



Validation in Medical Visualization

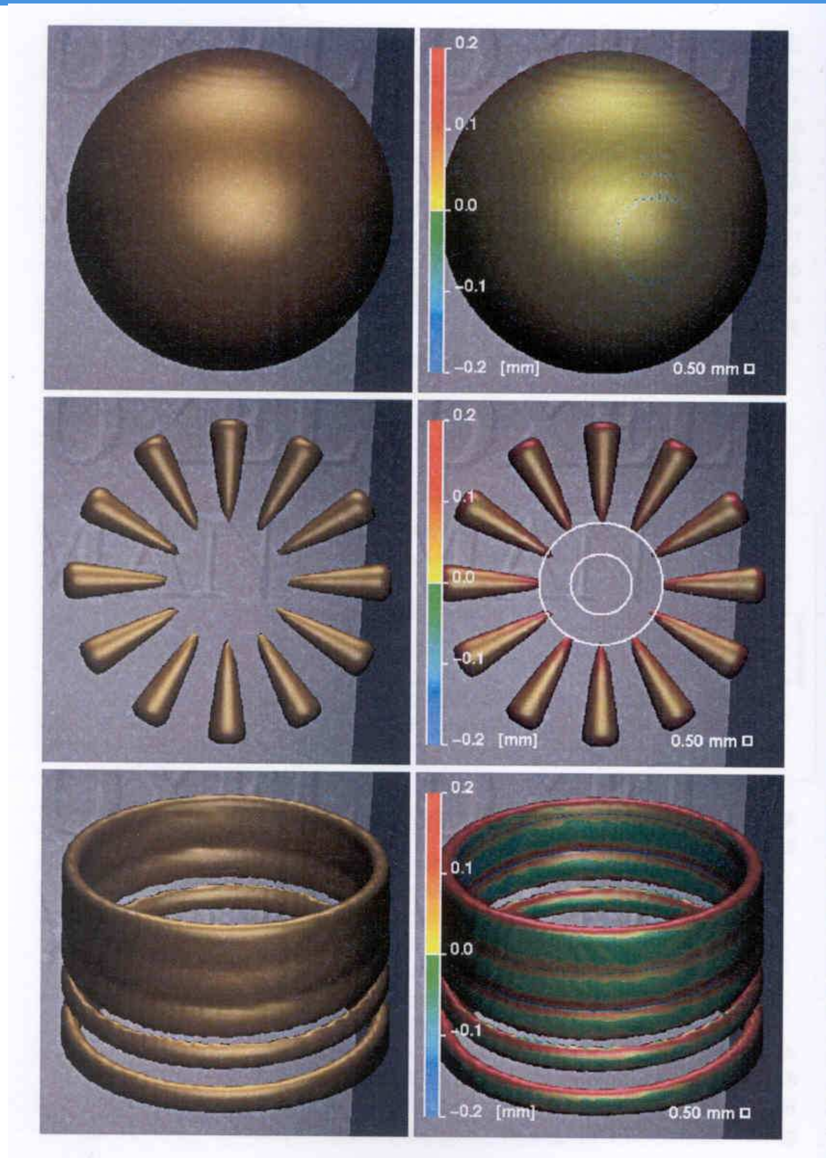
- Accuracy of the generated visualizations (with given image data) depends on a variety of parameters:
  - type and parameter of the interpolation
  - distances of the sampling points
  - gradient filters, …

Validation in Medical Visualization

- Essential parameters of accuracy:
  - Position fault: distance between a displayed point (e.g., border between 2 materials) and its precise location
  - Fault of normals: deviation of the approximated normal from the actual normal (angle in degree)
- How can accuracy be evaluated?
  - Qualitatively through the viewing of pictures. Problem: An exact solution is unknown.
  - Quantitatively through the volume visualization of phantoms: exact results are known. Problem: Transferability to clinical data.

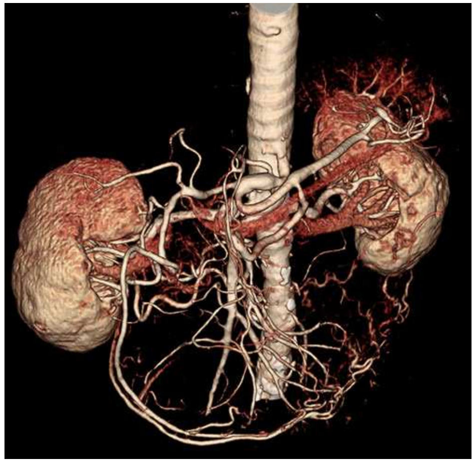
Validation in Medical Visualization

- Test piece: ball, SIEMENS star, and disconnected cylinder.
- Left: surface visualization.
- Right: volume visualization after discretization (1 mm³). Color coding of the arising position faults.

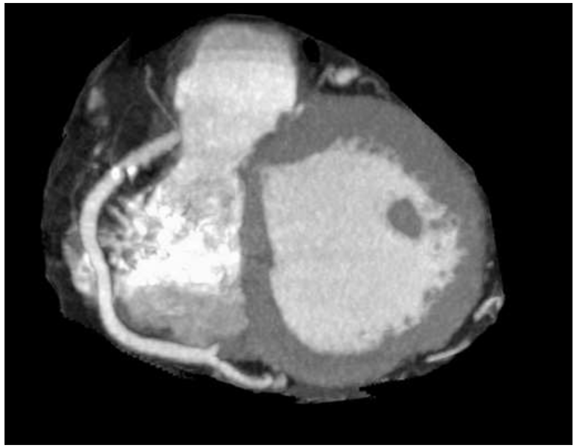


© Pommert [2004]

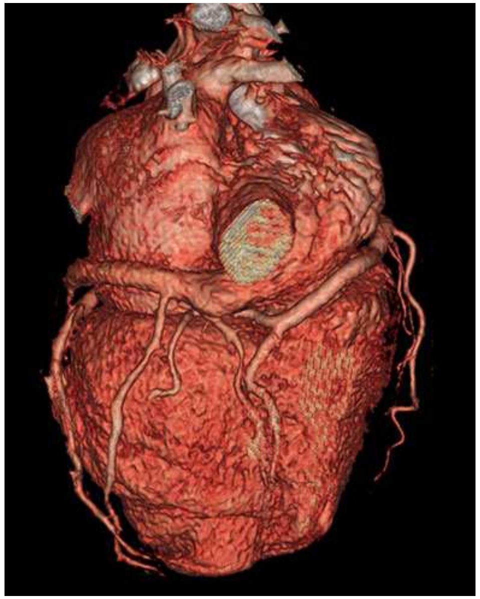
Tools for Volume Visualization: Volume per 1000 – Image Gallery

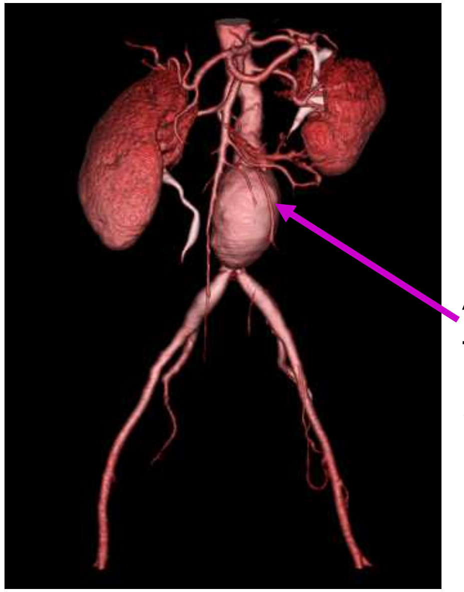


CTA of the abdominal vessels

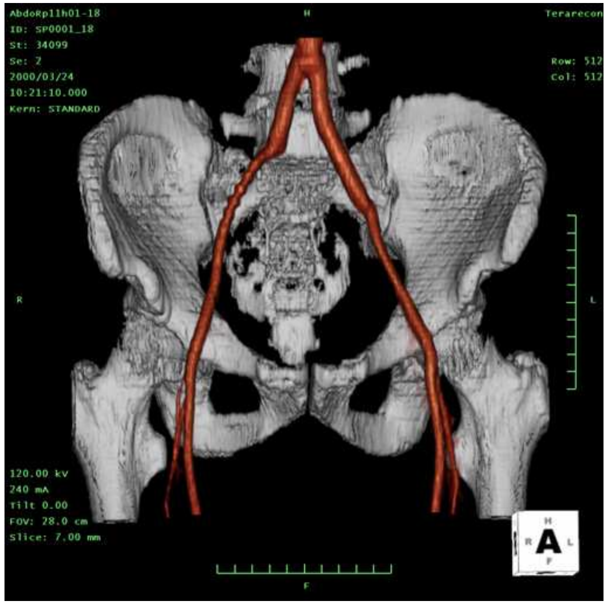


MIP restricted to a subvolume (slab)
Data: Cardiac CTA



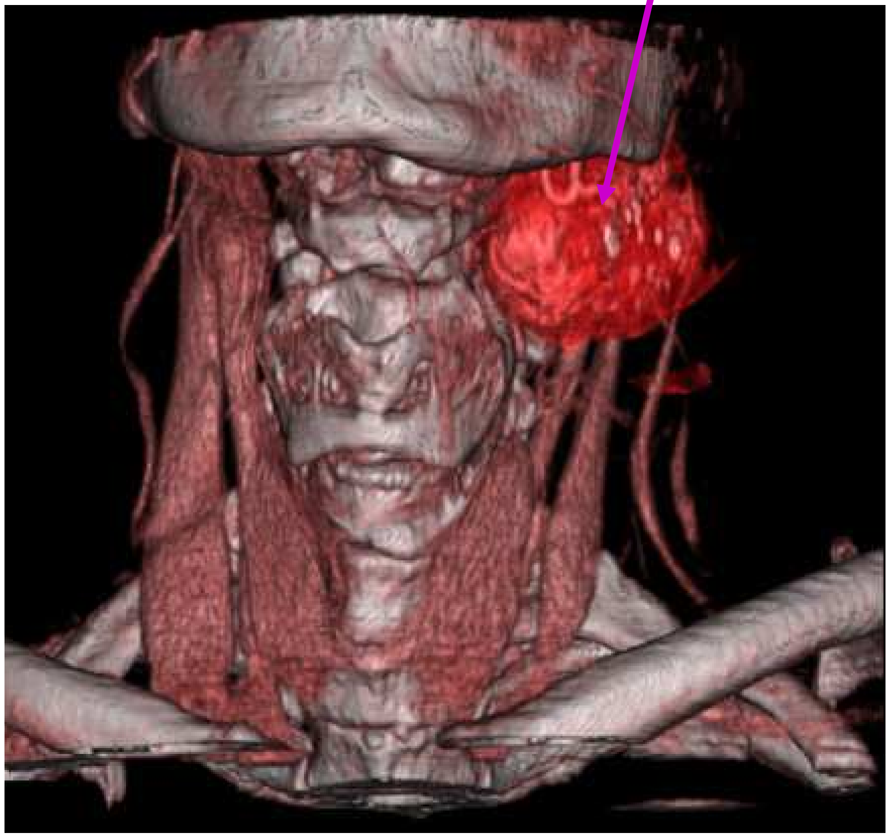


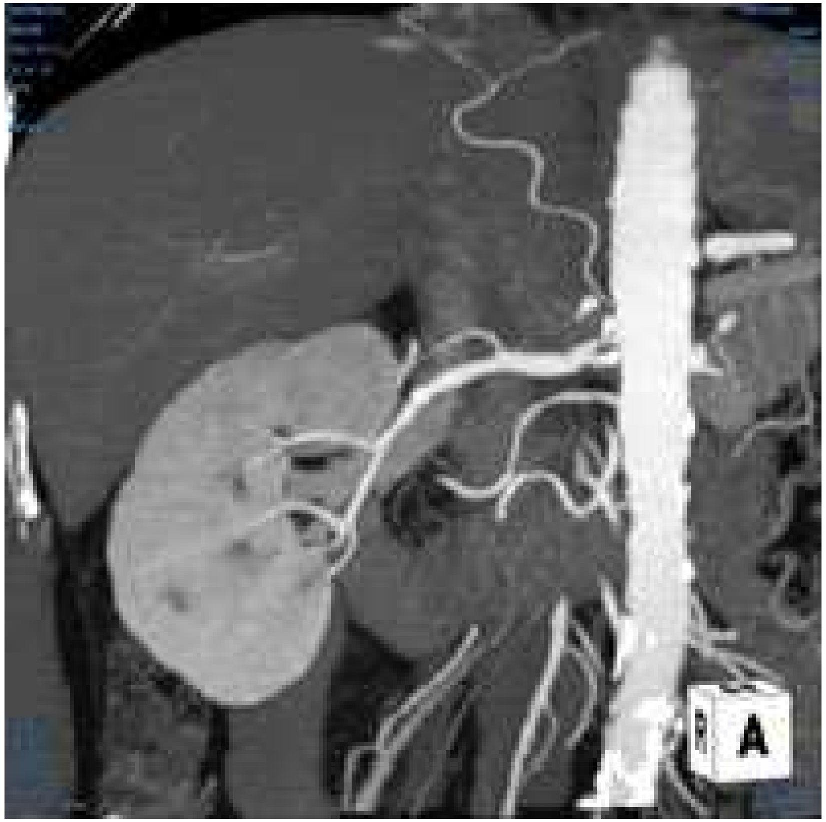
Aneurysm of the abdominal aorta



Tools for Volume Visualization: Volume per 1000 – Image Gallery

tumor in the neck area





MIP illustration of the kidney (vessels)

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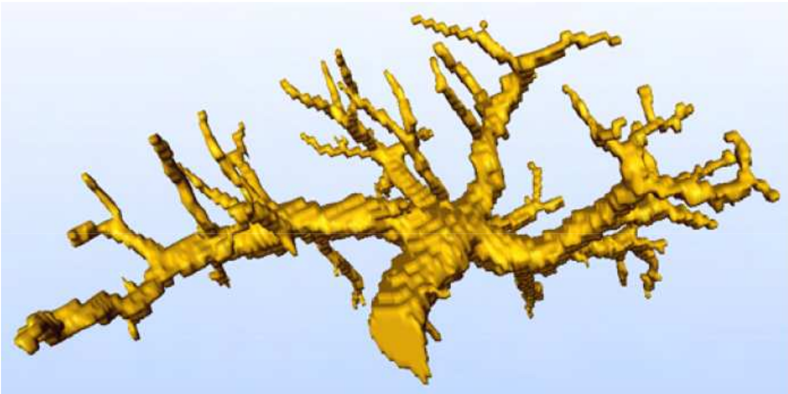
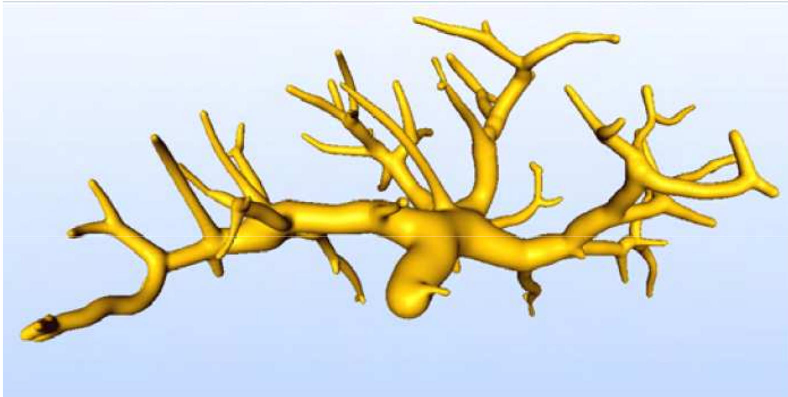
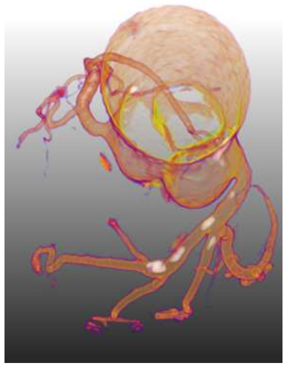
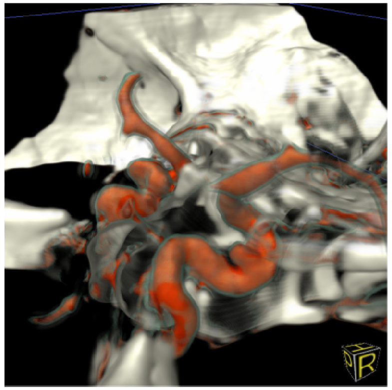
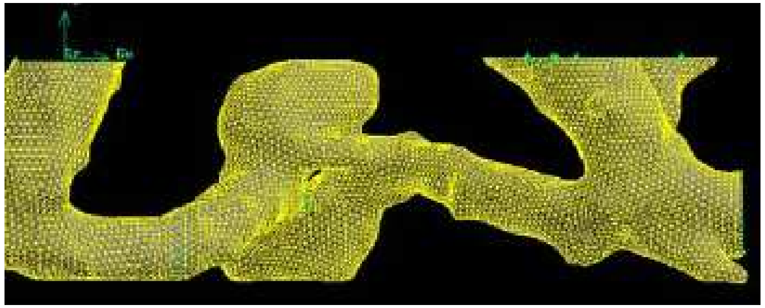
Visualization of Vascular Structures

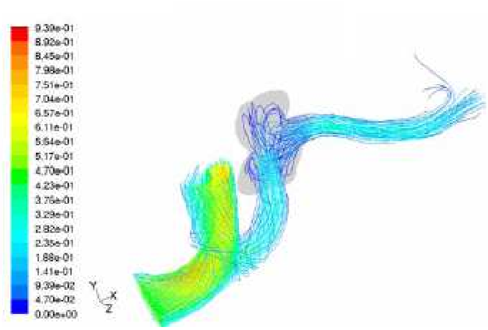












Outline

- Methods for 3D Visualization of Vasculature
- Direct Volume Rendering
  - Tagged volume rendering of coronaries
- Model-free Surface Visualization
- Model-based Surface Visualization
  - Explicit Construction of Vascular Geometries
  - Implicit and Parametric Methods
- From Vascular Surface Geometry to Simulation Models

"Traditional" Visualization Approaches

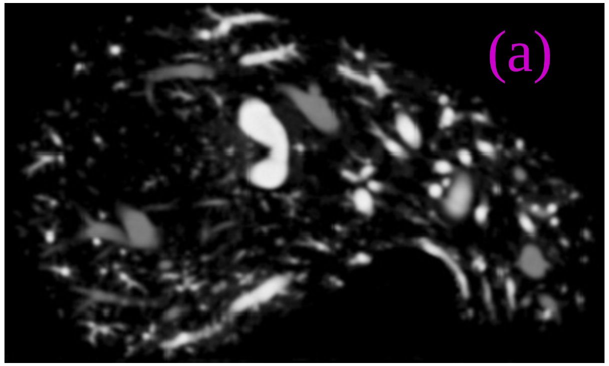
- Traditional approaches:

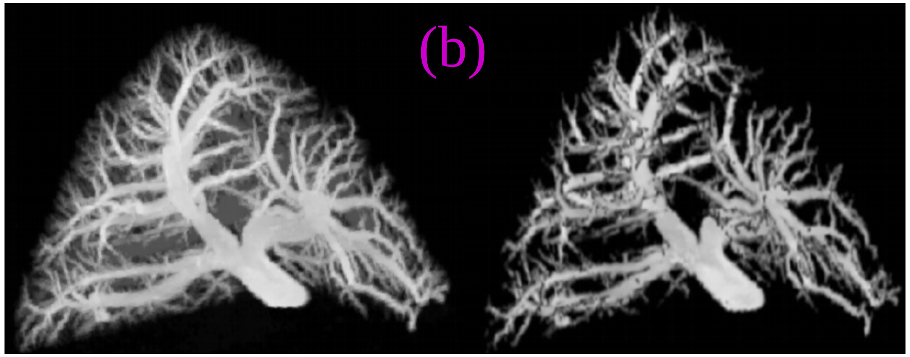
(a) slice-based examination

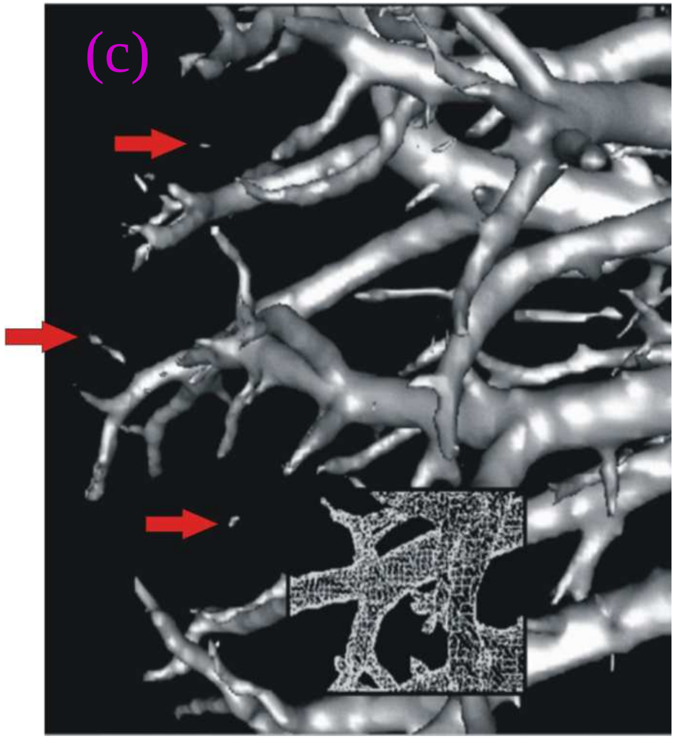
(b) Maximum Intensity Projection, Closest Vessel Projection [Zuiderveld, 1995]

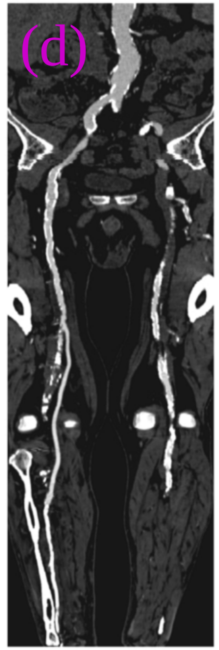
(c) Isosurface Rendering

(d) Curved Planar Reformation









[Kanitsar, 2001]

Vascular Diagnosis vs. Surgery Planning

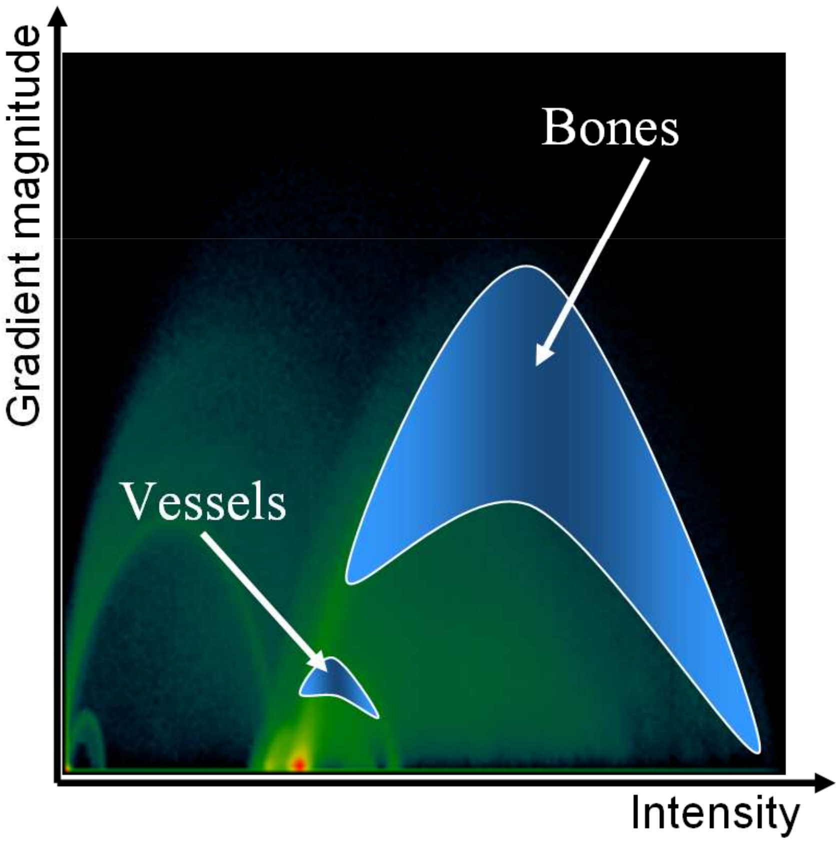
- Visualization in vascular diagnosis and vascular surgery:
  - Close adherence to the image data (vascular cross section)
  - Mostly slice-based examination, Curved Planar Reformations
  - 3D visualization must be accurate
  - Vascular surgery: bypass surgery, endoscopic treatment of aneurysms

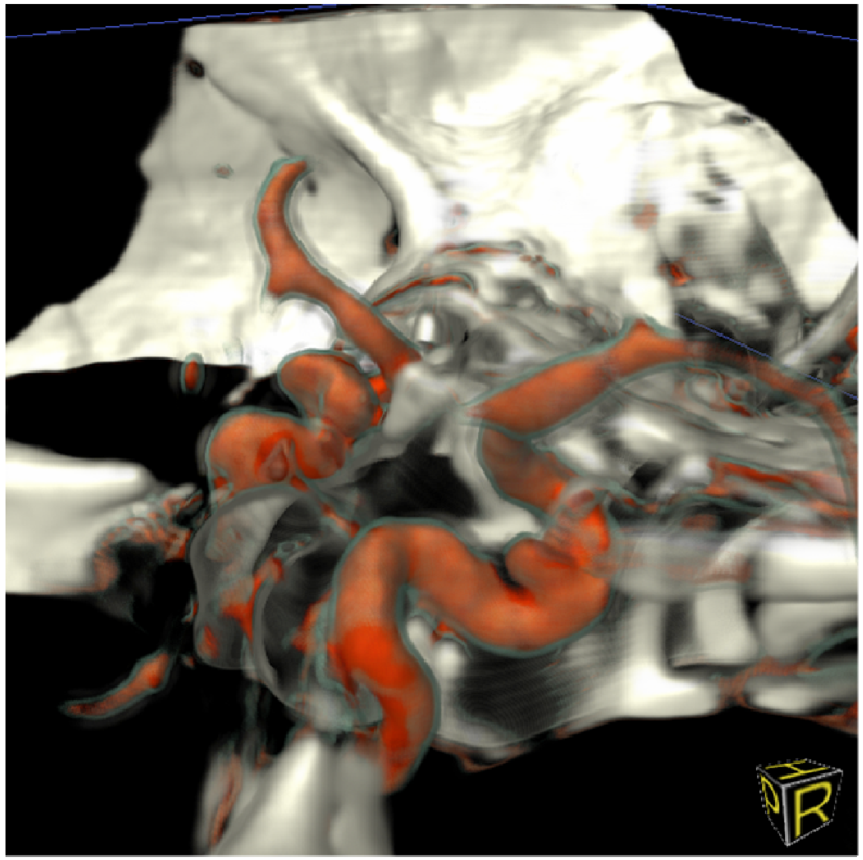
- Visualization in surgery planning and medical education:
  - Clear communication of topology and morphology
  - Comprehension of spatial relations to other structures
  - Correct depiction of curvature, depth relations and diminution of the diameter towards the periphery
  - Traditional methods not well-suited due to image noise, partial volume effect and limited resolution of CT and MRT
  - Reconstruction of vascular structures based on a model

Direct Volume Rendering

MIP visualization. Right image: After applying a „vesselness“-filter. [Frangi, 1998]

Direct Volume Rendering





1D Transfer Functions do not allow to distinguish skeletal structures and contrast-enhanced vessels. [Vega, 2003]

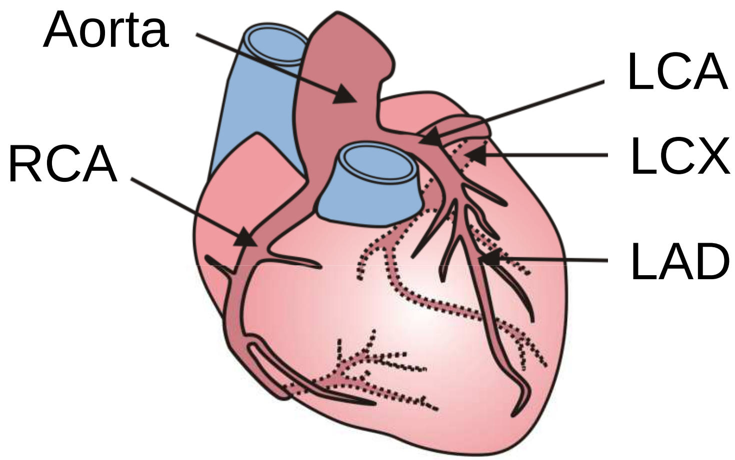
Direct Volume Rendering

- Specialized visualizations may be generated based on segmentation information (tagged volume rendering)
- Visualization may be restricted to segmented vascular structures or focus+context visualizations may be generated
- Application in diagnosis of vascular diseases, such as aneurysms, coronary artery disease

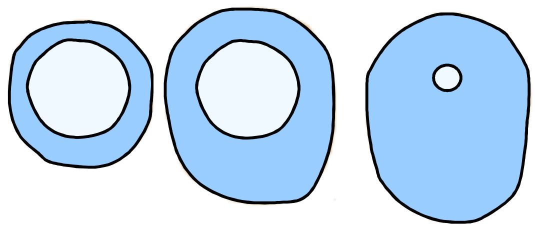
Direct Volume Rendering: Coronary Vessels

- **Coronary heart disease (CHD)**

- **Soft, Fibrous and Hard Plaques**
- **Stenotic narrowings (Stenosen)**



Scheme of the heart and the coronary arteries

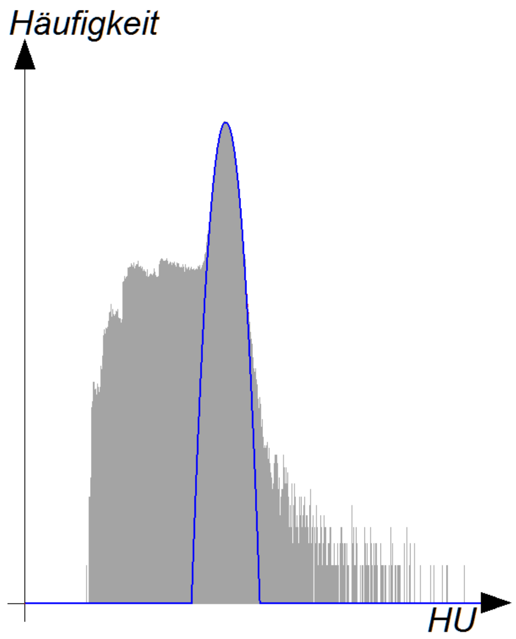


Cross sections of the coronary arteries

Direct Volume Rendering: Coronary Vessels

- **TF-Spezcfication based on the density distribution …**
  - **… of blood (μ_{Blut}, σ_{Blut})**
  - **… an the vessel wall (μ_{Wand}, σ_{Wand})**

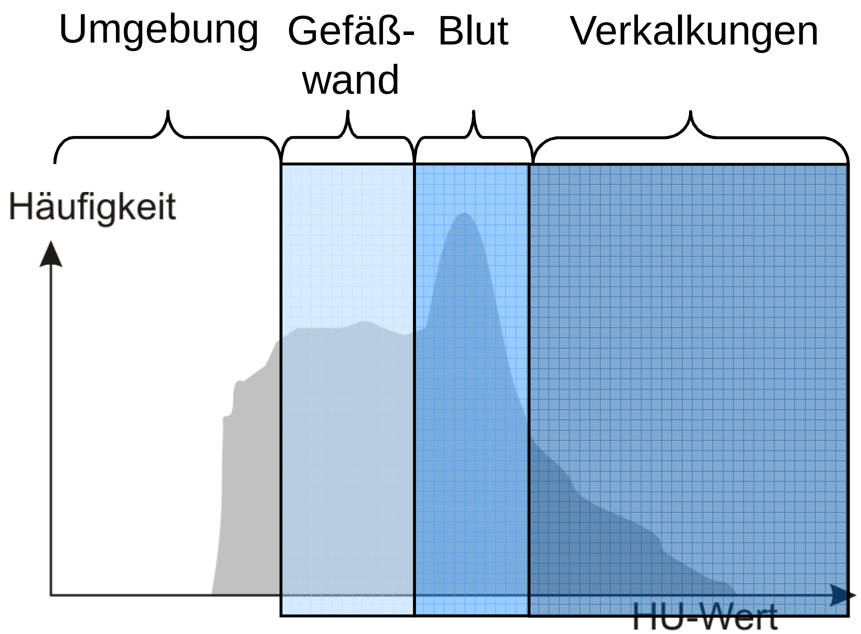
- **Calculation of μ_{Blut}, σ_{Blut} based on the segmentation mask**
- **Delineation of calcifications**
  - **No fixed threshold Schwellenwert**
  - **$\mu_{Blut} + 3\sigma_{Blut}$**



Logarithmically scaled histogramm of the segmentation result

Direct Volume Rendering: Coronary Vessels

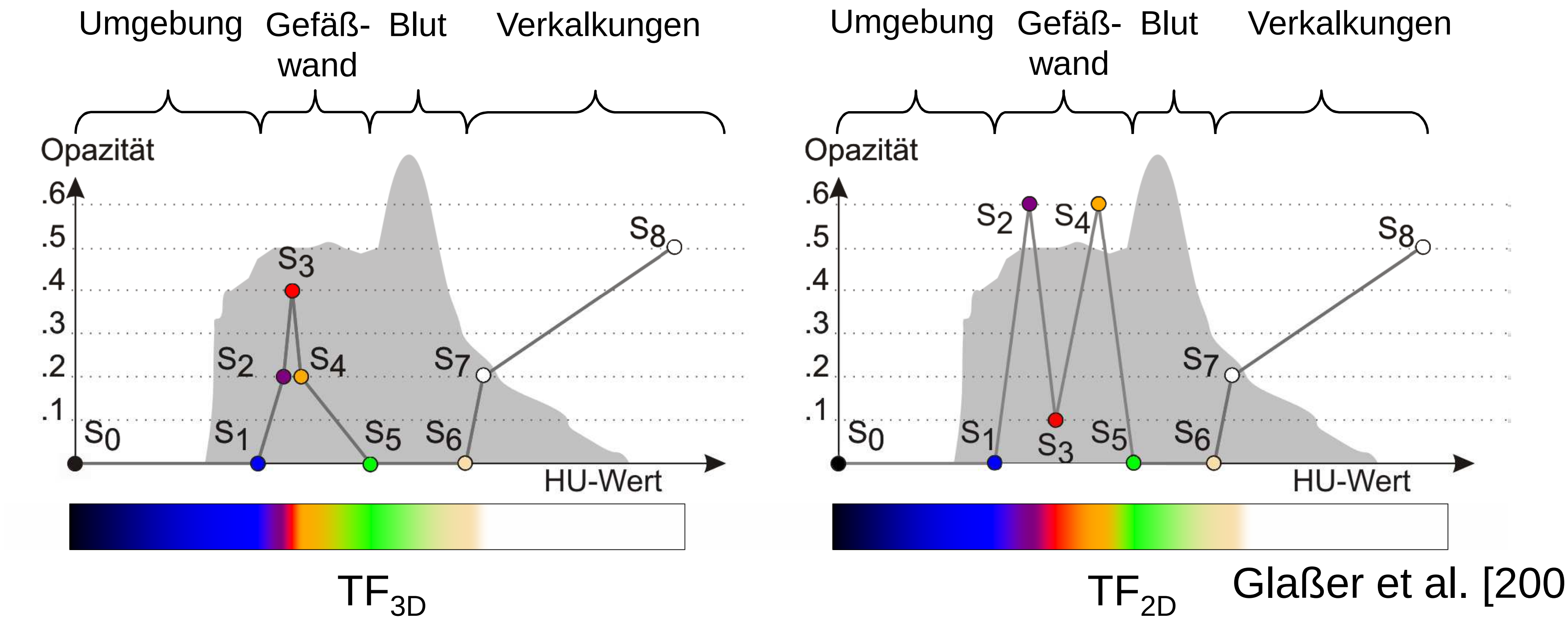
- **Definition of control points S_0 - S_8**
- **Computation of parameters μ_{Blut}, σ_{Blut} and μ_{Wand}, σ_{Wand}**
- **Specifikation of TF_{2D} and TF_{3D} based on the histogramme**



Glaßer et al. [2009]

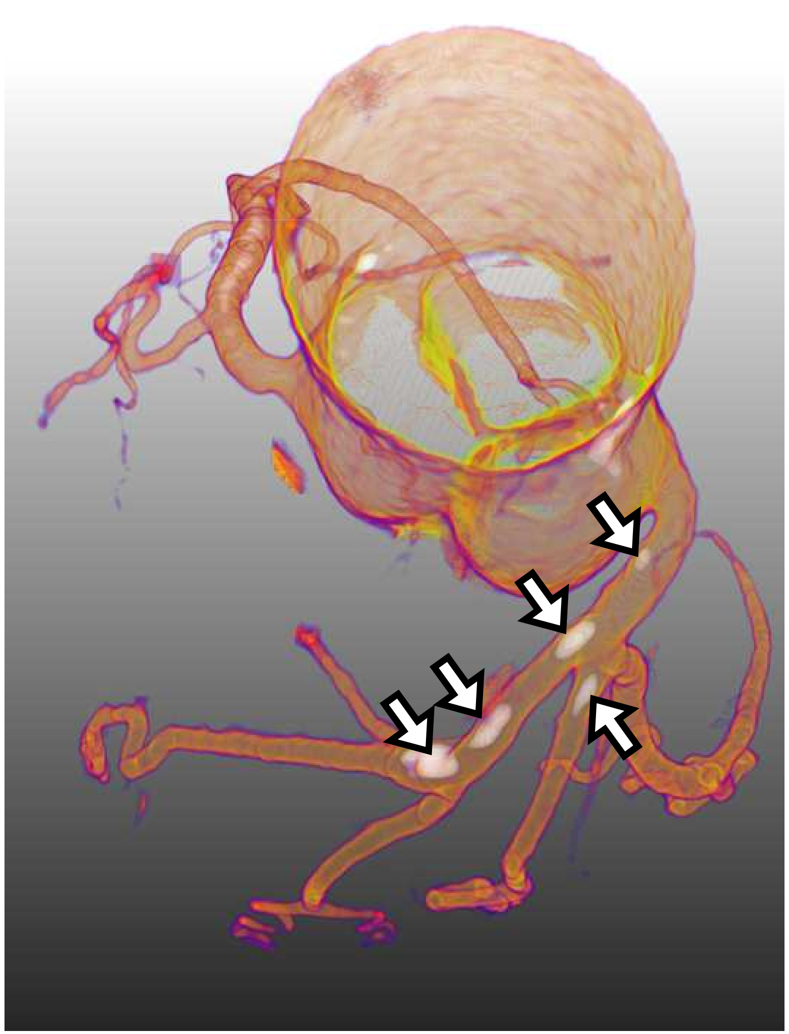
Direct Volume Rendering: Coronary Vessels

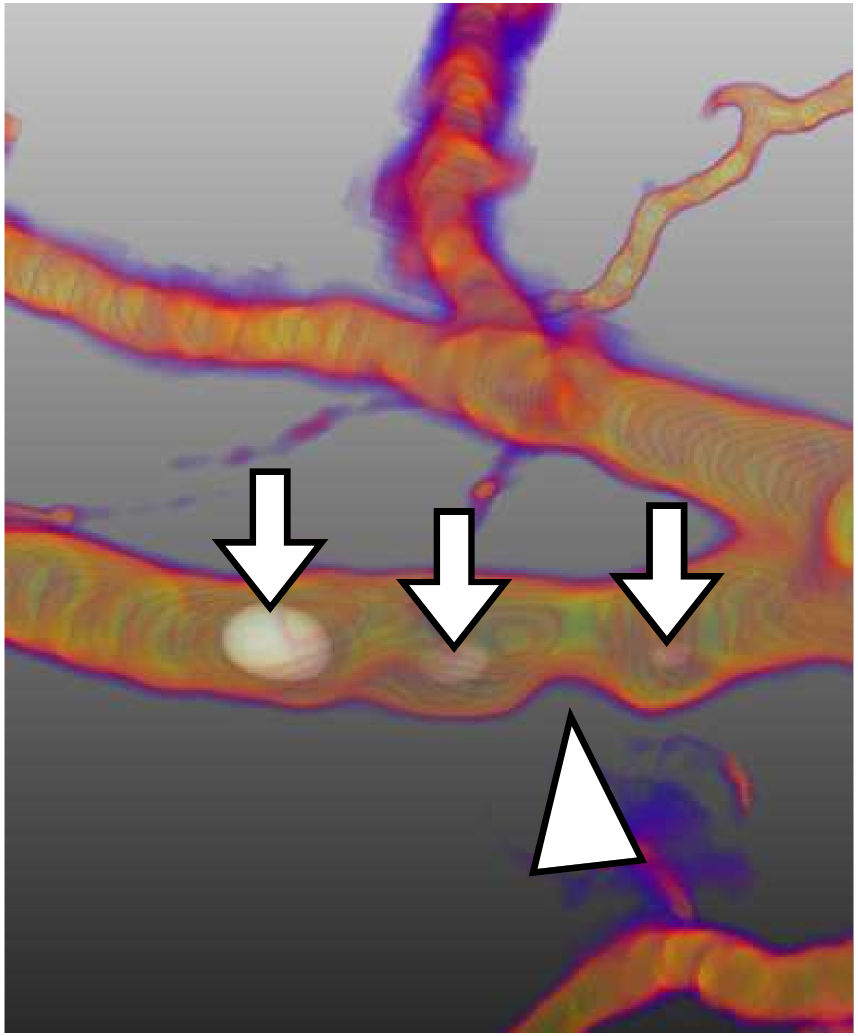
- **Assignment of colour and opacity**
  - **Decreased opacity for TF3D**
  - **For enhanced recognition: strongly saturated colours**
  - **Calcifications and Stents should be white:**



Glaßer et al. [2009]

Direct Volume Rendering: Coronary Vessels



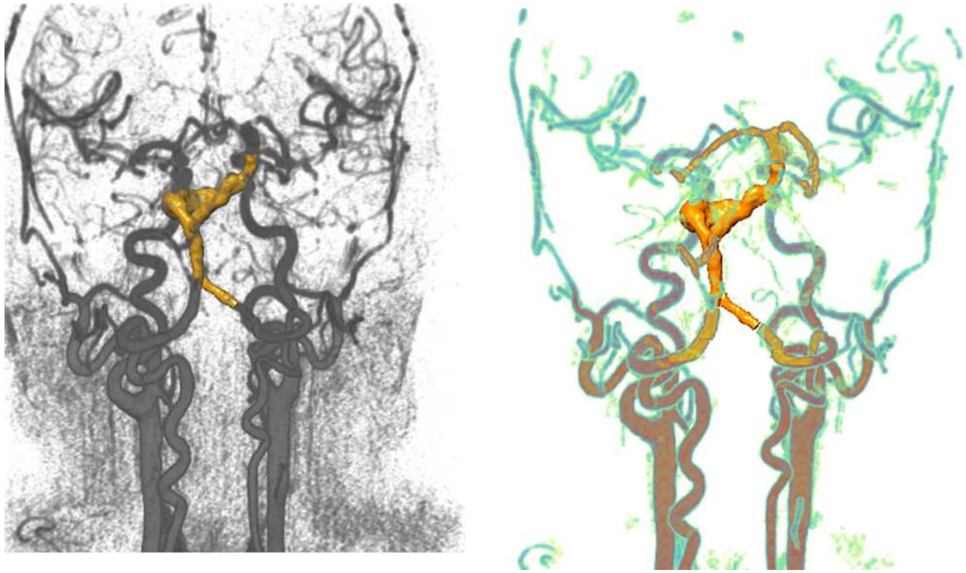


DVR of two datasets with automatically specified TFs
(Datasets from Dr. S. Achenbach)

Glaßer et al. [2009]

Direct Volume Rendering: Focus-and-Context Rendering

- Enhanced visualization of cerebral vasculature
- Diagnosis of an aneurysm
- Focus: aneurysm, immediate inflow and outflow
- Focus visualization: saturated colours, high opacity
- Context visualization: decreasing saturation and opacity



Neugebauer et al. [2009] (CARS)

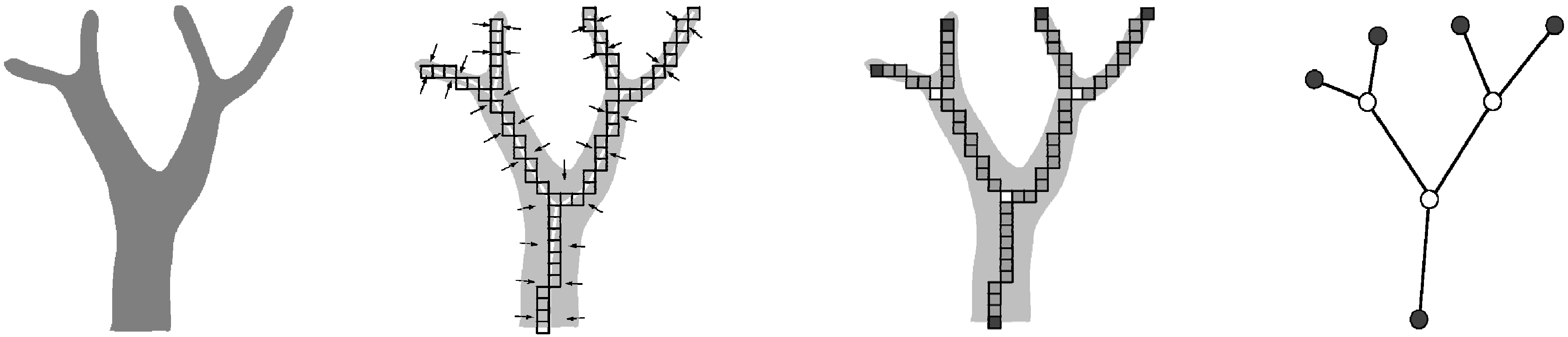
Direct Volume Rendering: Hybrid 2d and 3d Rendering

- 3D surface rendering of segmented vessels
- Direct volume rendering of the surrounding (skeletal structures as anatomic context)
- MPR orthogonal to the vessel centerline

Boskamp et al. [2004]

Image Data and Vessel Analysis

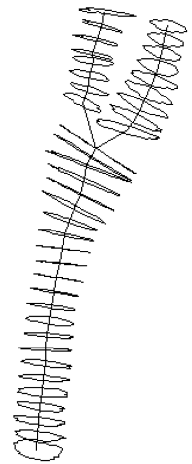
- High resolution CT- or MR-data ➔ Segmentation ➔ Skeletonization ➔ Analysis of shape and branching pattern



[Selle, 2000]

Results of vessel analysis:

- Graph represents vascular topology
  - Edges = branches, nodes = branchings
- List of skeleton voxels per branch
- Radii per skeleton voxel
- Branching information



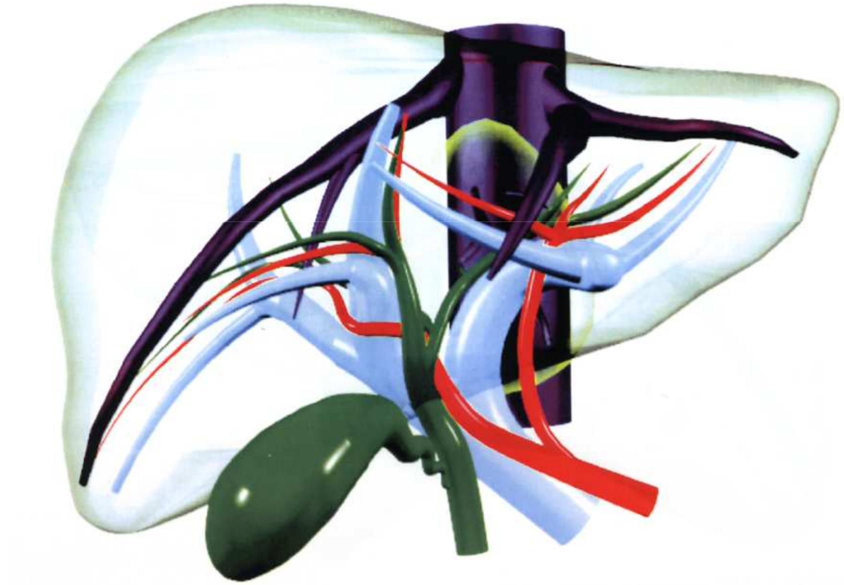
[Ehricke, 1994]

Model-based Visualization –
Model Assumption and Requirements

Simplifying model assumption:

- Circular cross-sections of non-pathological vessels

Keep in mind: methods are not intended for vessel diagnosis



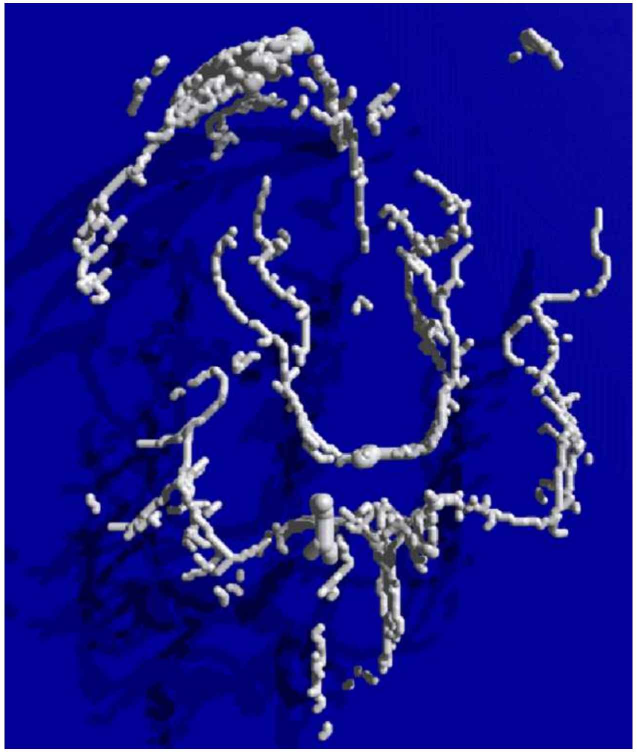
[Mazziotti, 1997]

Requirements:

- Correct representation of the vessel diameter
- Smooth, organic looking vessel shape
- Uniform treatment of all branching types
- Closed vessel ends
- Avoidance of structures inside the vessels

Model-based Visualization – Cylinder Fitting

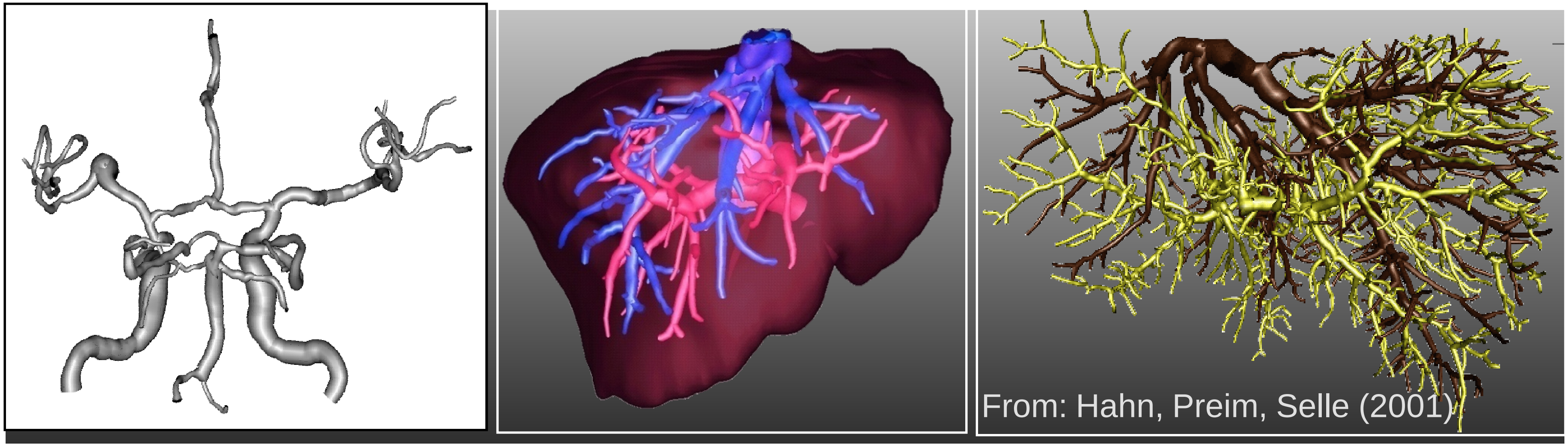
- Gerig et al., 1993: “Symbolic Description of 3d structures applied to cerebral vessel tree obtained from MR angiography volume data”.
- Graph representation (edges, nodes) of the vessel tree for structural analysis, e.g. identification of subtrees
- Representation of the local vessel diameter by means of fitting cylinders along the vessel skeleton



[Gerig, 1993]

Model-based Visualization – Truncated Cones Fitting

- Filtering: Smoothing of the skeleton and radius (Binominal filter)
- Mapping: 1. Concatenation of truncated cones along the skeleton
  2. Mapping of truncated cones to polygons



From: Hahn, Preim, Selle (2001)

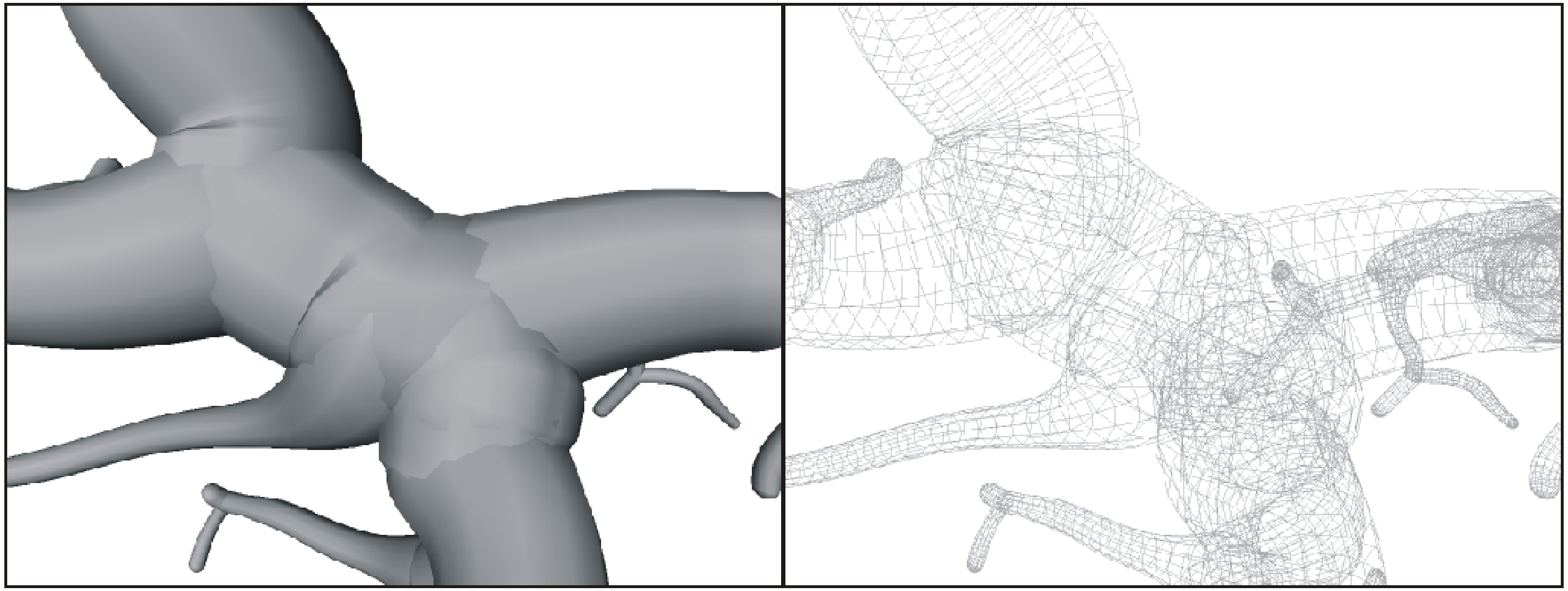
Left: Cerebral blood vessels (MR-Data: Prof. Terwey, Bremen)

Middle: Hepatic vein and portal vein of clinical dataset
(CT-Data: Prof. Galanski, MH Hannover)

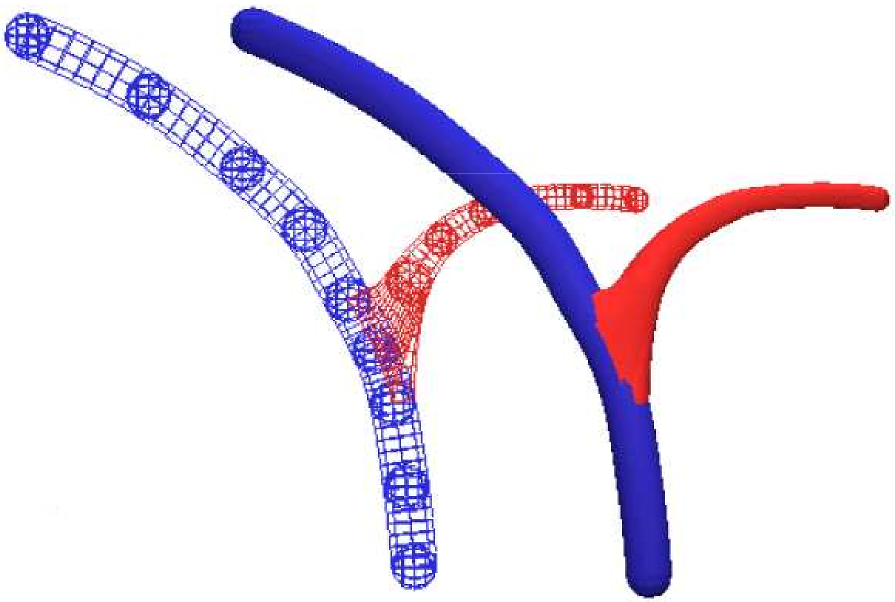
Right: Corrosion cast of the human liver (Data: Prof. Fasel, Uni Genf)

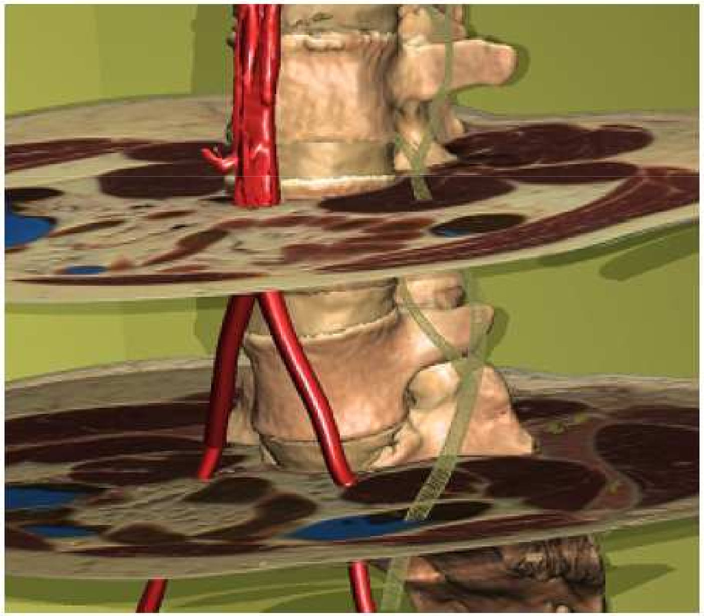
Model-based Visualization – Truncated Cone Fitting

- Discontinuities at branchings become obvious at close-up views
- Inner polygons arise and therefore not suitable for virtual angioscopy
- But: A very fast method which has been in routine use since 2004 (used for planning ~ 3000 interventions)



Model-based Visualization – Freeform Surfaces



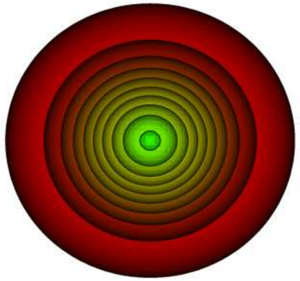


Modelling incompletely segmented nerves and vascular structures with B-splines. Application within the VoxelMan
[Pommert, 2001]

Visualization of Vascular Structures: Implicit Methods

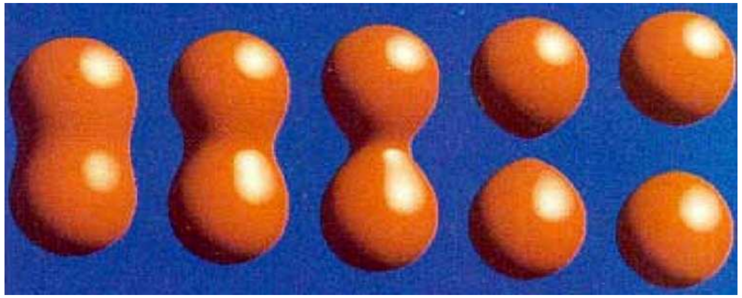
Idea (exploration of implicit surfaces):

- Implicit functions (F(x,y,z) – Iso = 0)
- Original application in computer graphics
  - Blobby Molecules for the display of electric fields, Blinn [82]



$$F(p) = e^{-\omega x^2}$$

$$\omega = width\ coefficient$$



[Blinn, 1982]

Implicit surfaces for the visualization of tree structures

- Energy distribution: skelett points as energy sources
- Skeleton points define isospheres
- Problem: Smooth surfaces at line segments

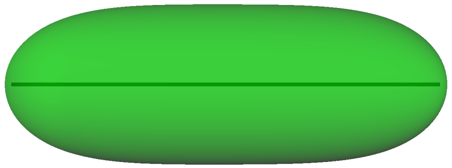
  → Solution: Convolution Surfaces (Jules Bloomenthal)

Visualization of Vascular Structures: Convolution Surfaces

Convolution Surfaces (Bloomenthal and Shoemake [1991])

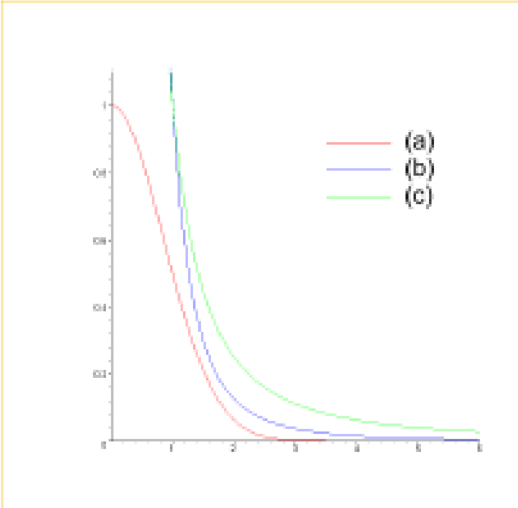
- Convolution of a signal with a filter
- Here: Convolution of line segments with a 3d-lowpass filter

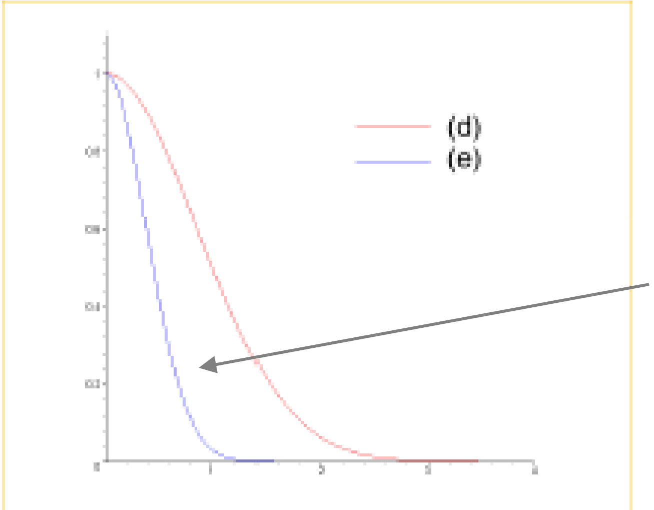
$$F(p) = \int_S h(s-p)ds = (h \otimes S)(p)$$



- Polygonization with an isovalue depending on the filter

Visualization of Vascular Structures: Convolution Surfaces





$$h(p) = e^{-d^2\omega},\ \omega = 5\ln 2,\ d > 0$$

$$F(p) = e^{-(r(H)/r(H))^2 5\ln 2} - Iso = e^{-5\ln 2} - Iso = 0$$

$$Iso = 1/32 = 0.03125.$$

Exploration of filter functions.
Selection guided by the following criteria:

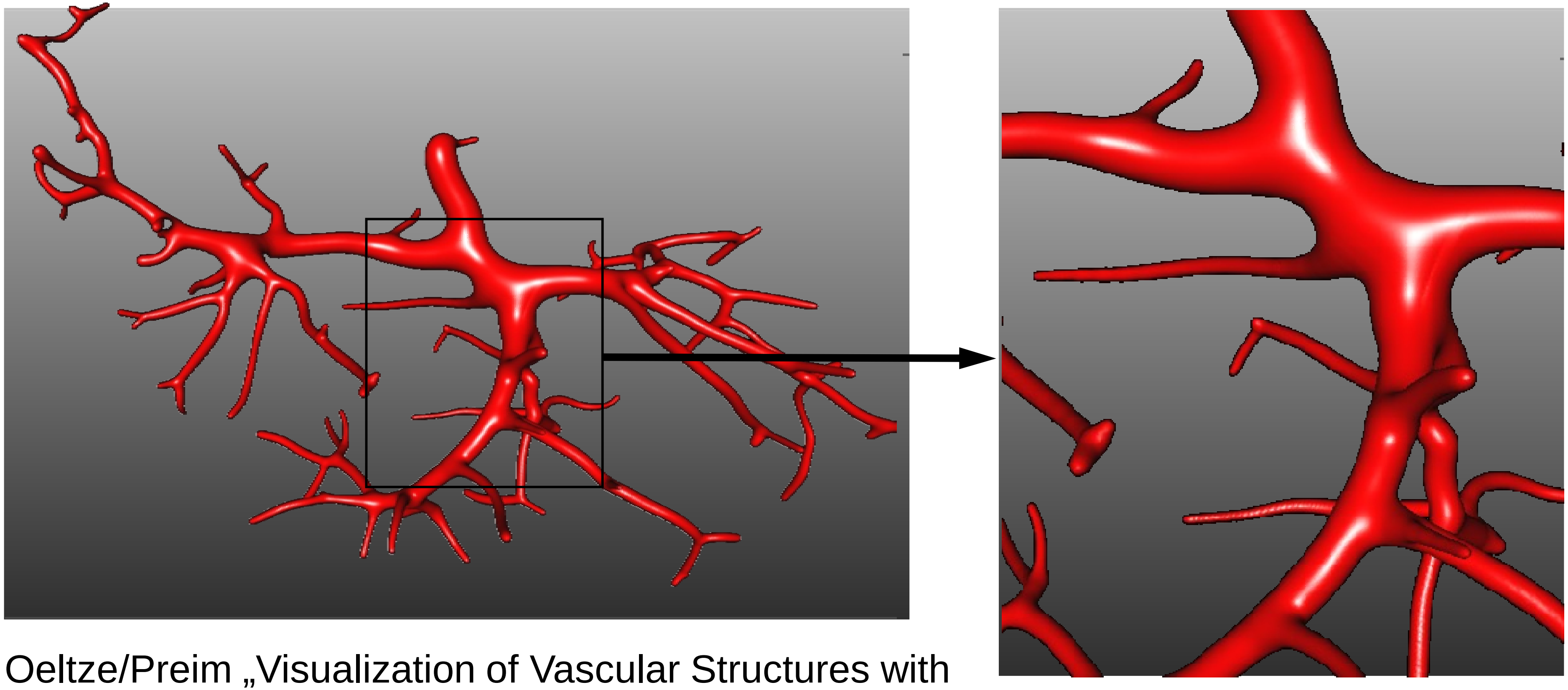
- Correct display of the radius,
- Accuracy
- Fast computation

Result:

- A narrow Gaussian filter is a good choice.
- For even narrower filter kernels the implicit surface converges against the truncated cone visualization.

Visualization of Vascular Structures: Applications of Convolution Surfaces

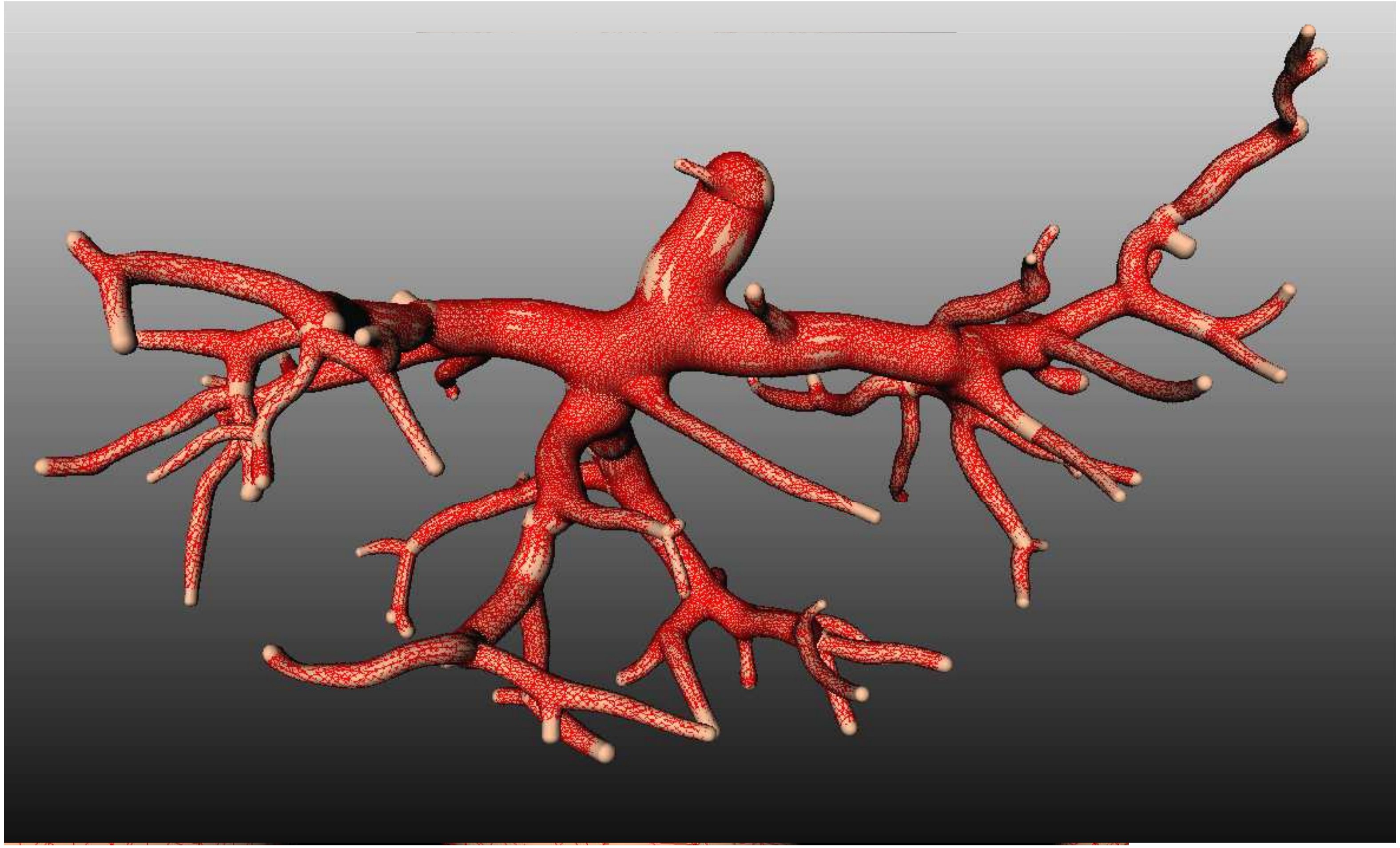
Portal vein of a human liver



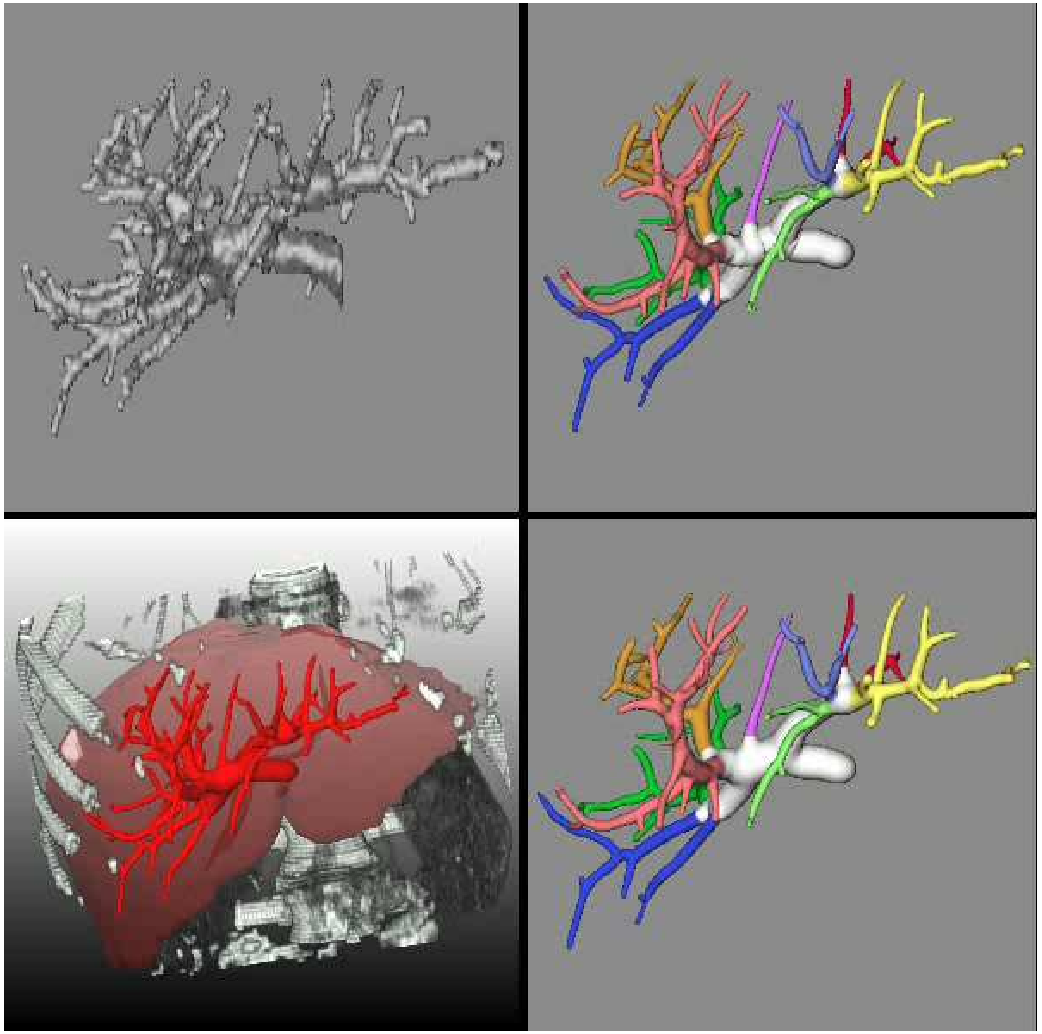
Oeltze/Preim „Visualization of Vascular Structures with Convolution Surfaces“,

Visualization of Vascular Structures: Validation of Convolution Surfaces

Comparison: Convolution surface as wireframe; truncated cones as shaded surface visualization.

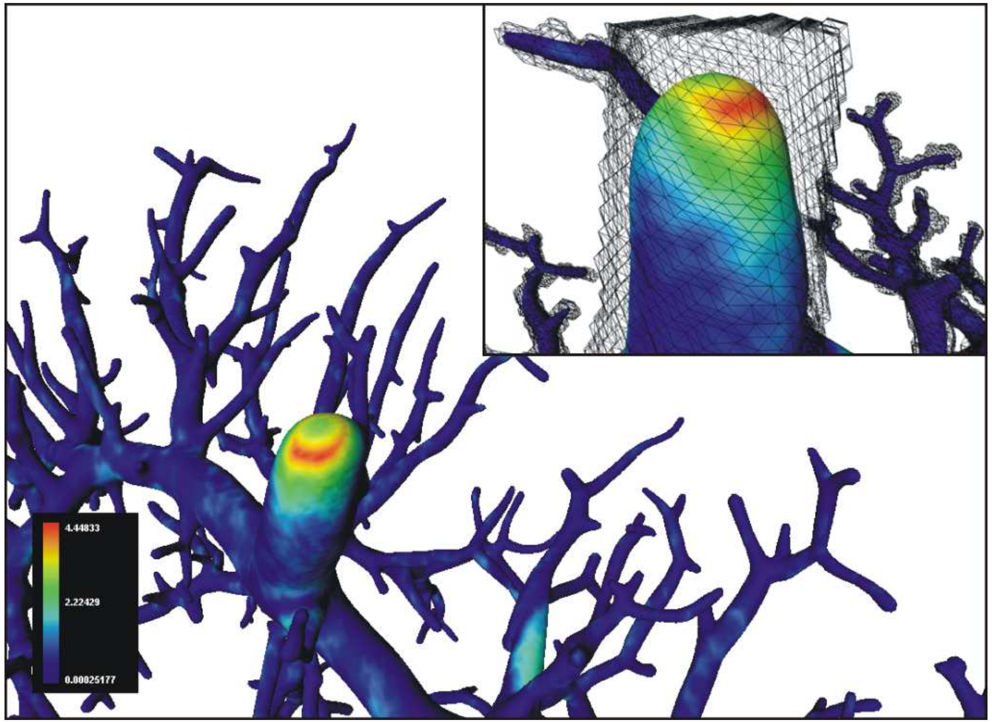


Visualization of Vascular Structures: Validation of Convolution Surfaces



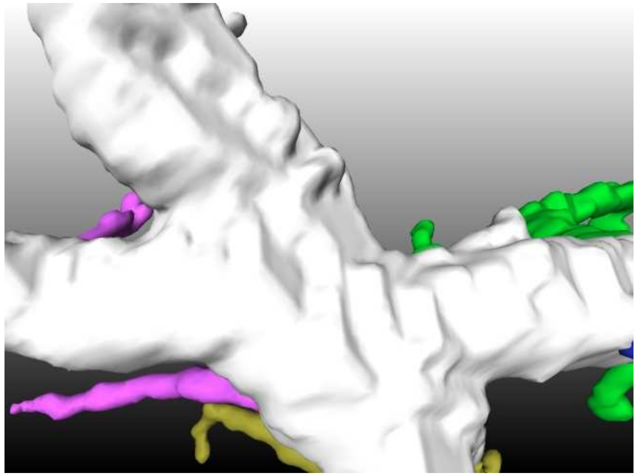
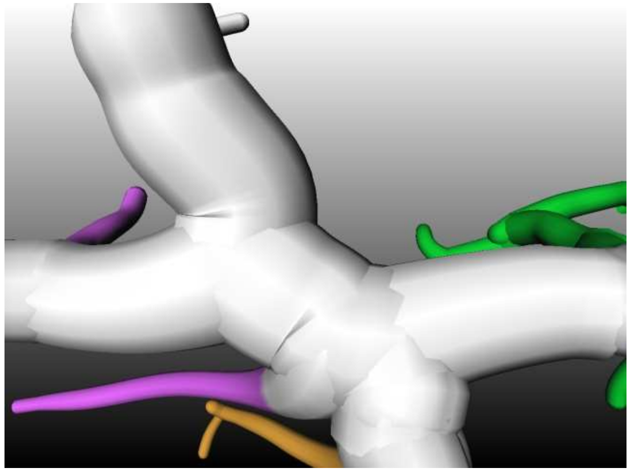
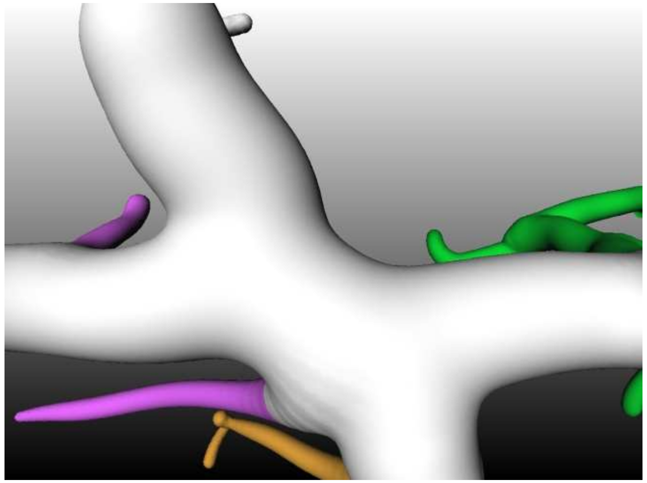
Visualization of Vascular Structures: Validation of Convolution Surfaces

- Quantitative validation (directional distances) between CS and Truncated Cones and CS to Isosurface of the segmentation result.



CS → Isosurface: Large distances only at the root of vascular trees

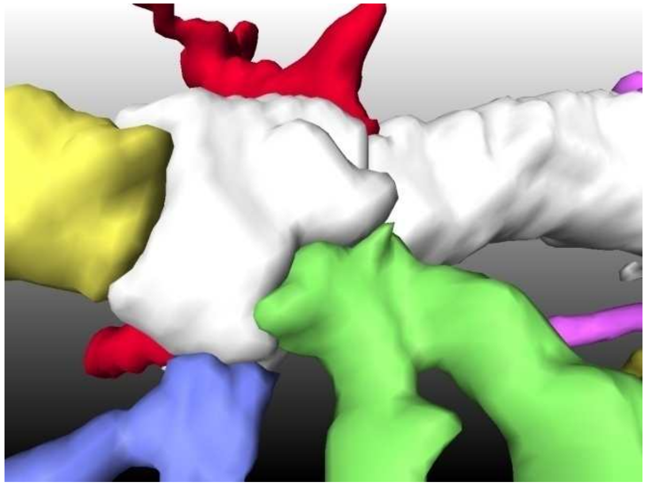
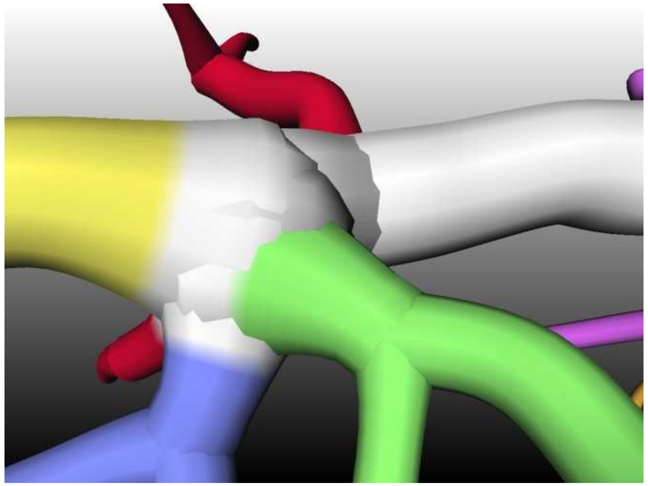
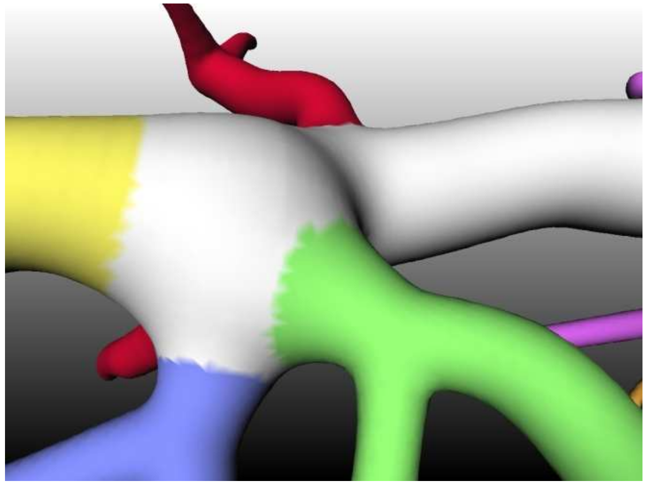
Visualization of Vascular Structures: Evaluation of Convolution Surfaces

Isosurface of the segmentation result

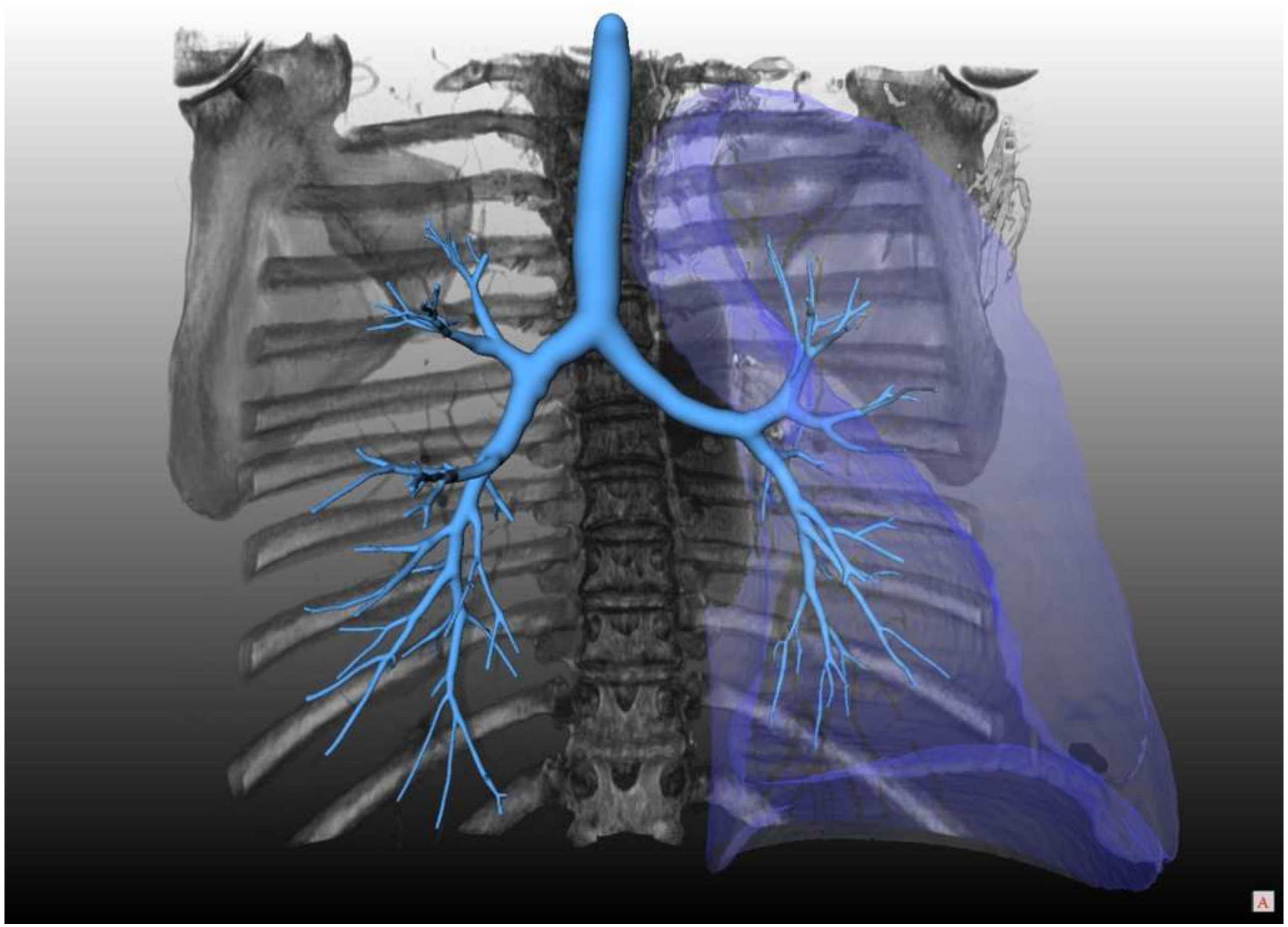
Truncated Cones

Convolution Surfaces

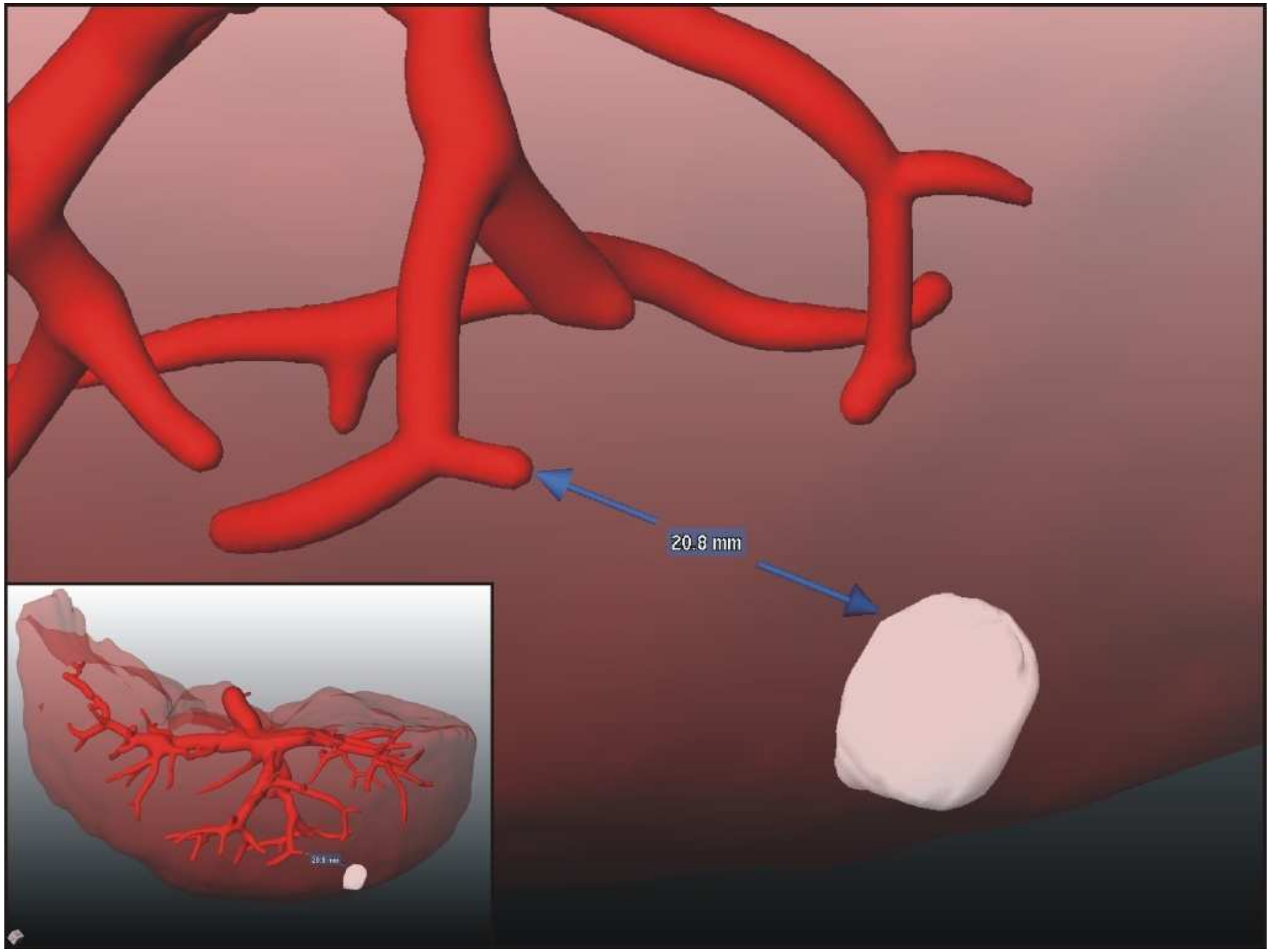
Application Scenarios – Analysis of the Bronchial Tree

Bronchial tree (> 3000 branchings, > 3 M triangles, 54 seconds) in a human lung (volume rendering).

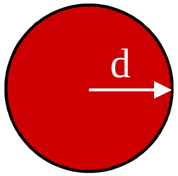
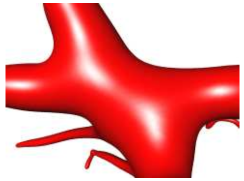
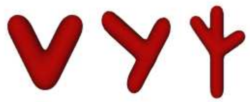
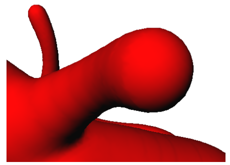
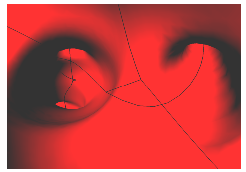


Application Scenarios – Tumor Resection

Measurement of the minimal distance between the portal vein and a tumor in preparation for a tumor resection.

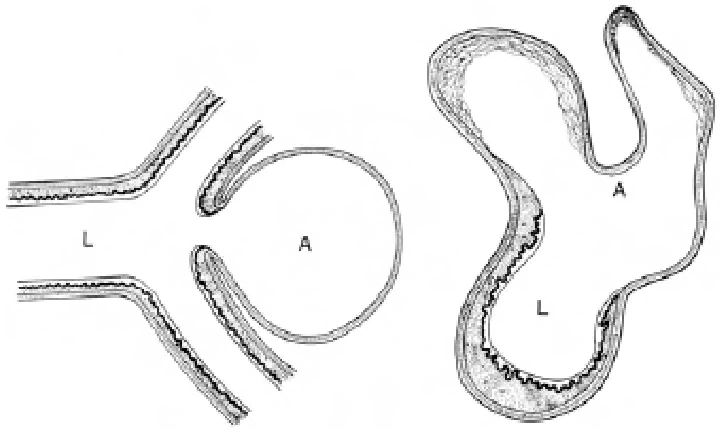


Model-based Visualization – Comparison

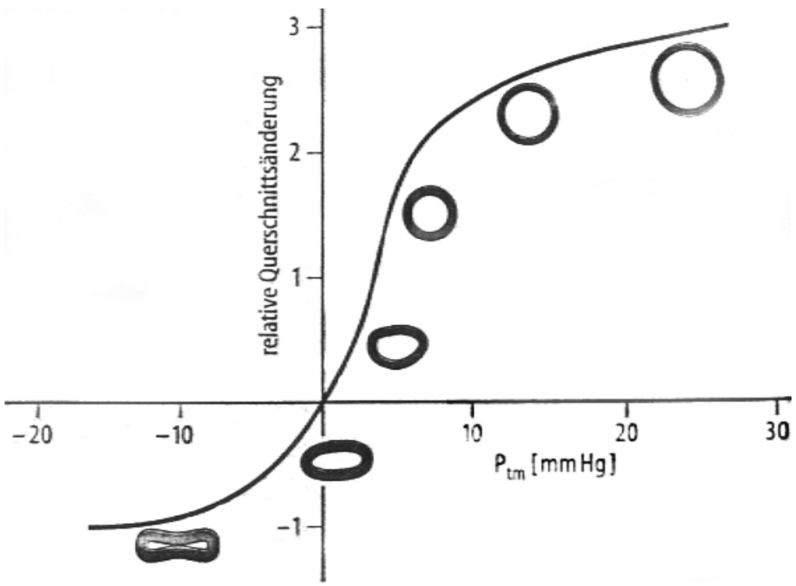
Method	Geometry					
Gerig, 1993	Cylinder	no local diminution	no	yes	no	no
Hahn, 2001	Truncated cone	Yes	no	yes	yes	no
Ehricke, 1994	Freeform Surfaces	yes*	yes*	no*	no*	yes*
Felkel, 2002	Subdivision Surface	Yes	yes	yes	no	yes
Bornik, 2005	Simplex Mesh	yes	yes	yes	yes	yes
Oeltze, 2004	Convolution Surface	yes	yes	yes	yes	yes

Model-Free Visualization

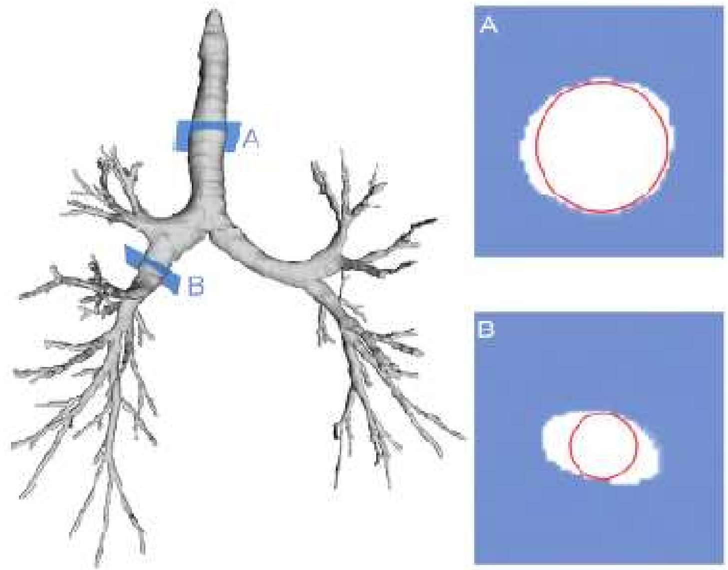
- Simplifying model-assumption of circular cross-sections is invalid for pathologic vessel parts, e.g. aneurysms
- Even Non-pathologic vessels may exhibit non-circular cross-sections



[Osborn, 1999]



[Schmidt, 2004]



[Schumann, 2006]

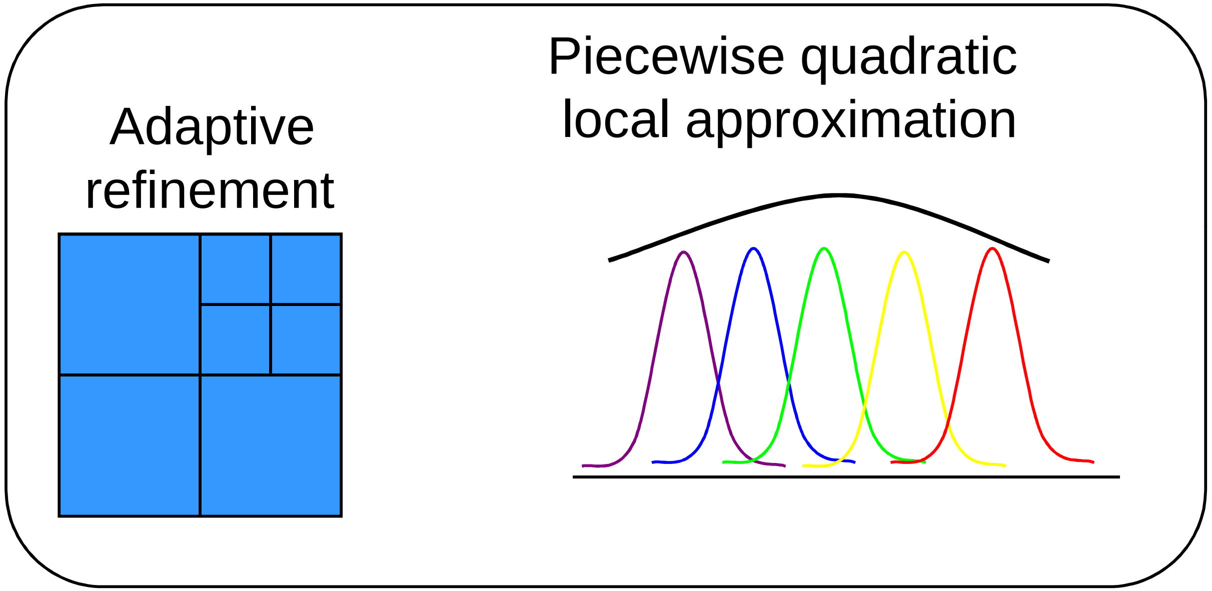
Model-Free Visualization –
Multi-level Partition of Unity Implicits

Approximation of a point cloud by a surface [Ohtake et al. 2003]

- Visualization of vasculature based on post processed segmentation result (points placed within boundary voxels)
- Arbitrary cross-sections may be reconstructed
- Suitable for vessel diagnosis

- Algorithm:
  - Spatial subdivision of the point cloud by an octree
  - Local approximation by means of surfaces
  - Blending of local approximations results in global approximation

Multi-level Partition of Unity Implicits

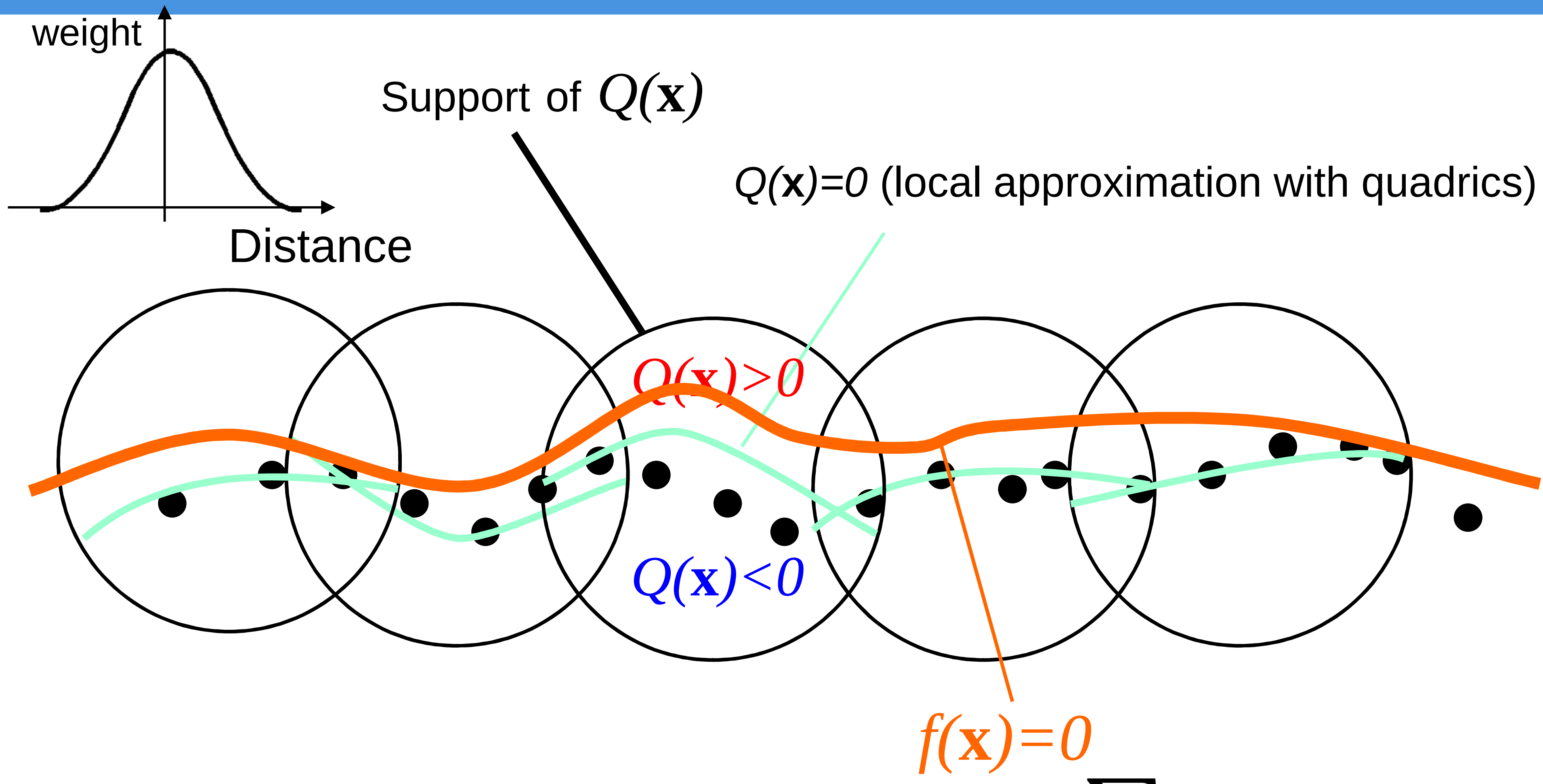


- Fast reconstruction of surfaces from scattered data
- Surface approximation with adaptive error control
- Search for points in spherical regions

Approximation with
14 million points

[Ohtake et al. 2003]

Model-Free Visualization Partition of Unity

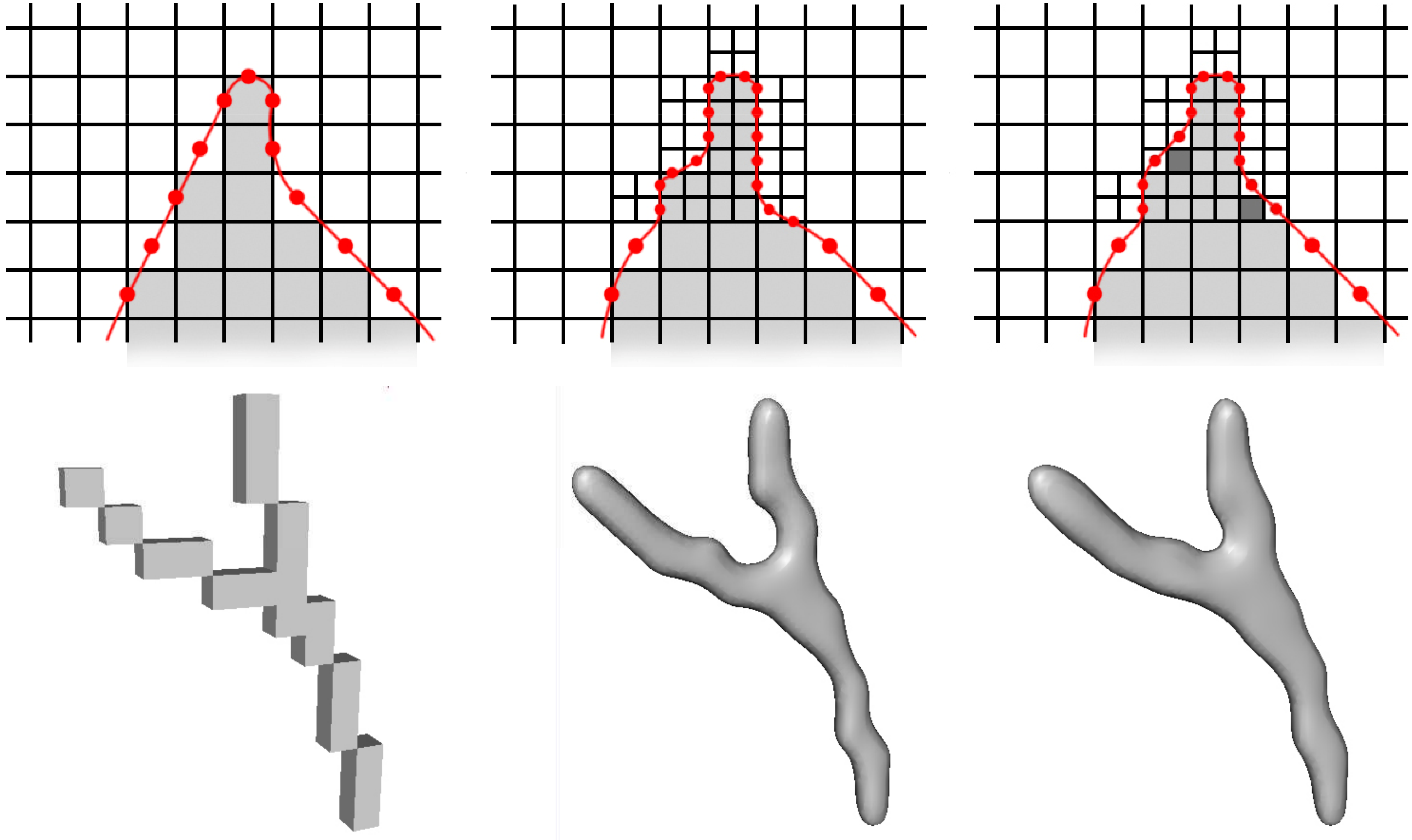


Weighted average of local approximations

$$f(\mathbf{x}) = \frac{\sum w_i(\mathbf{x}) Q_i(\mathbf{x})}{\sum w_i(\mathbf{x})}$$

Model-Free Visualization

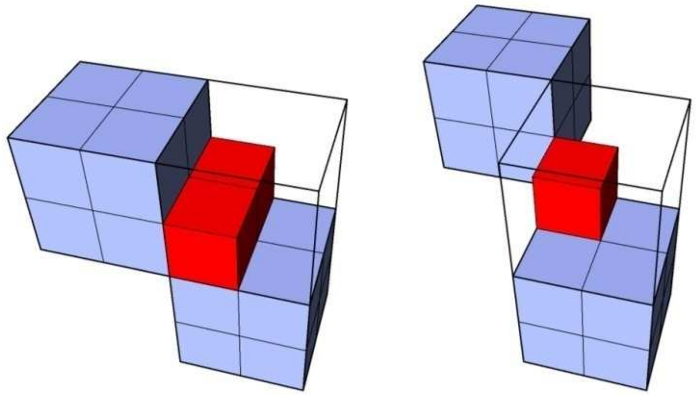
Adaptive subsampling of thin branches



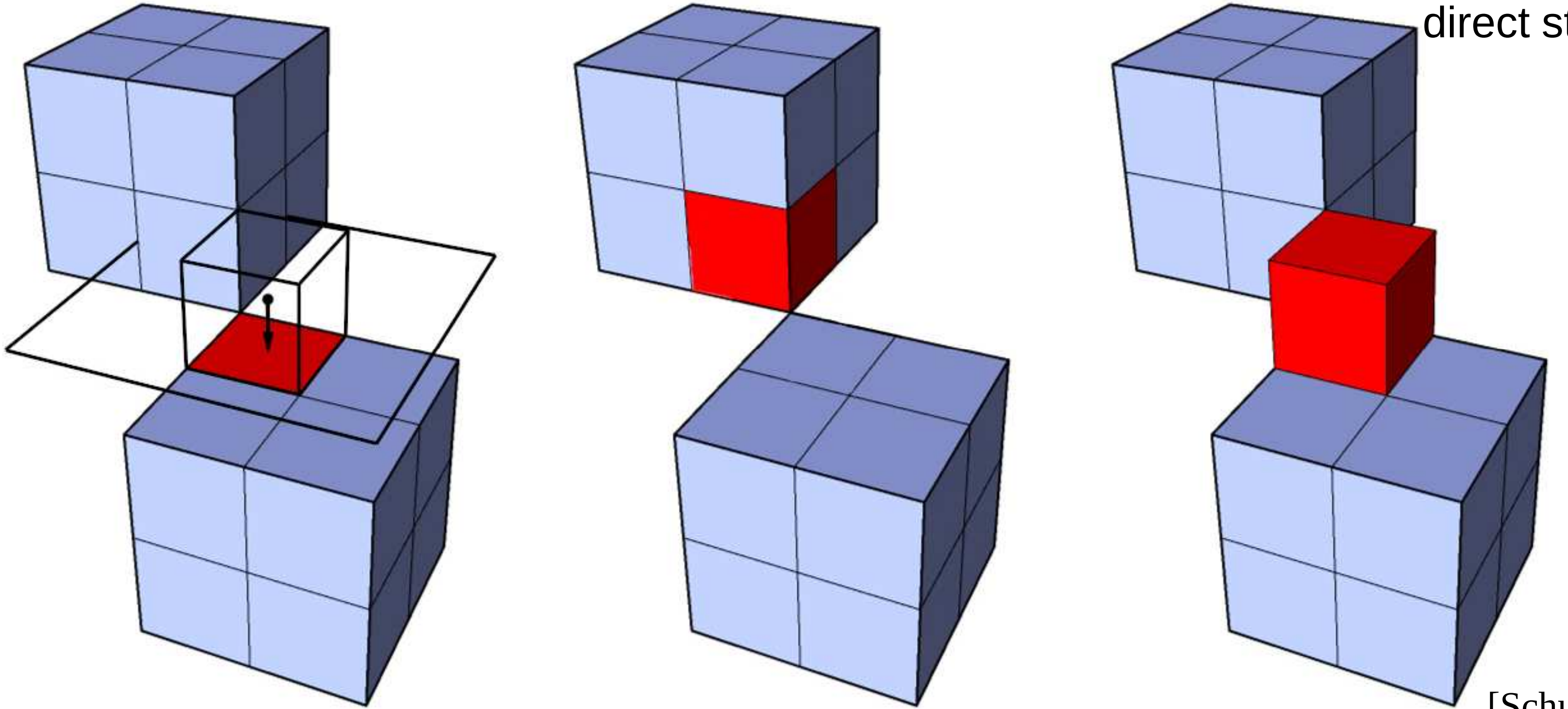
[Schumann, 2006 und 2007]

Model-Free Visualization

To reduce aliasing, subvoxel are included at certain features.

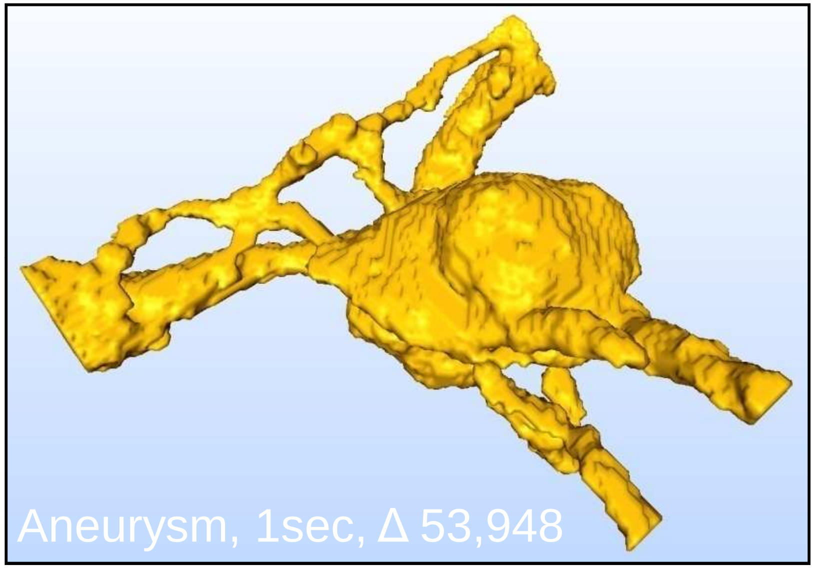


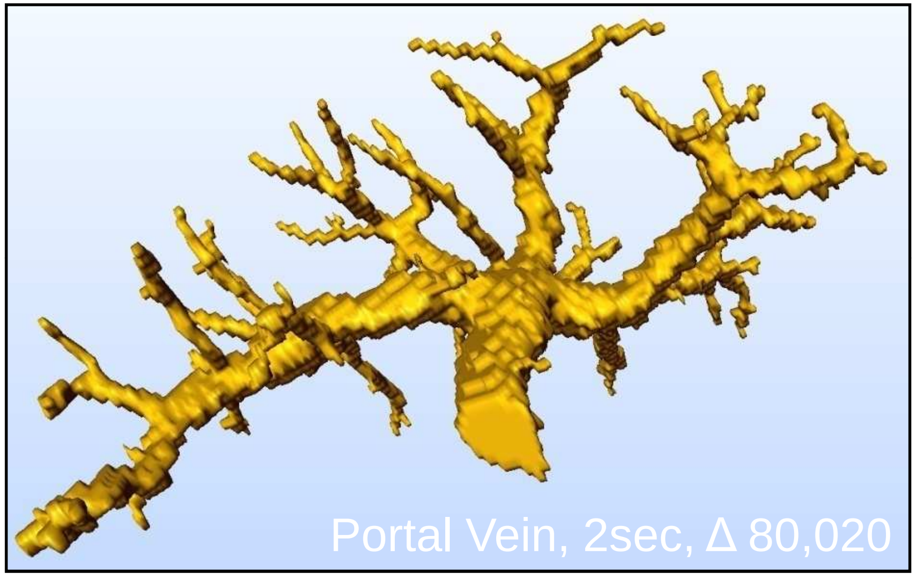
direct step / diagonal step



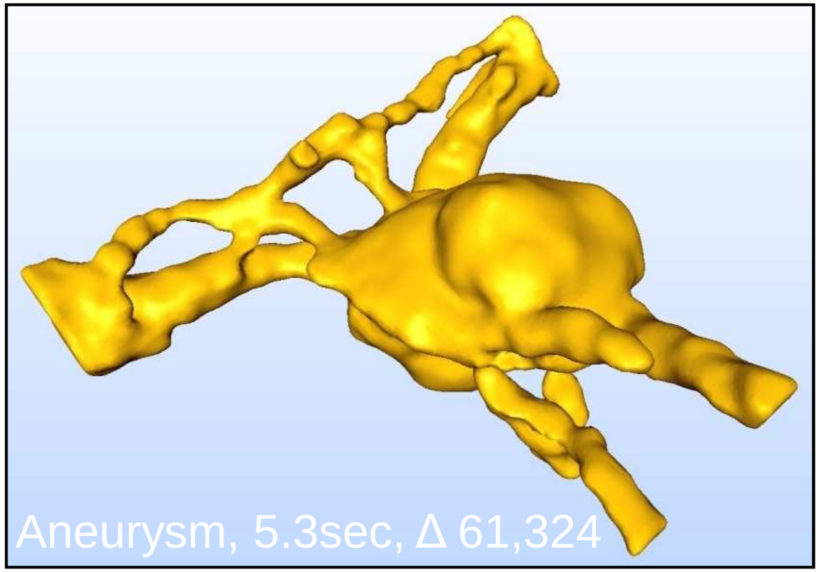
[Schumann, 2006 und 2007]

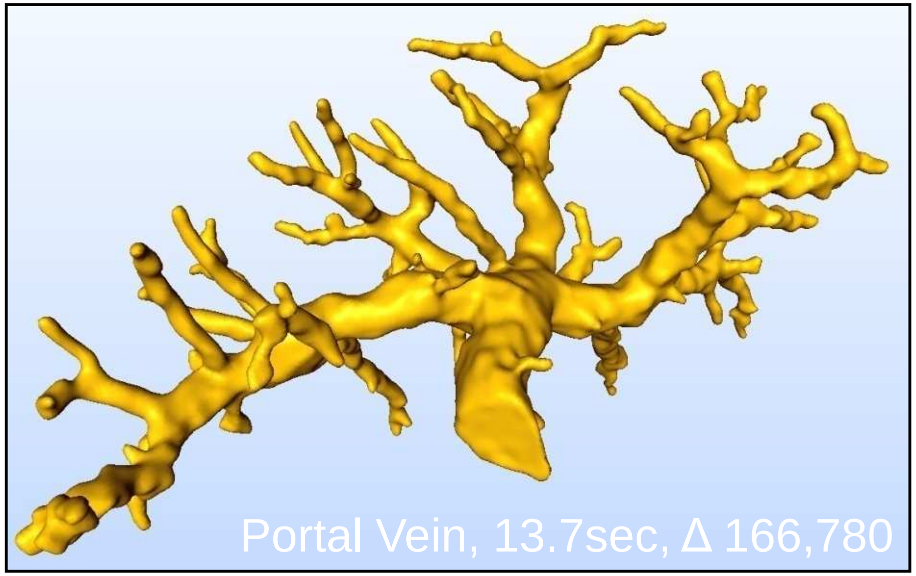
Model-Free Visualization – Results (1)





MC

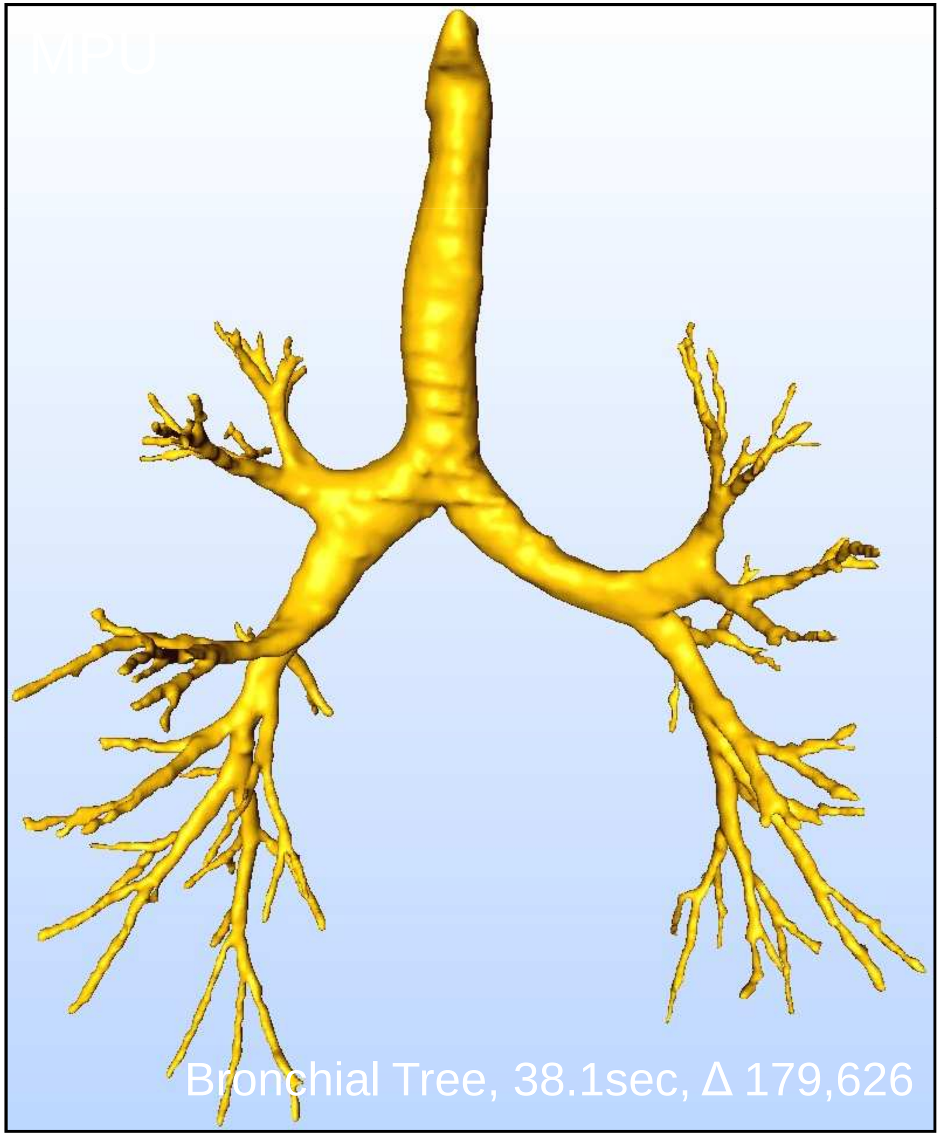


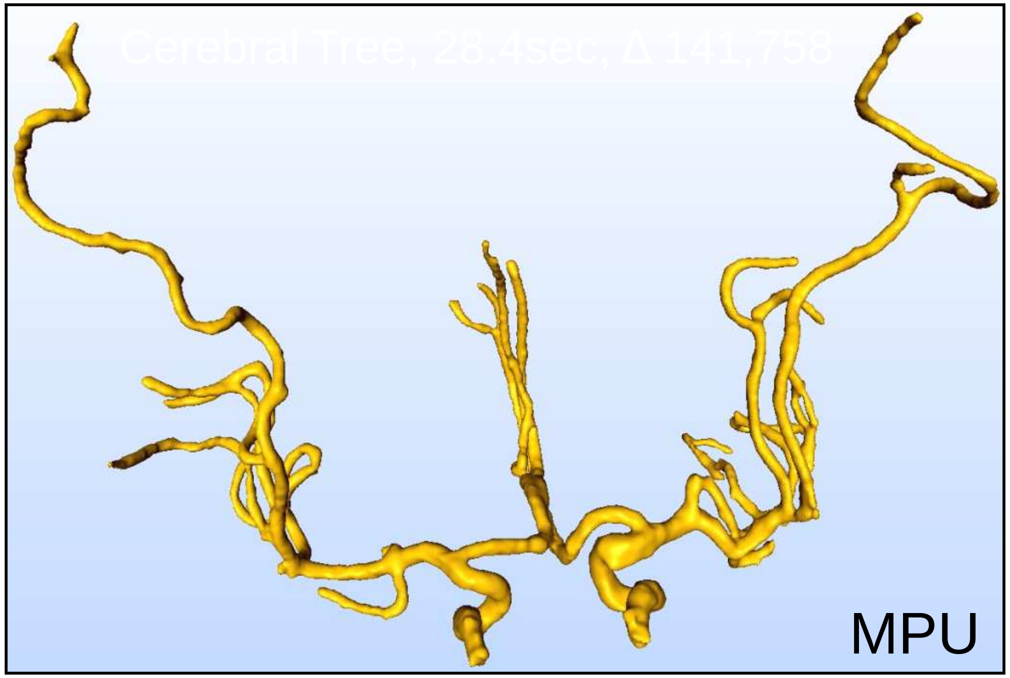


MPU

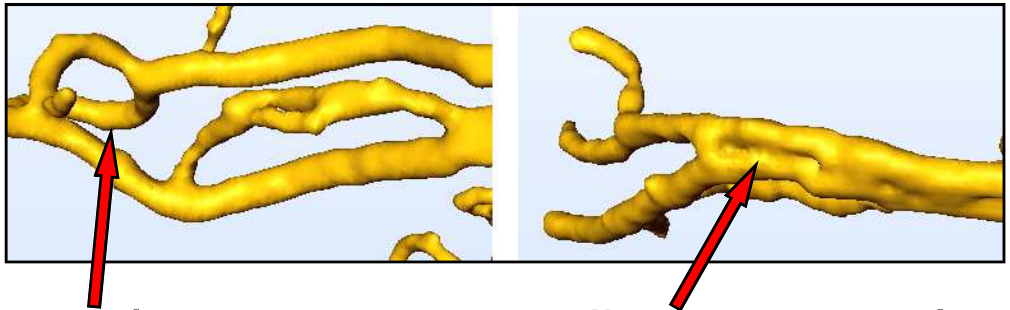
[Schumann, 2006 und 2007]

Model-Free Visualization – Results (2)

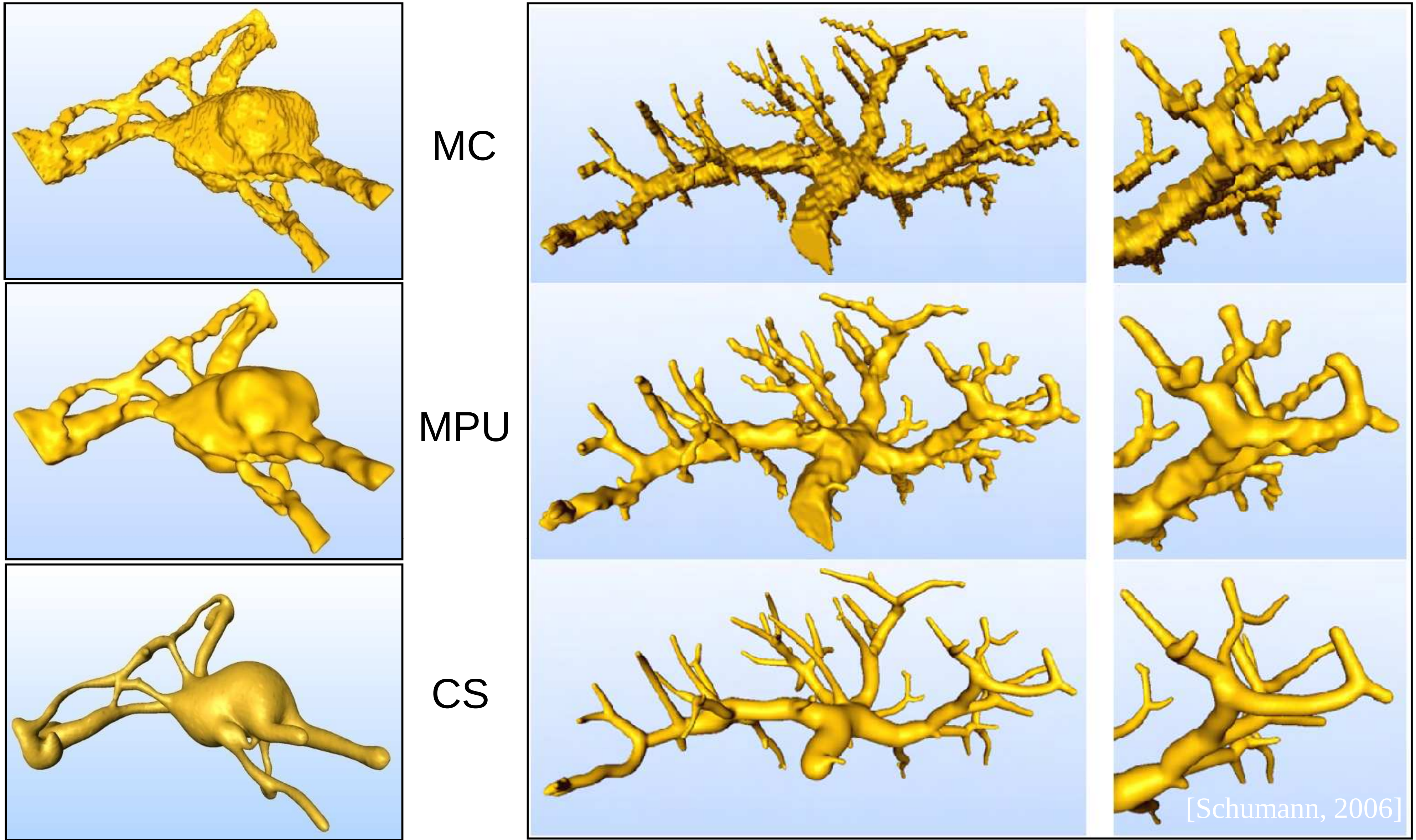




[Schumann, 2006]

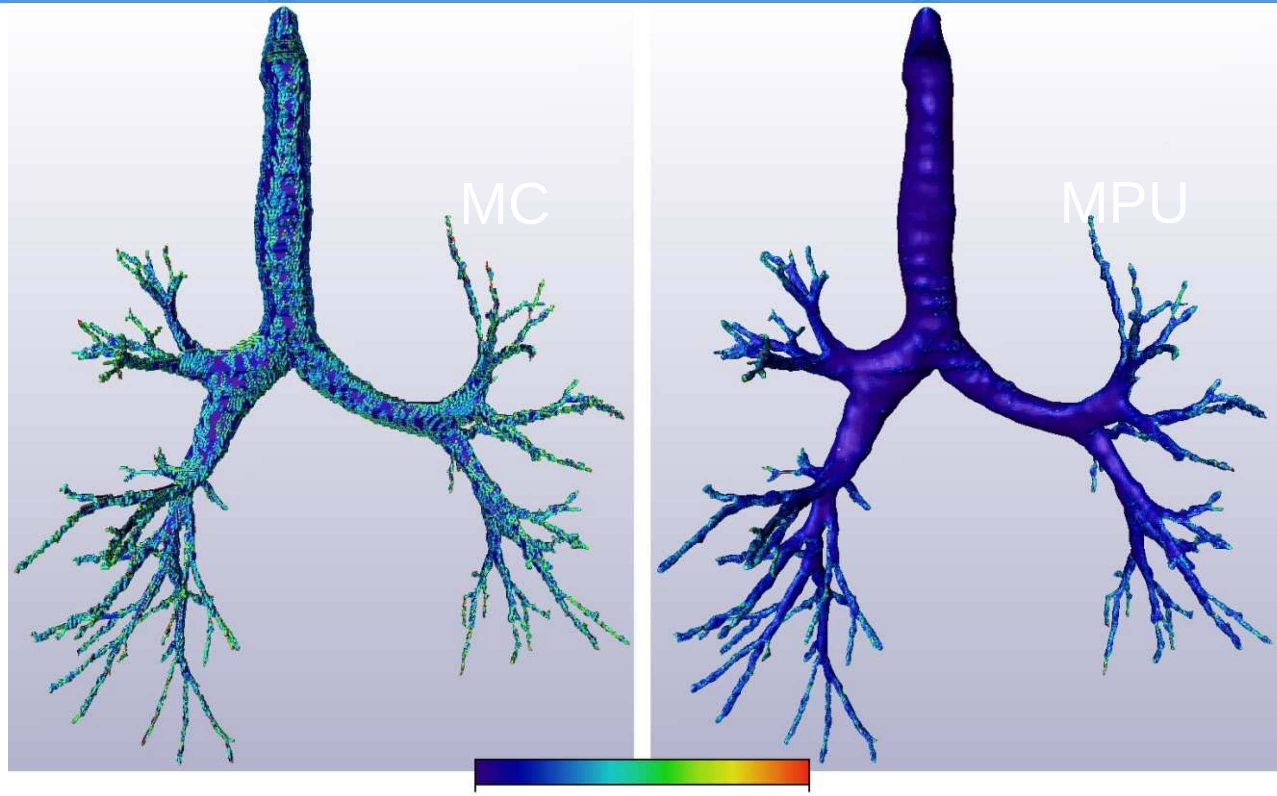


Model-Free Visualization – Results (3)

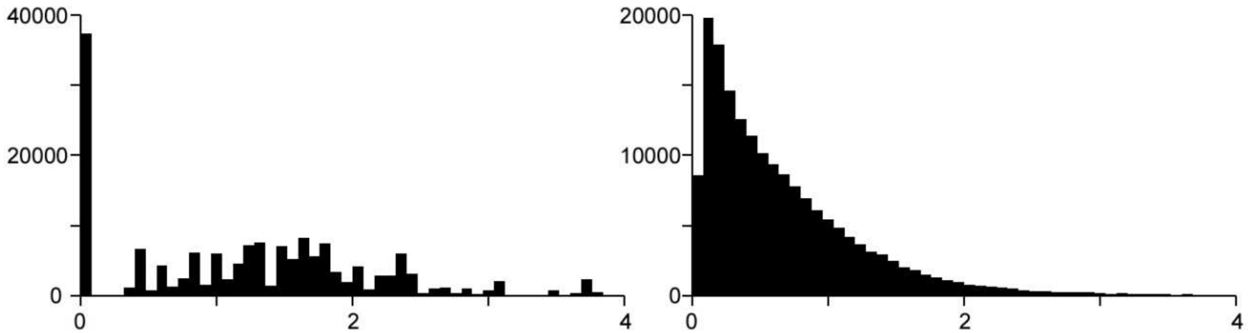


Model-Free Visualization – Smoothness

- Maximum curvature as a measure of smoothness
- Computed using AMIRA™
- Comparison of MC and MPU



- Histogram of the curvature values



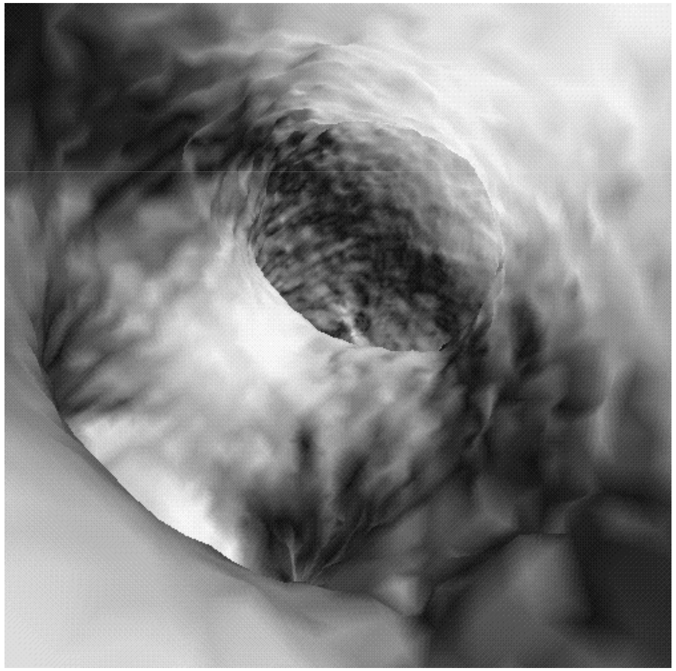
[Schumann, 2006 and 2007]

Model-Free Visualization – Surfaces Distances

Surface distances from MC- to MPU-result in voxel diagonals (V_d)

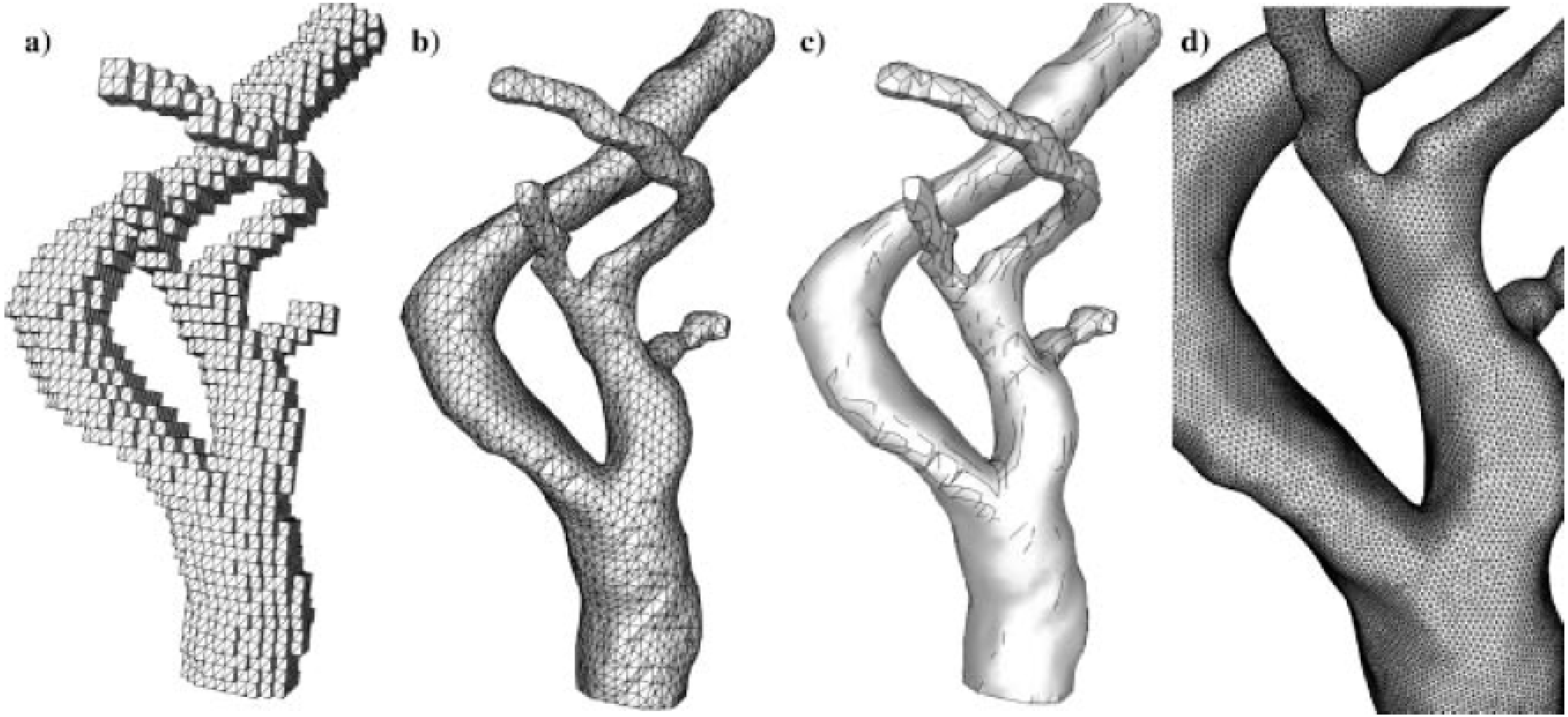
Dataset	Φ	σ	Rms	Median	Max	$>V_d/2$ [%]
Bronchial Tree	0.17	0.11	0.21	0.16	1.4	0.69
Portal Vein	0.17	0.11	0.2	0.15	0.84	0.82
Cerebral Tree	0.2	0.13	0.24	0.2	1.68	1.7
Aneurysm	0.21	0.16	0.27	0.19	1.9	4.1
Average	0.19	0.13	0.23	0.17	1.46	1.84

Virtual Angioscopy



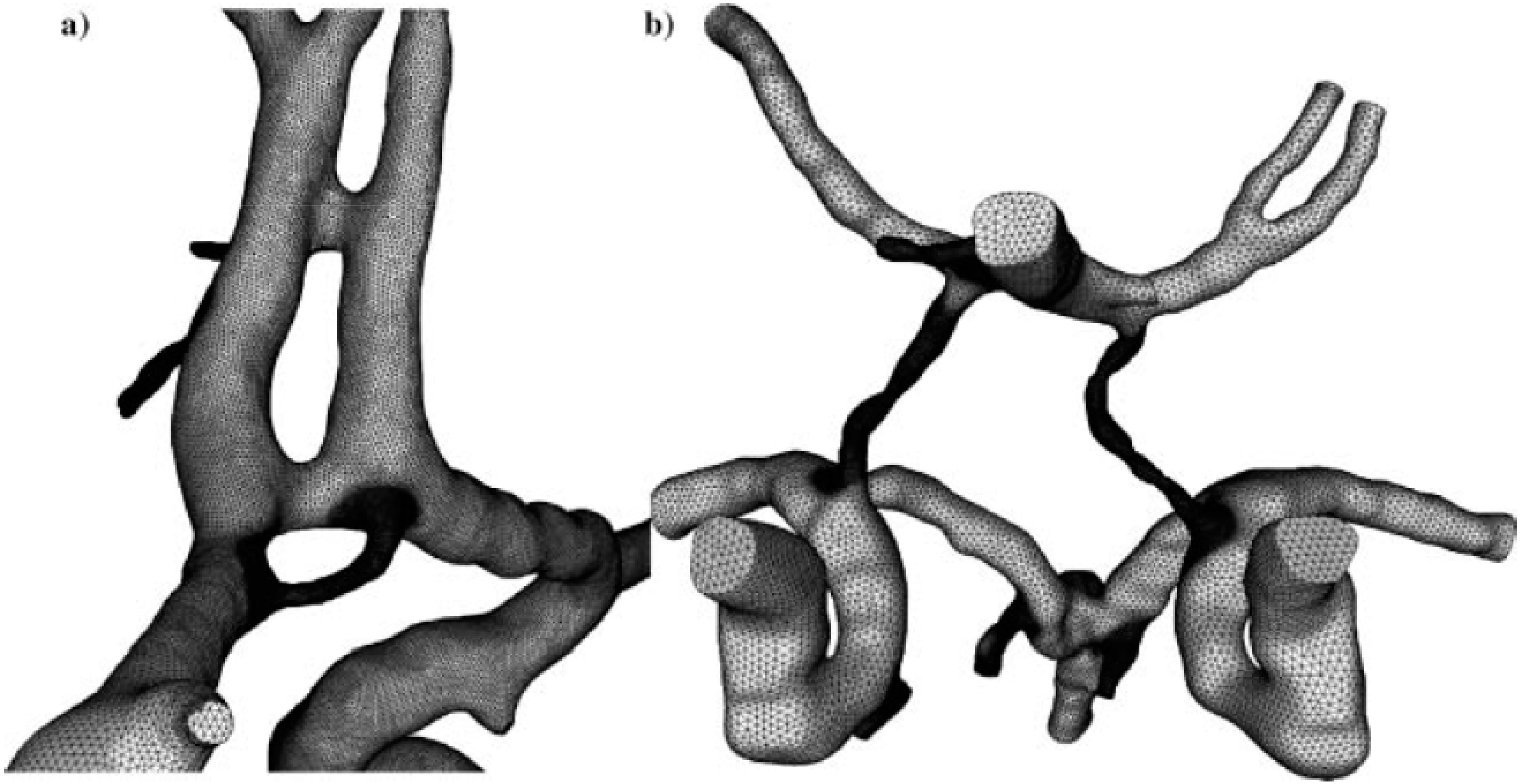
Visualization technique: Isosurface rendering based on smoothed segmentation result. Combination of overview and detail view. Specific application: Planning interventional treatment of cerebral aneurysms. [Bartz 99]

Simulation and Visualization of Blood Flow: Model Generation



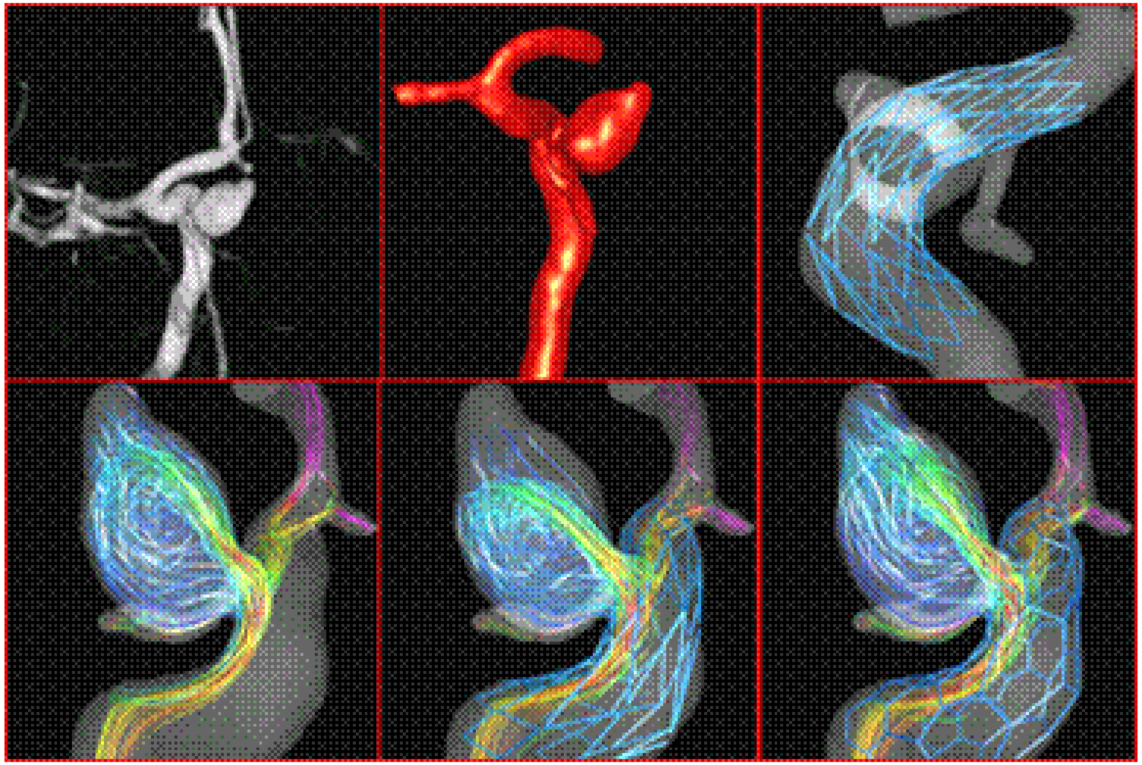
Voxel model – smoothed surface model – feature lines – adaptive refinement by considering Verfeinerung feature lines [Ceb01]

Model generation: Subdivision



- Adaptive refinement of grid resolution (element size) considering curvature
- Patient 1:   60 K Triangles →   800 K Tetraeder
- Patient 2: 175 K Triangle → 4 000 K Tetraeder, [Ceb01]

Visualization of Vasculature and Simulated Flow



- Inserting virtual stents for evaluating resulting hemodynamic situation. Clinical goal: Reconstruction of normal hemodynamic relations by optimal choic and placement of a stent
- Source: Webpage Juan Cebral

Conclusion

- Therapy planning and medical education require clear communication of topology and morphology
- Model-based reconstruction of the vascular surface
  - *Subdivison* and *Convolution Surfaces* closely adhere to the data and generate smooth, organic looking surfaces
- !!! Not suitable for vessel diagnosis due to simplifying model assumption of circular cross-sections
- Vessel diagnosis requires accurate representation of vascular cross-section
- Model-free reconstruction of the vascular surface directly from the segmentation result by means of MPUs
- !!! Suitable for vessel diagnosis since no model assumption is made
- Quantitative analysis of global/local deviations for validation

Future Work

- Accelerating the visualization with Convolution Surfaces and MPUs to facilitate an application in clinical routine
- Hybrid visualization, integrating Convolution Surfaces and MPUs for vessel parts with nearly circular cross-sections and for vessel parts whose cross-sections strongly deviate from this model assumption, respectively
- Mapping of additional information to the vascular surface, e.g. existence of plaque or blood flow quantities
- Adapting general methods to specific needs, e.g., exploration of the cardiovascular system

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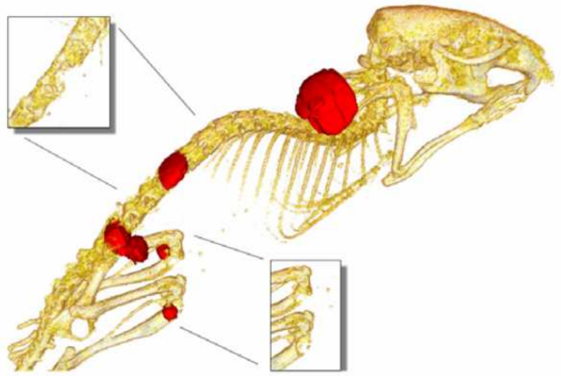
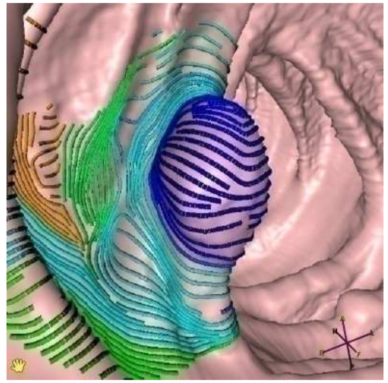
DTI Visualisation

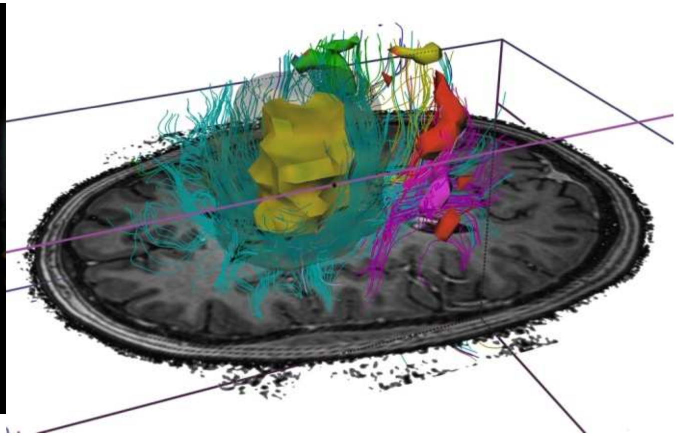


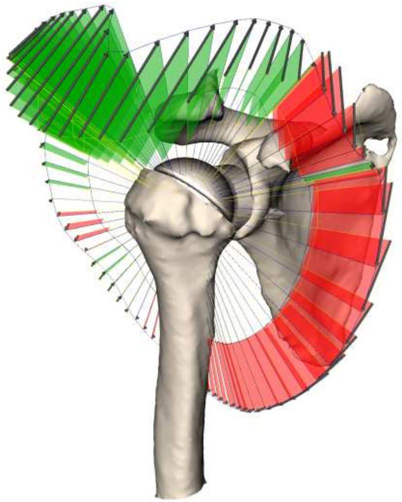
Dr. Charl Botha
TU Delft / Leiden University Medical Centre

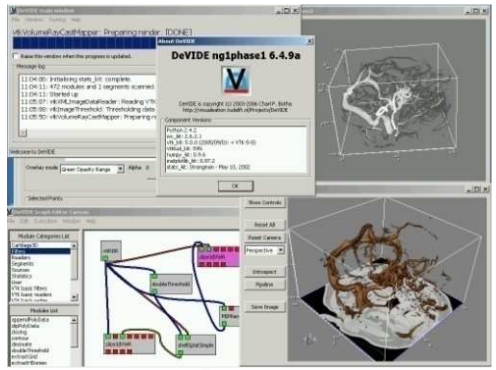


http://visualisation.tudelft.nl/CharlBotha
http://visualisation.tudelft.nl/MedVis

Research by:
Jorik Blaas, Charl Botha, Charles Majoie (AMC),
Bart Peters (AMC), Aart Nederveen (AMC), Frans Vos, Frits Post







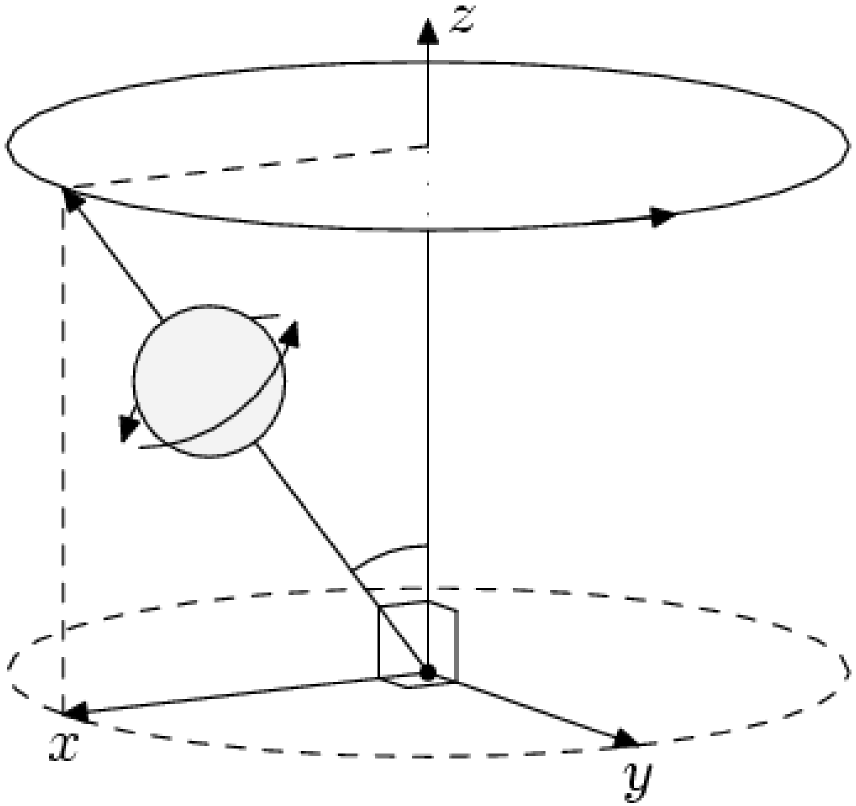
Delft University of Technology

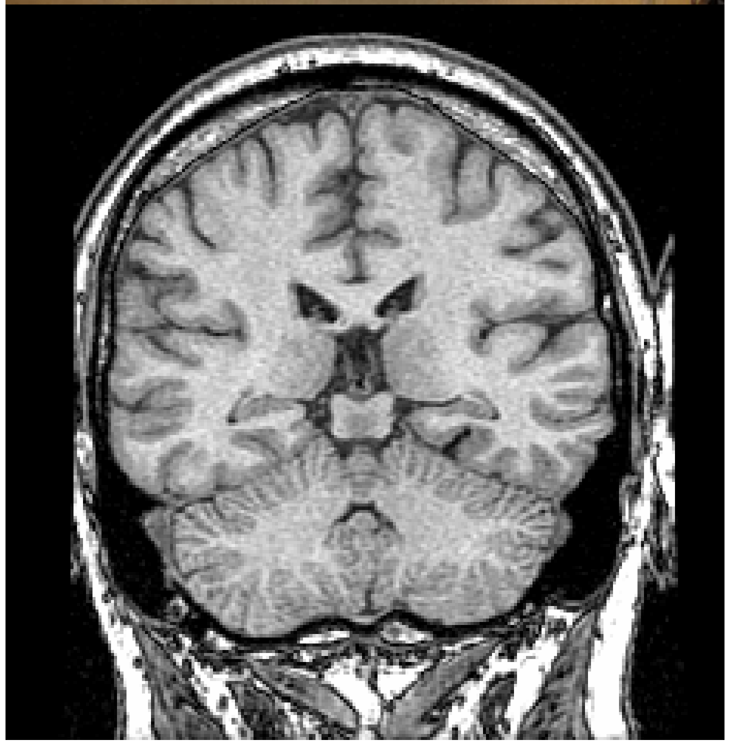
Overview

- General DTI Visualisation.
- Fast selection of interesting fibre bundles.
- fMRI + DTI resection planning prototype.

MRI in 20 seconds

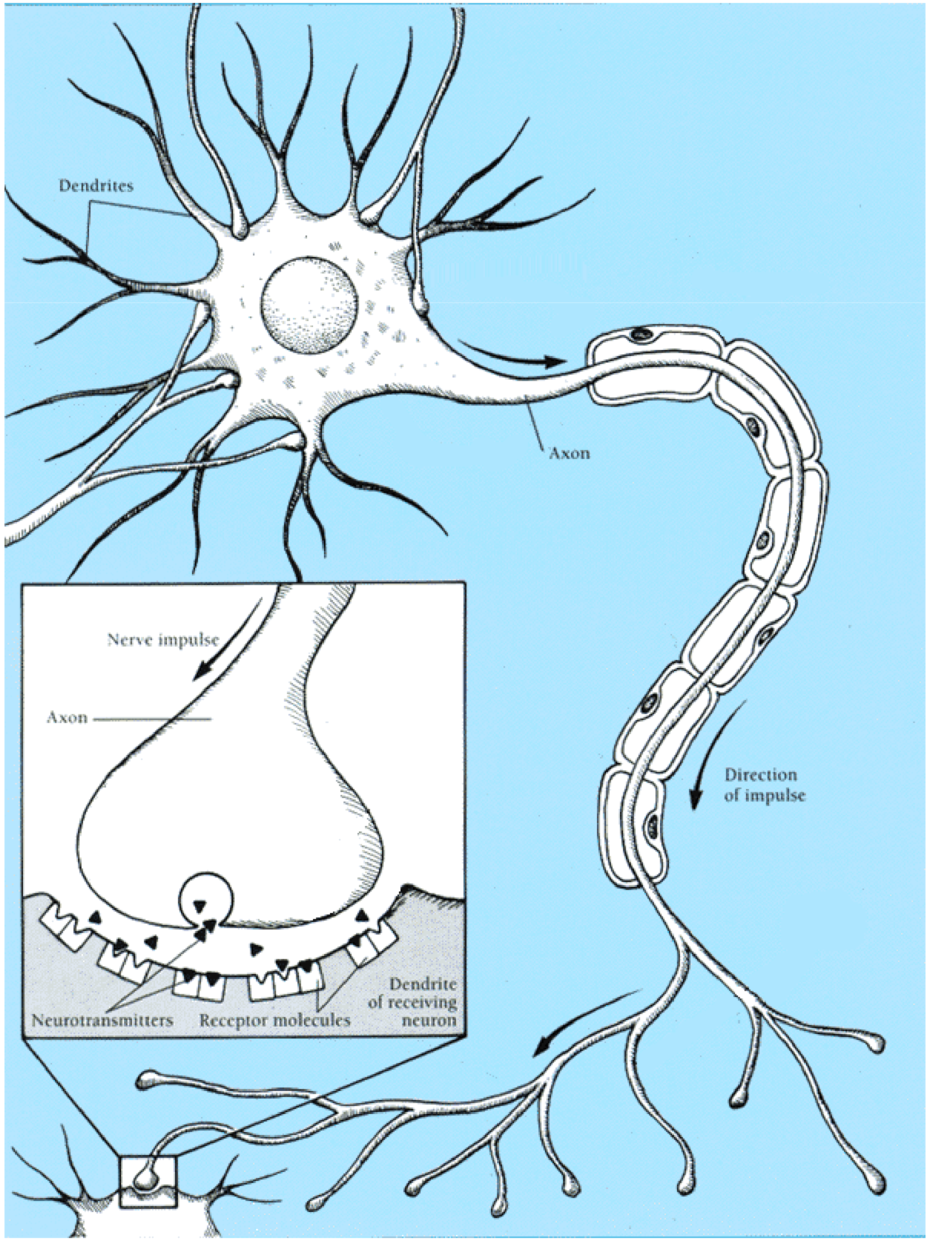
- Protons spin.
- In a B-field, they precess.
- Knock down with RF.
- They recover, we measure.





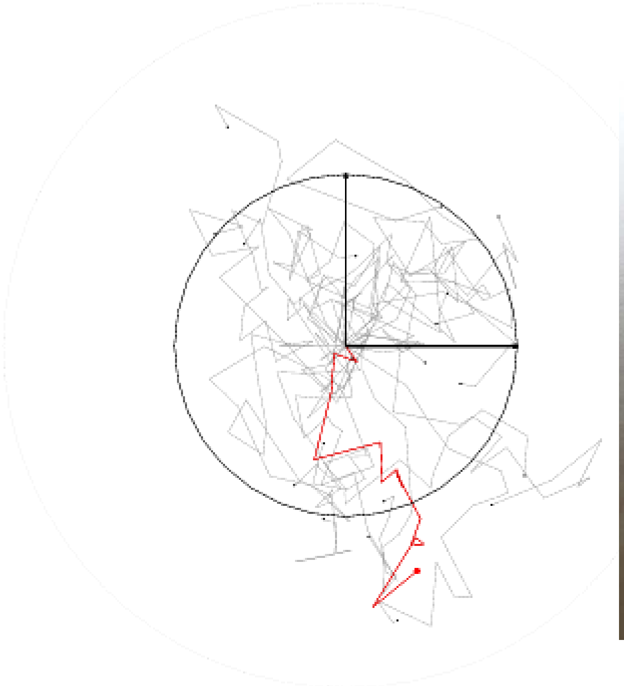
Physiology of the neuron

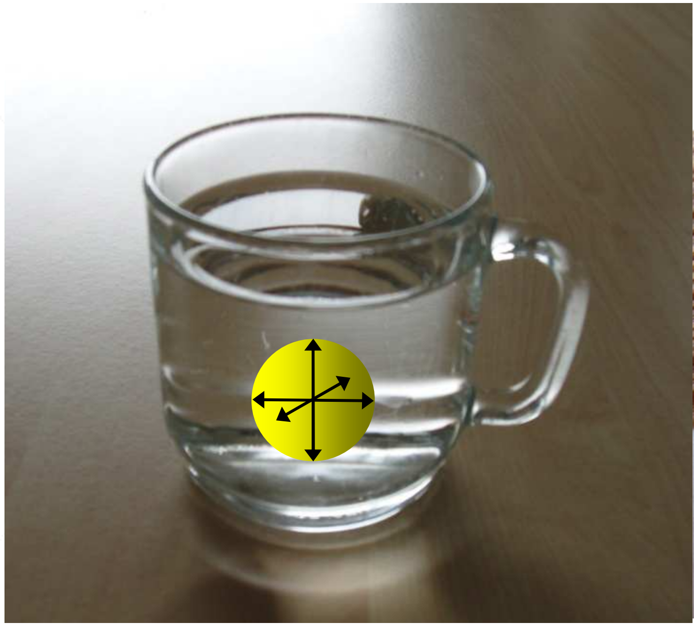
- There are ±100 billion*, i.e. 100 thousand million of these in your head.
- Axons form fibre bundles connecting regions of activity in your brain.
- Myelin sheaths surround axons.



Water diffusion

- Brownian motion.
- Free vs restricted.



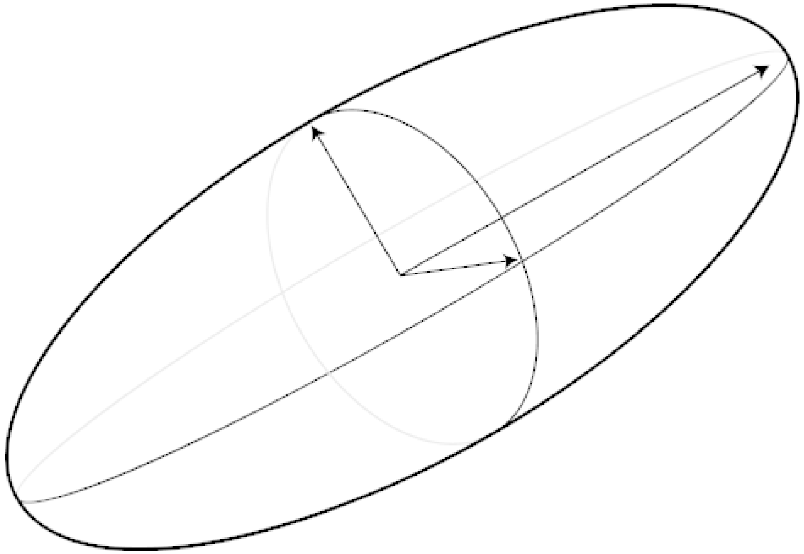


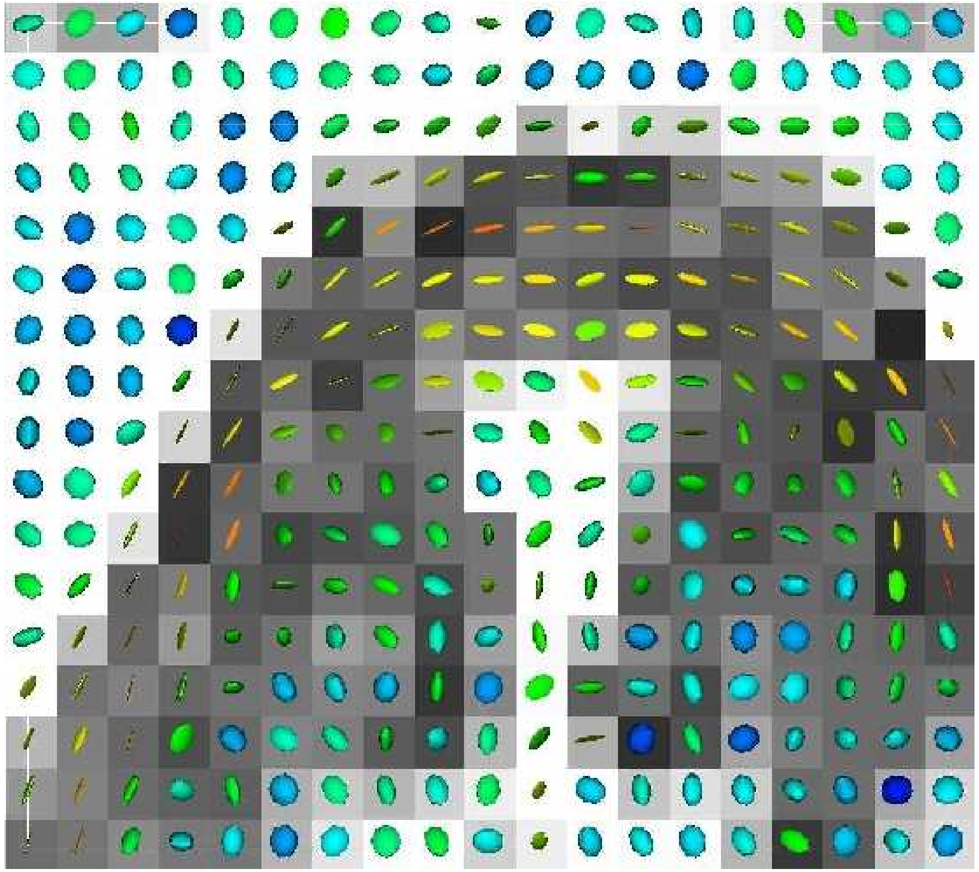
The Diffusion Tensor

- Water diffusion is restricted by neuron fibre bundles.
- Time passes between knocking over a precessing proton and measuring its response.
- If the proton moves, it affects the measurement!
- Do a number of diffusion weighted measurements.
- Reconstruct tensors (3x3 matrices) at all measurement points.
- This tensor represents the water diffusion at any point.
- Its eigenvectors and eigenvalues define an ellipsoid that also describes water diffusion at that point.

Diffusion Tensors

- Ellipsoid visualisation:

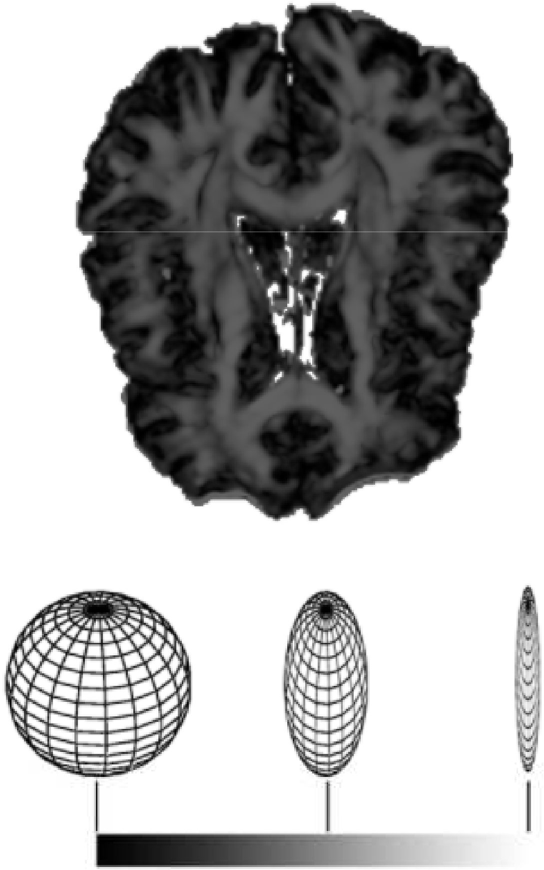


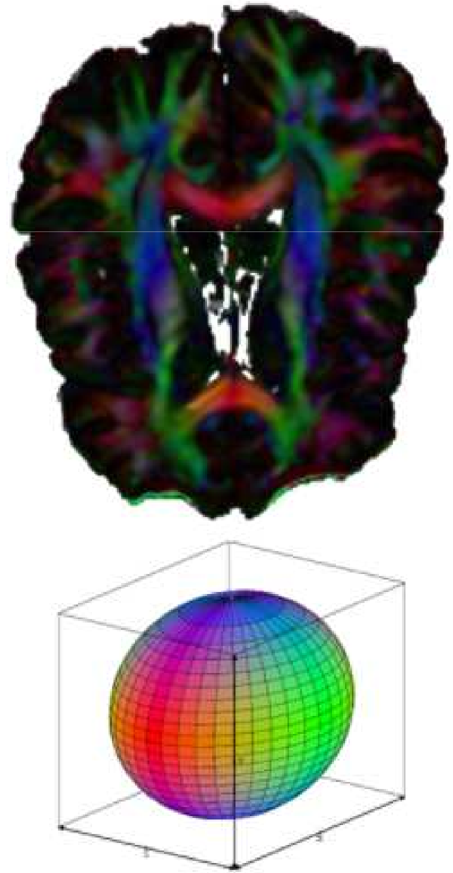


Water Diffusion in the Brain

Simulation of the diffusion of water particles in a slice of the human brain, based on DTI.

FA and direction maps

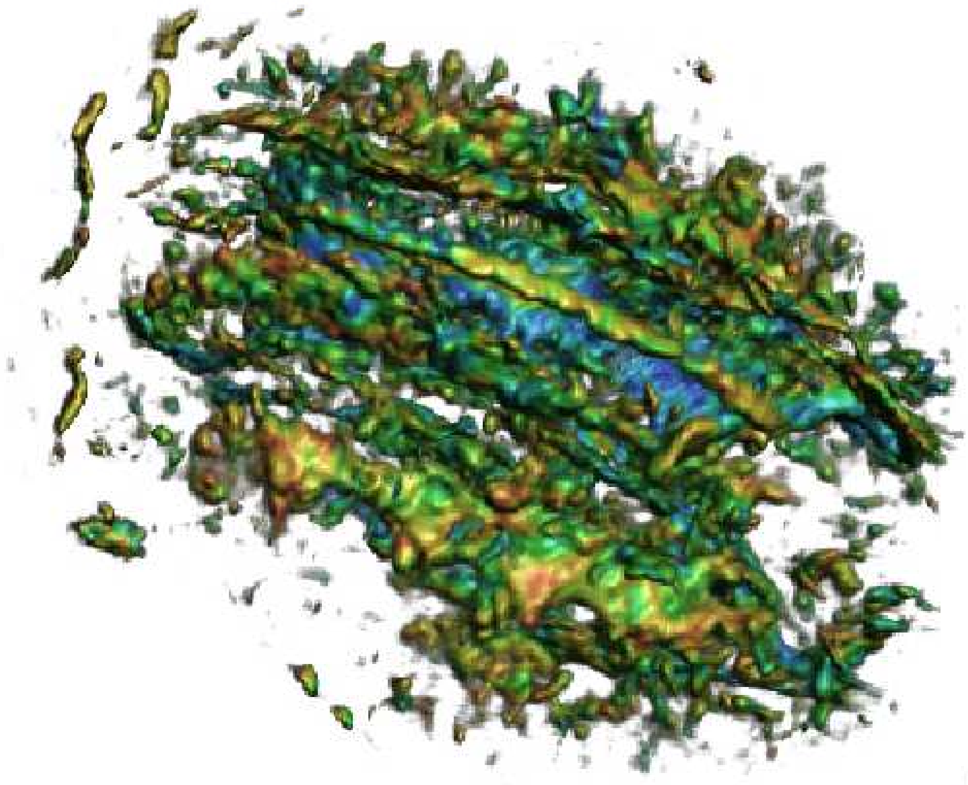


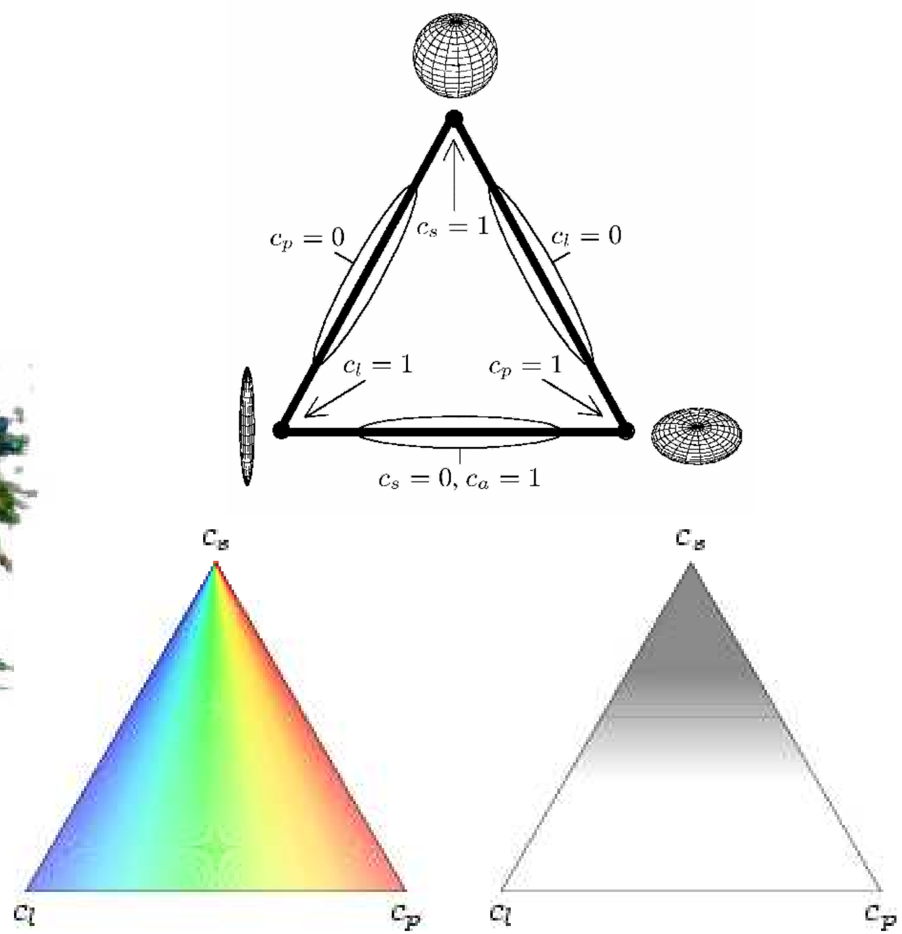


- Fractional anisotropy: eigenvalue-derived metric mapped to greyscale.
- Direction map: principal eigenvector mapped to colour.

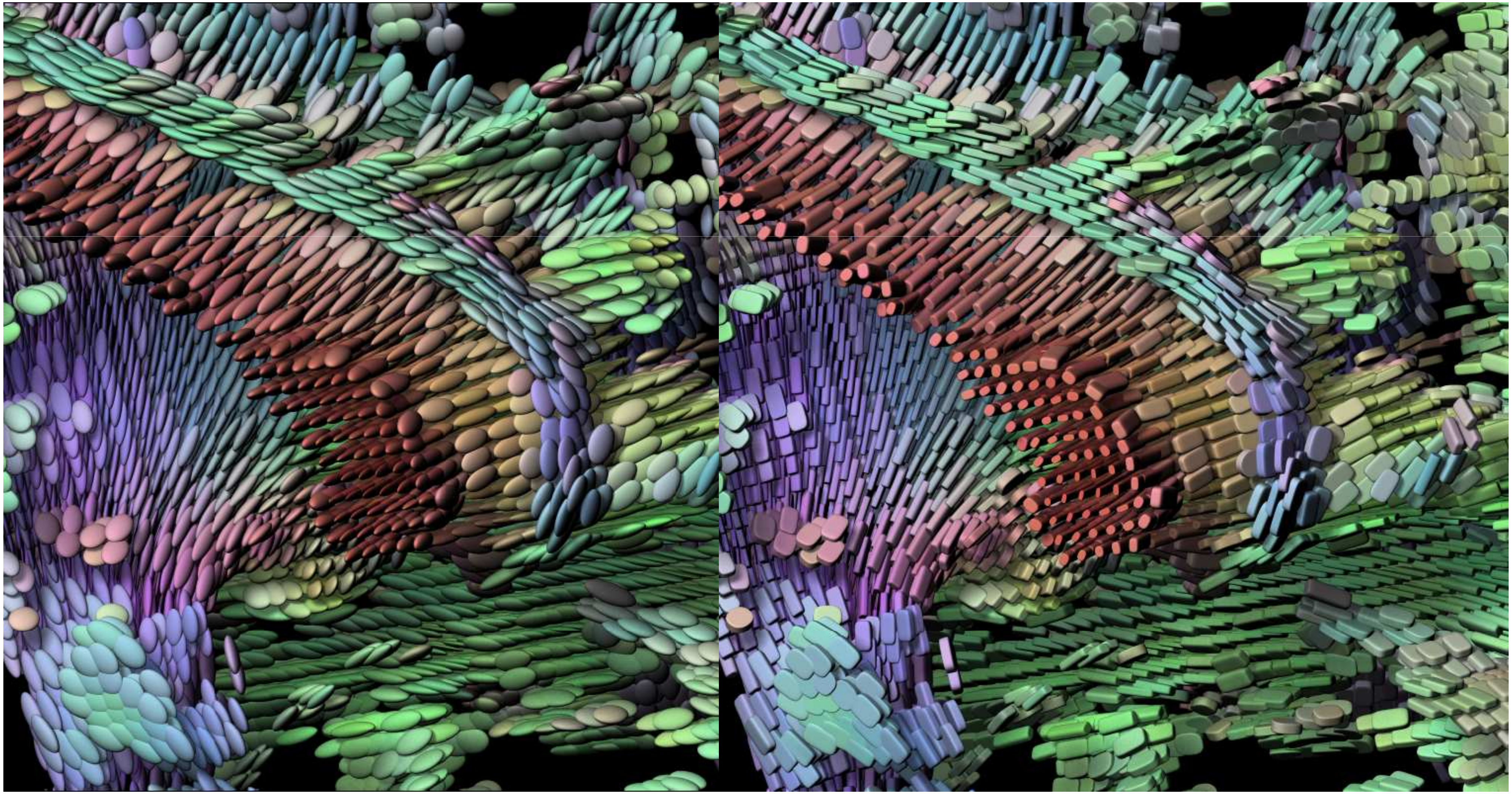
Direct Volume Rendering

- Assign colour + opacity based on tensor shape.





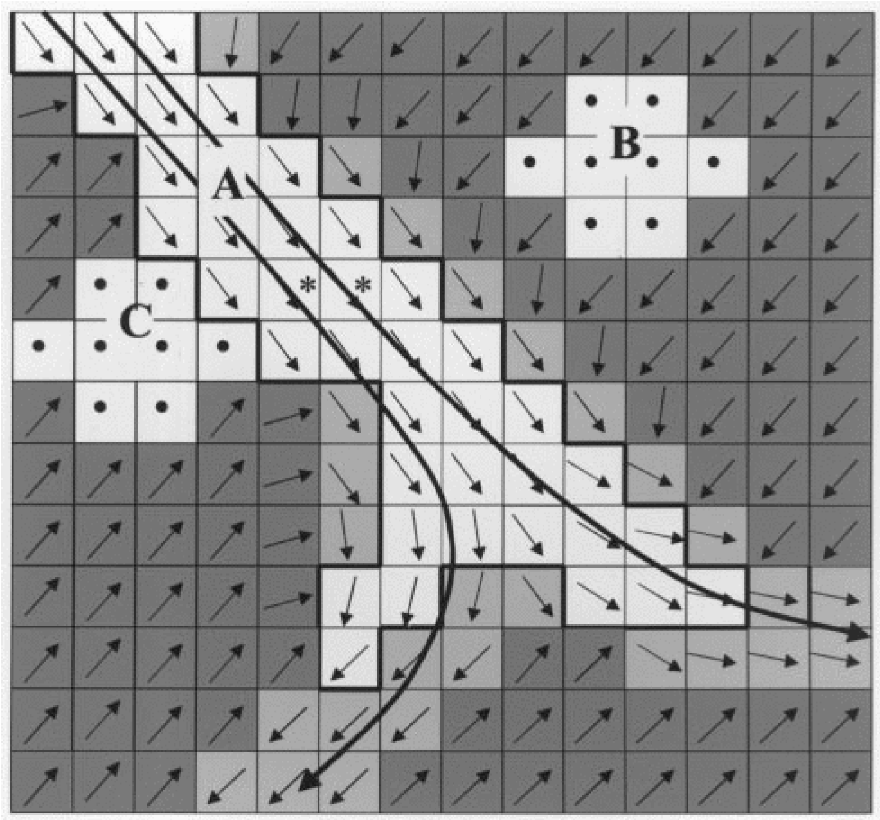
Glyphs in 3D



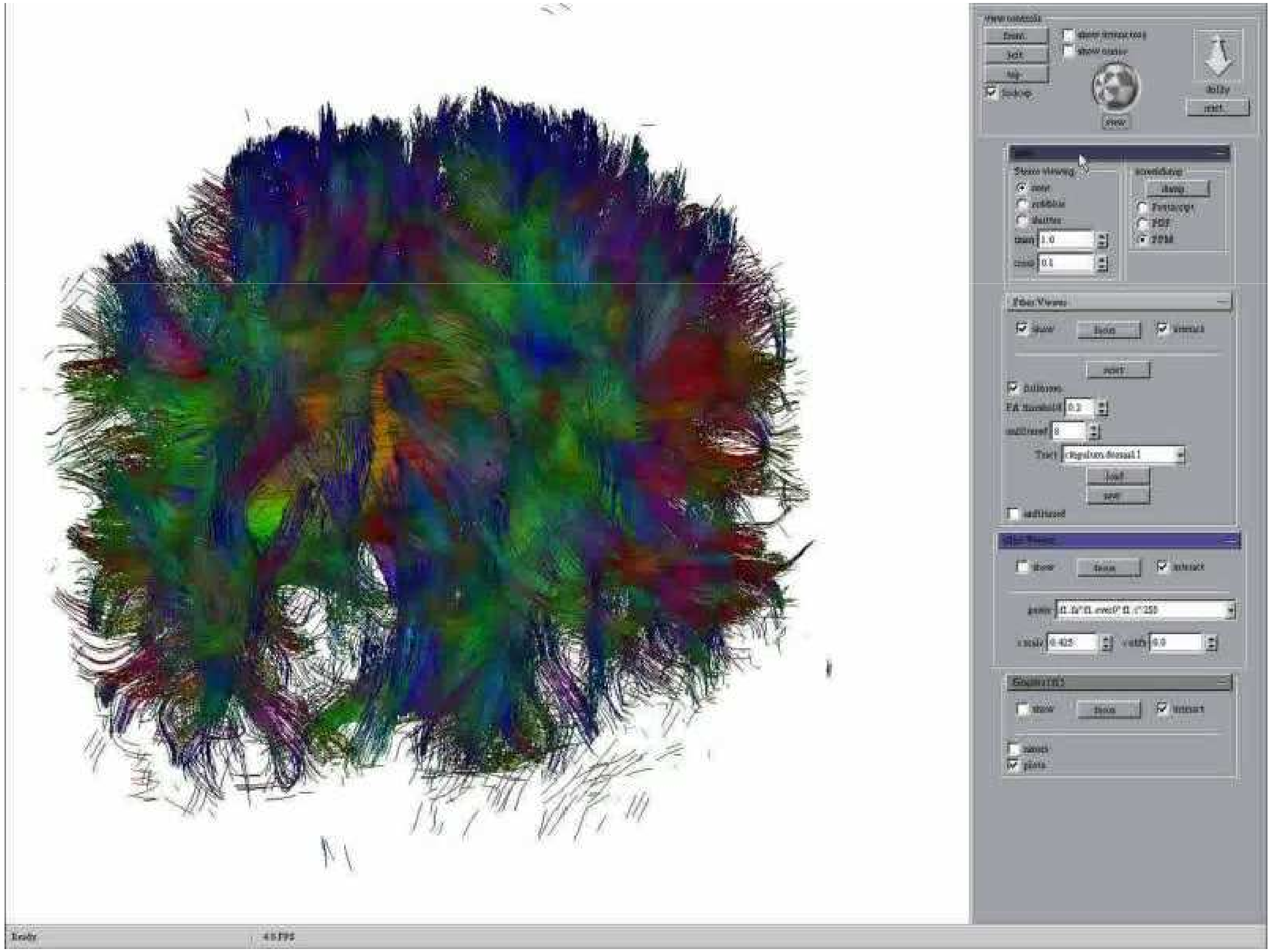
G. Kindlmann, Eurovis 2007: Tensor information can be mapped more completely to superquadric shape.

Fibre tracking

- We are actually interested in the connections.
- Use whole tensor / principal vector to derive curves *possibly* representing fibre bundles.
- Traditionally: Only track through ROI (3D).



Full brain tracking

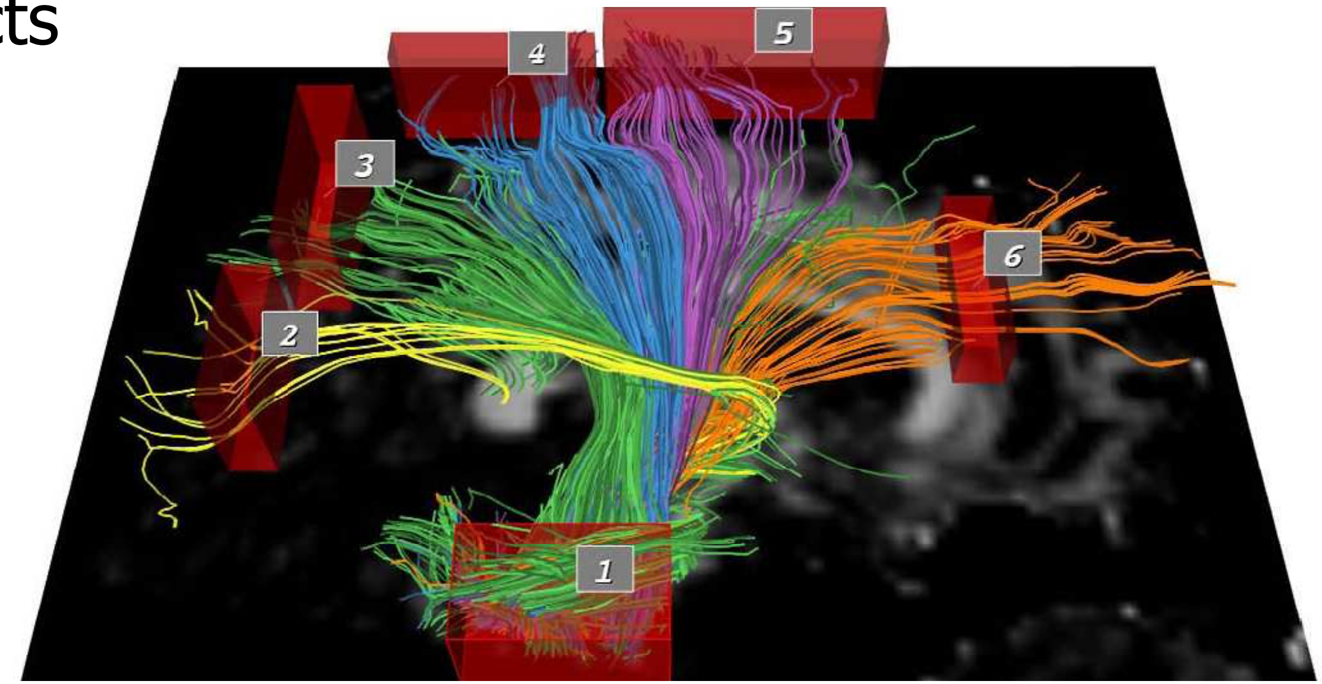


- Full-brain tracking is colourful, but not effective.
- How do we find the bundles that we want?

Problem selecting the 'right' fibers

Akers et al. (2004) introduced an interactive full-brain selection method.

- Accurate selection using multiple movable objects
- Filtering is performed on the full brain tractography
- Selection of a fiber depends on intersection with the movable objects



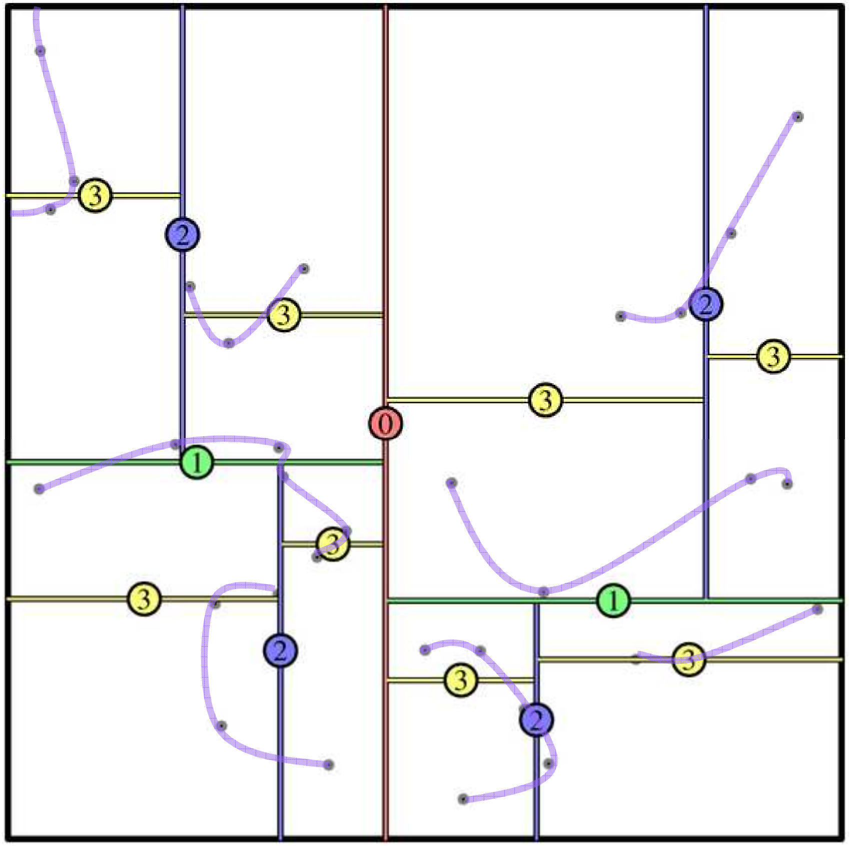
[Akers et al, Vis2004]

Performing selection Interactively

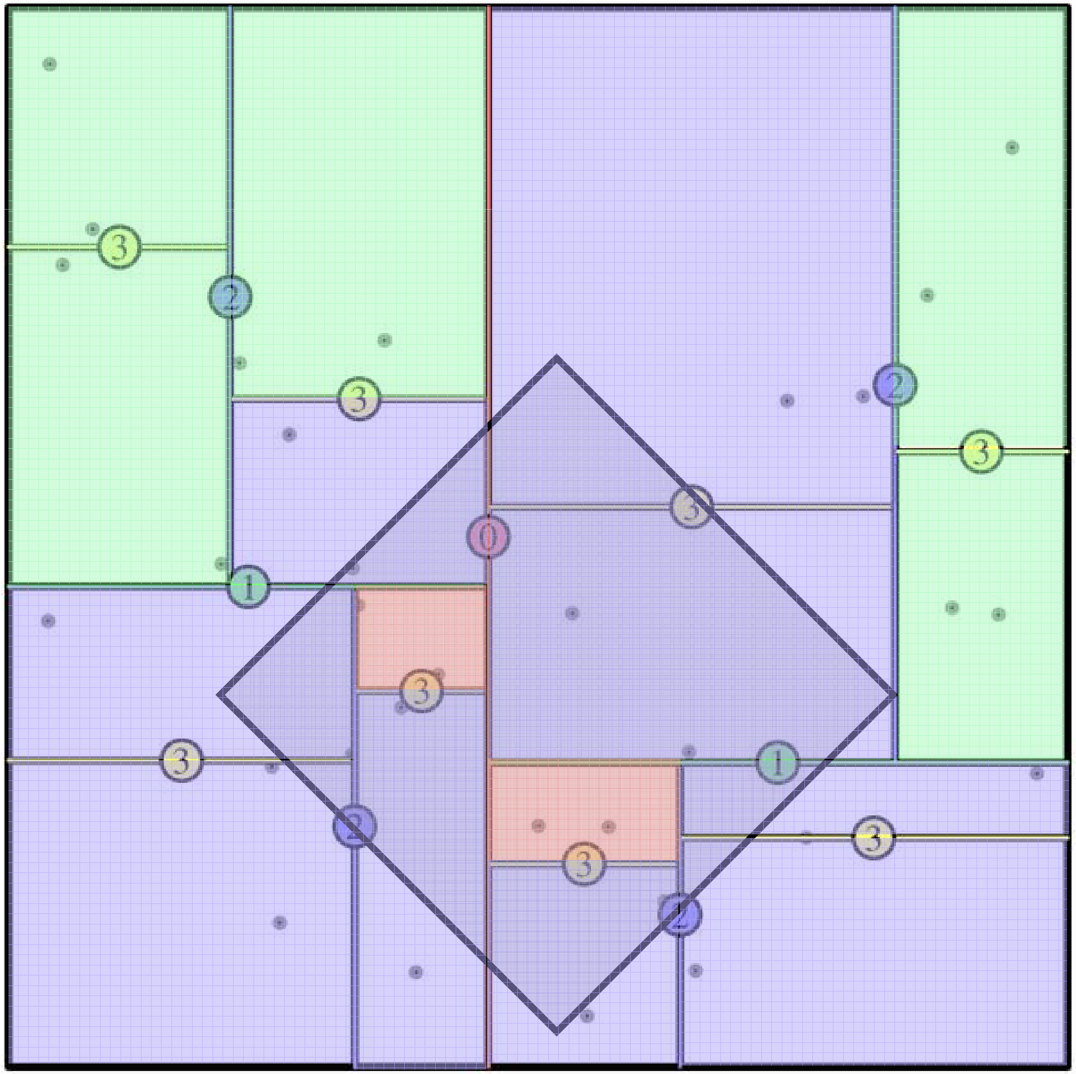
- More speed allows us to handle larger tractographies. (>40000 fibers, >2.5 million points)
- Faster response-time will ease the interactive selection process

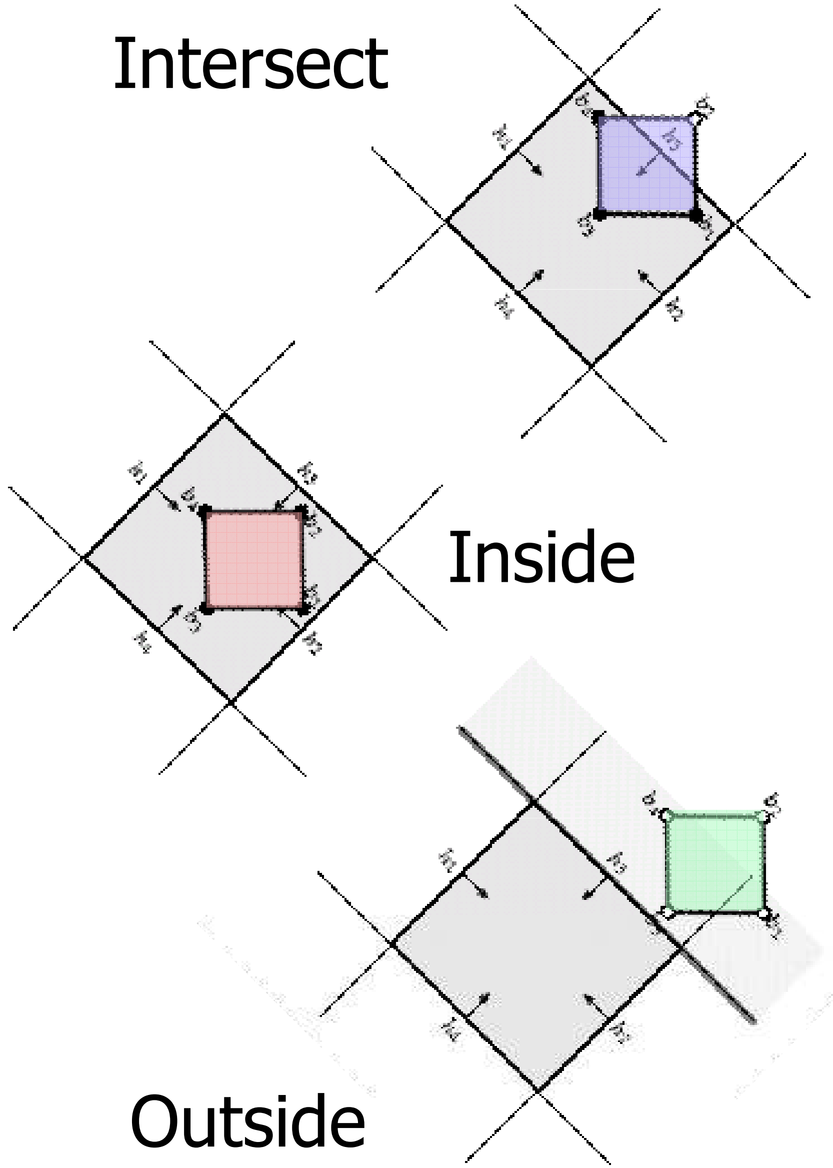
Making Things Interactive

- Spatial data structure storing all points of all fibers
- Fast queries enumerating all points in a convex volume



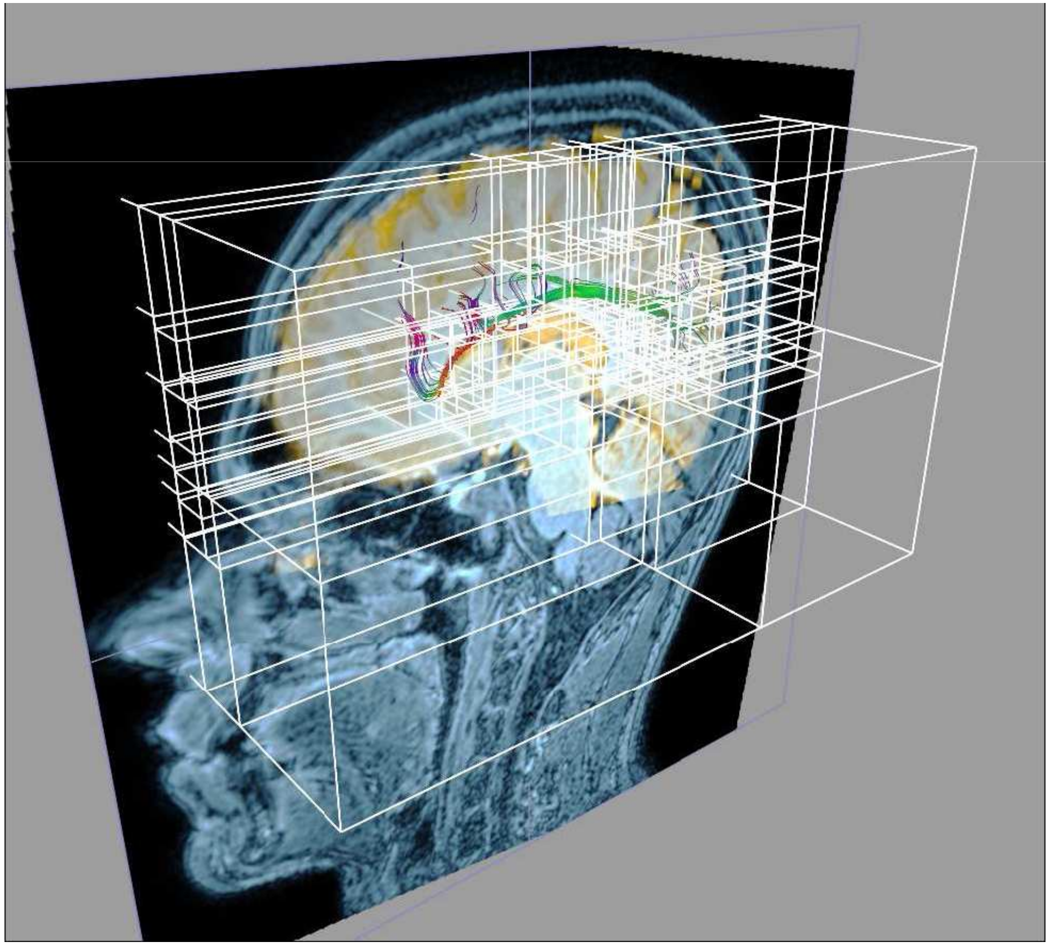
KD Trees



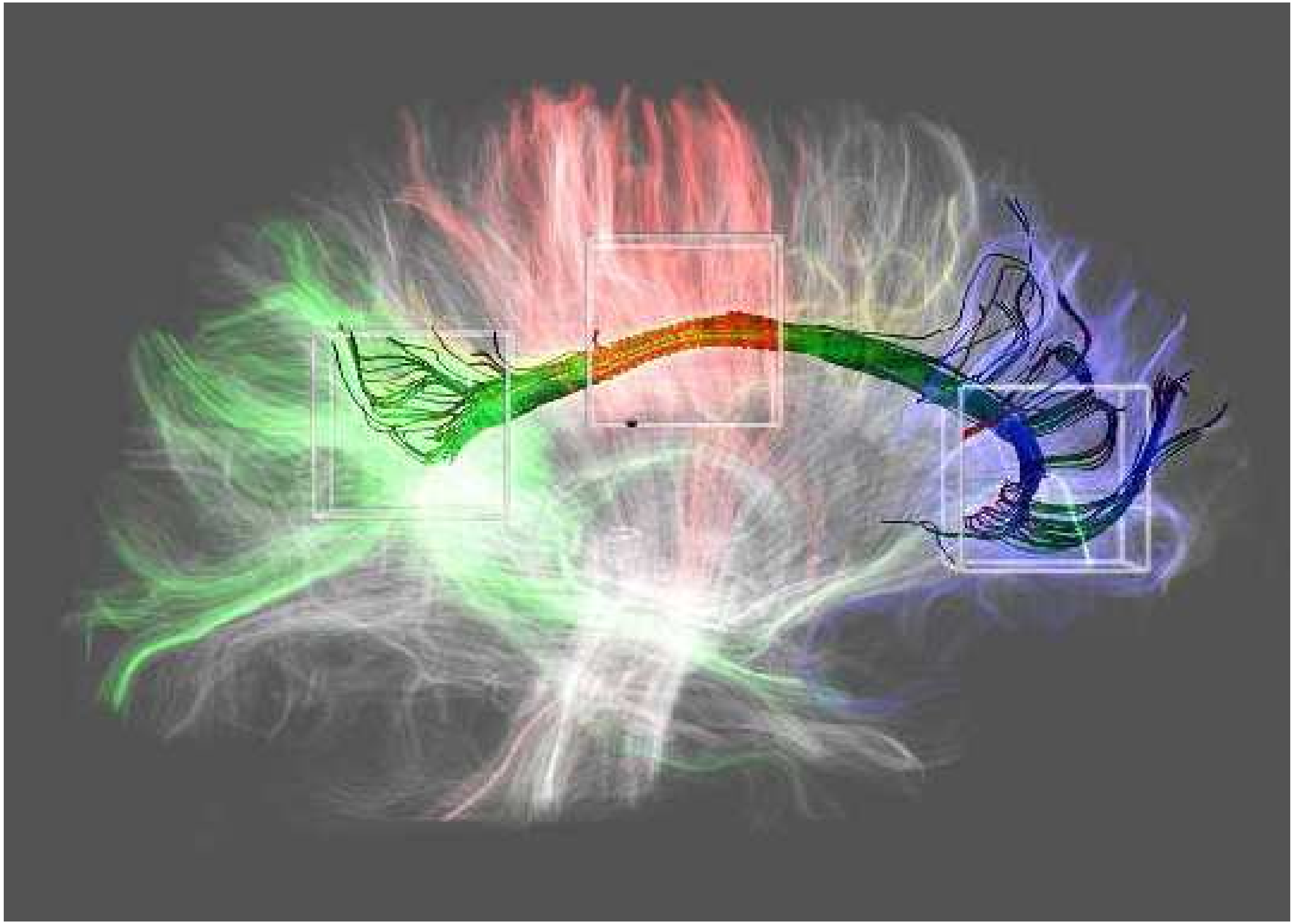


Fast Queries using the KD-Tree

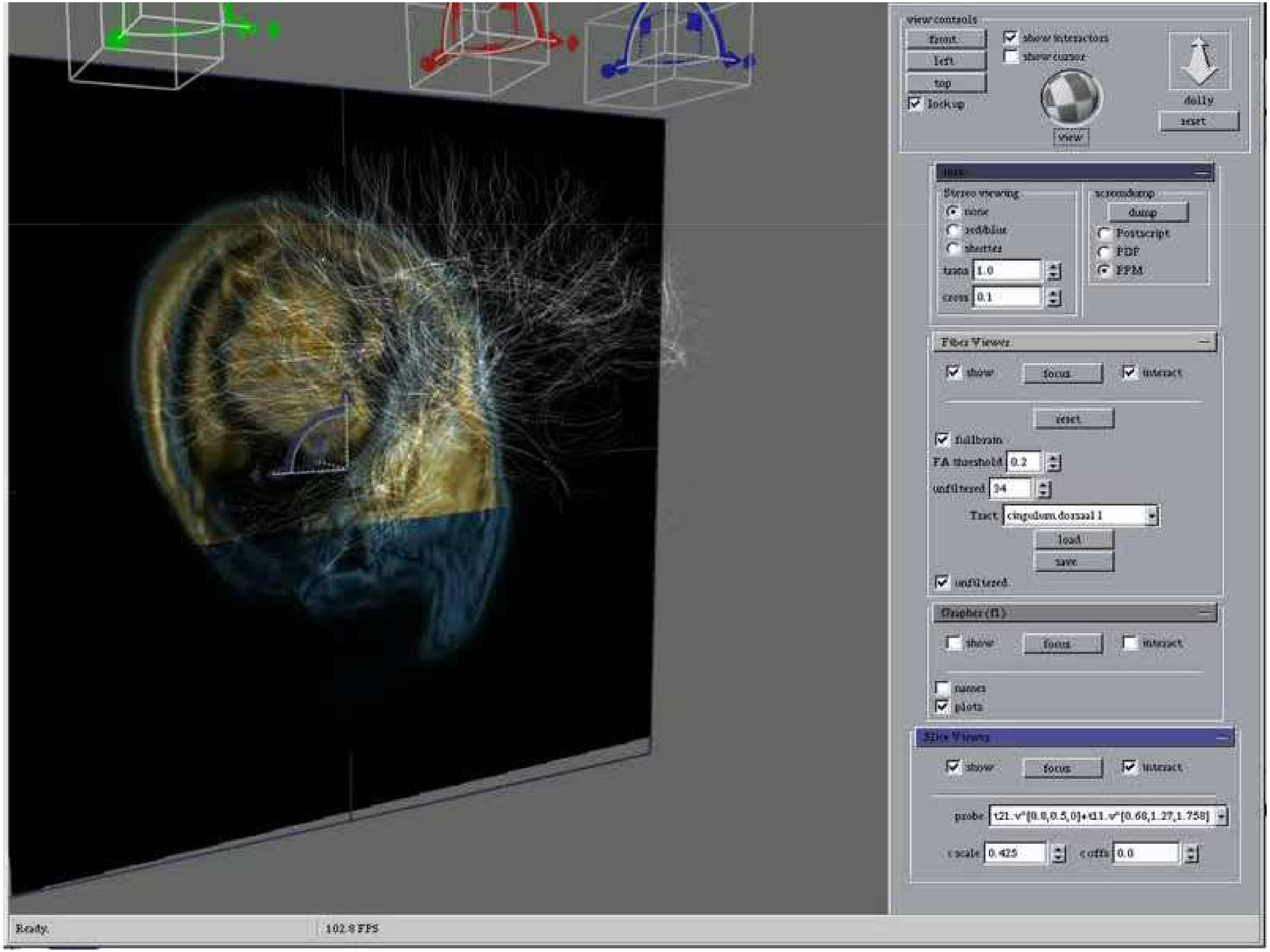
- Enumerating the fibers that pass through a given box can be performed at >50 fps. [1.5-3.5 Mfibers/sec]
- Multiple selection boxes can be used.
- Selections can be combined using arbitrary Boolean expressions.



Using Multiple Selection Areas



Advanced fibre-tracking!



Reproducibility Results

- Correlation between two observers of 0.903 and 0.976 for the right and left cingulum respectively.

	Left Cingulum		Right Cingulum	
Percentile	Obs. 1	Obs. 2	Obs. 1	Obs. 2
25	4359.25	4370.25	4969.00	5039.25
50	4801.00	4742.00	5505.50	5513.00
75	5196.75	5329.75	5689.50	5760.00
IQR	837.50	959.50	720.50	720.75

J. Blaas, C. P. Botha, B. Peters, F. M. Vos, and F. H. Post, Fast and reproducible fiber bundle selection in DTI visualization, *in* Proceedings of IEEE Visualization 2005 *(C. Silva, E. Gröller, and H. Rushmeier, eds.), pp. 59--64, October 2005.*

B. D. Peters, L. de Haan, N. Dekker, J. Blaas, H. E. Becker, P. M. Dingemans, E. M. Akkerman, C. B. Majoie, T. van Amelsvoort, G. J. den Heeten, and D. H. Linszen, White matter fibertracking in first-episode schizophrenia, schizoaffective patients and subjects at ultra-high risk of psychosis., *Neuropsychobiology*, vol. 58, no. 1, pp. 19--28, 2008.

DTI + fMRI planning prototype

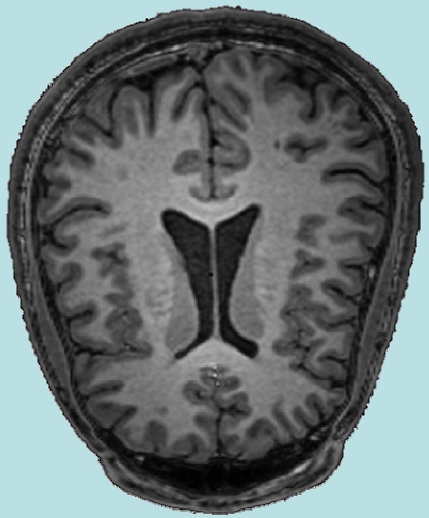
- Goal: *To assist brain tumor resection by combining multiple MRI datasets*
- Method: *Multi-field data fusion and interactive exploration*

J. Blaas, C. P. Botha, C. Majoie, A. Nederveen, F. M. Vos, and F. H. Post, Interactive visualization of fused fMRI and DTI for planning brain tumor resections, *in* Proc. SPIE Medical Imaging 2007 *(K. R. Cleary and M. I. Miga, eds.), vol. 6509, 2007.*

Magnetic Resonance Imaging

- Multiple types of MRI scans are available:
  - **Structural MRI**
  - Diffusion Tensor Imaging
  - Functional MRI (activation areas)

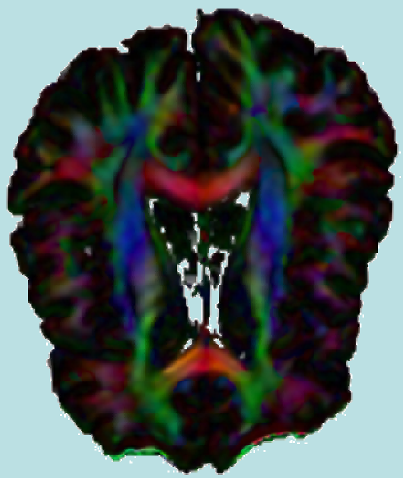
High Resolution
(0.5x0.5x1mm)
Good Context for orientation



Magnetic Resonance Imaging

- Multiple types of MRI scans are available:
  - Structural MRI
  - **Diffusion Tensor Imaging**
  - Functional MRI (activation areas)

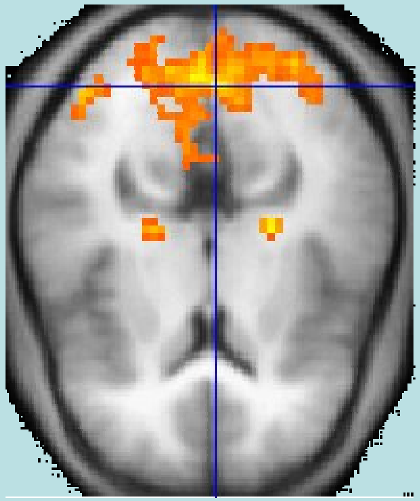
Tensor-valued fields
Can show the structure of nerve bundles
Lower Resolution



Magnetic Resonance Imaging

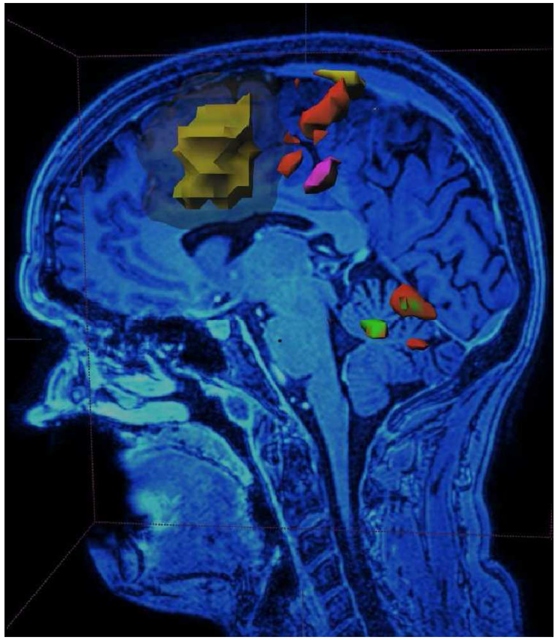
- Multiple types of MRI scans are available:
  - Structural MRI
  - Diffusion Tensor Imaging
  - **Functional MRI (activation areas)**

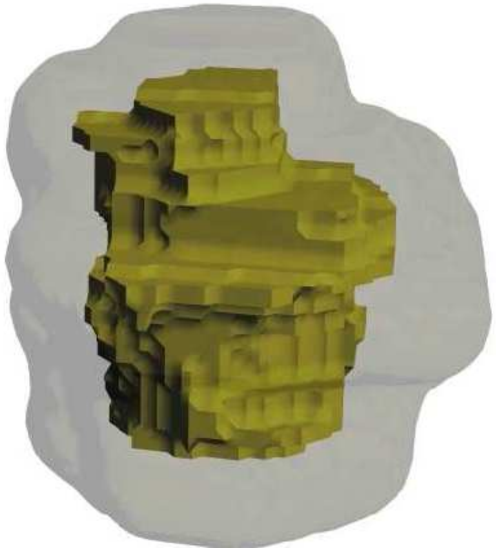
Scans are made while patient performs a task
Oxygenization is monitored
Areas in the brain used for the task can be extracted
Very Low Resolution



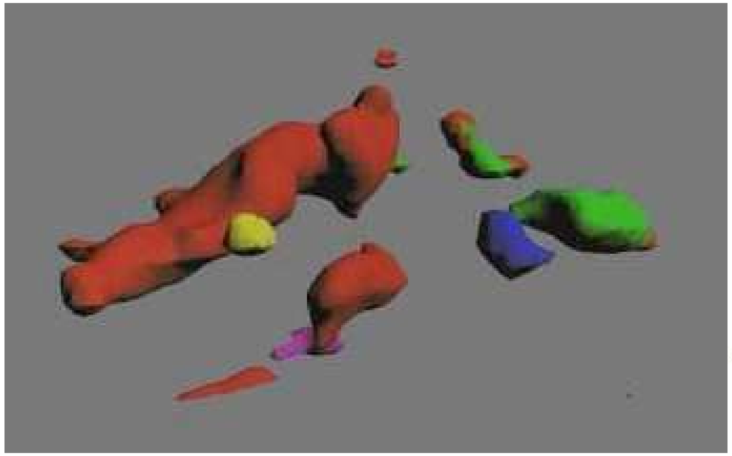
Visualizing the available data

- structural MRI T1
- fMRI: hand/foot L/R
- DTI + full-brain tractography

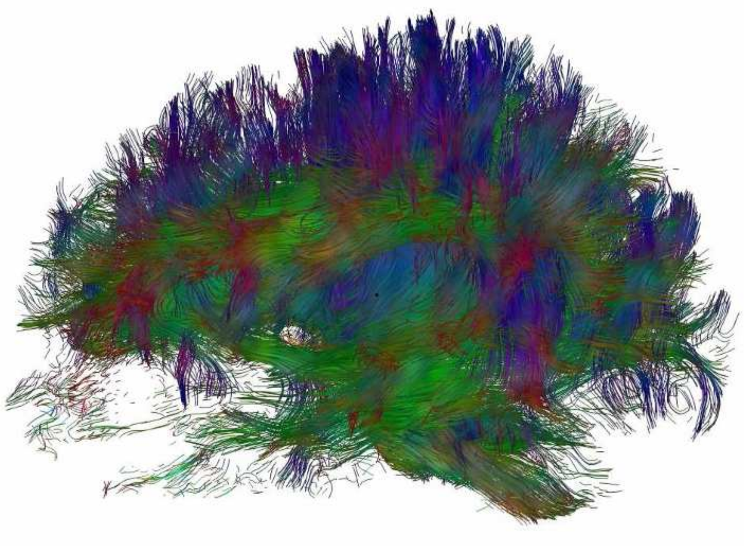




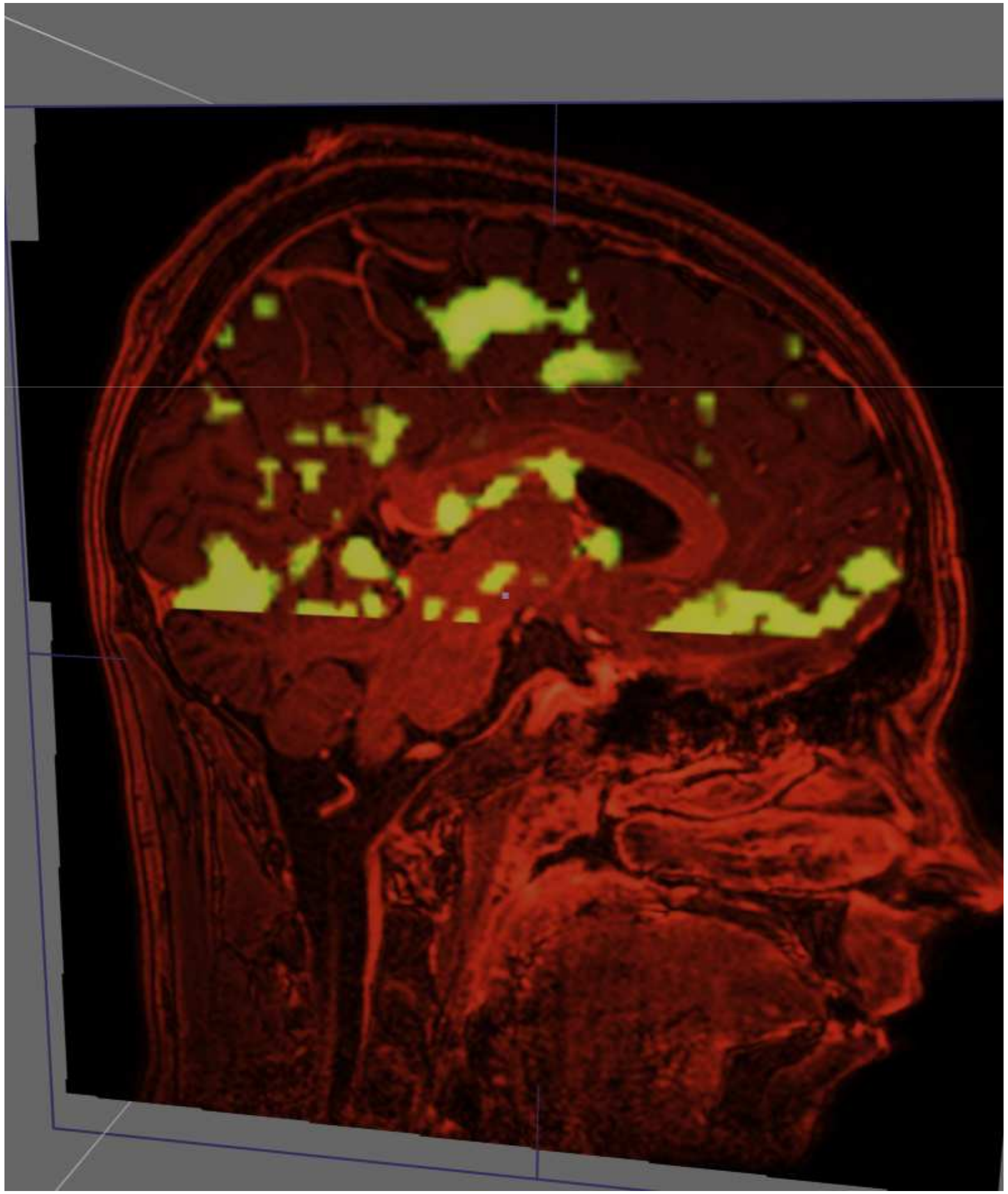
T1: tumor



fMRI: activation zones



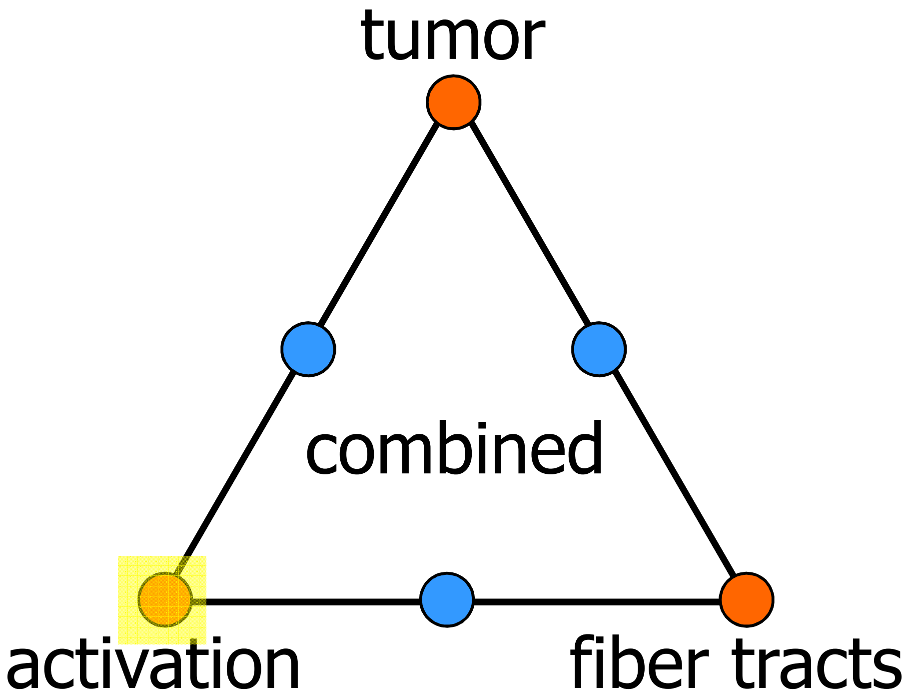
DTI: fiber tracts

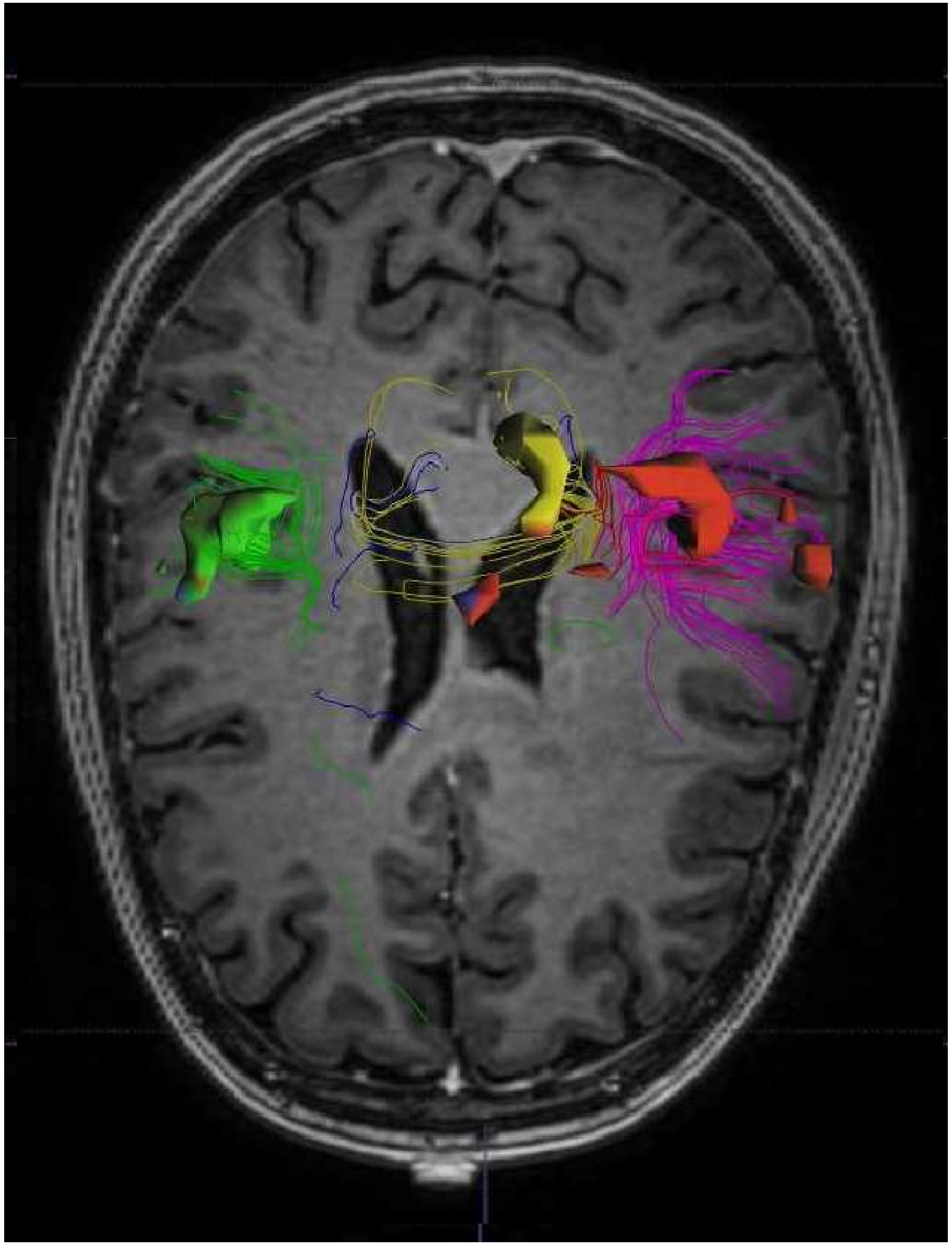


Activation and Structural

interactive queries:

- tumor vicinity
- activation zones
- fiber tract selection

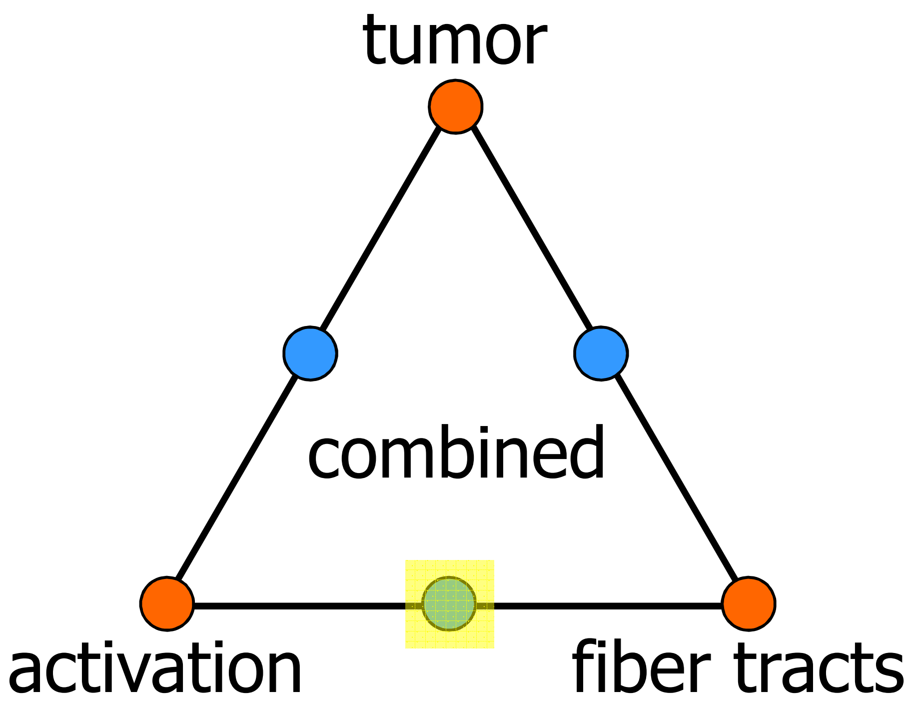


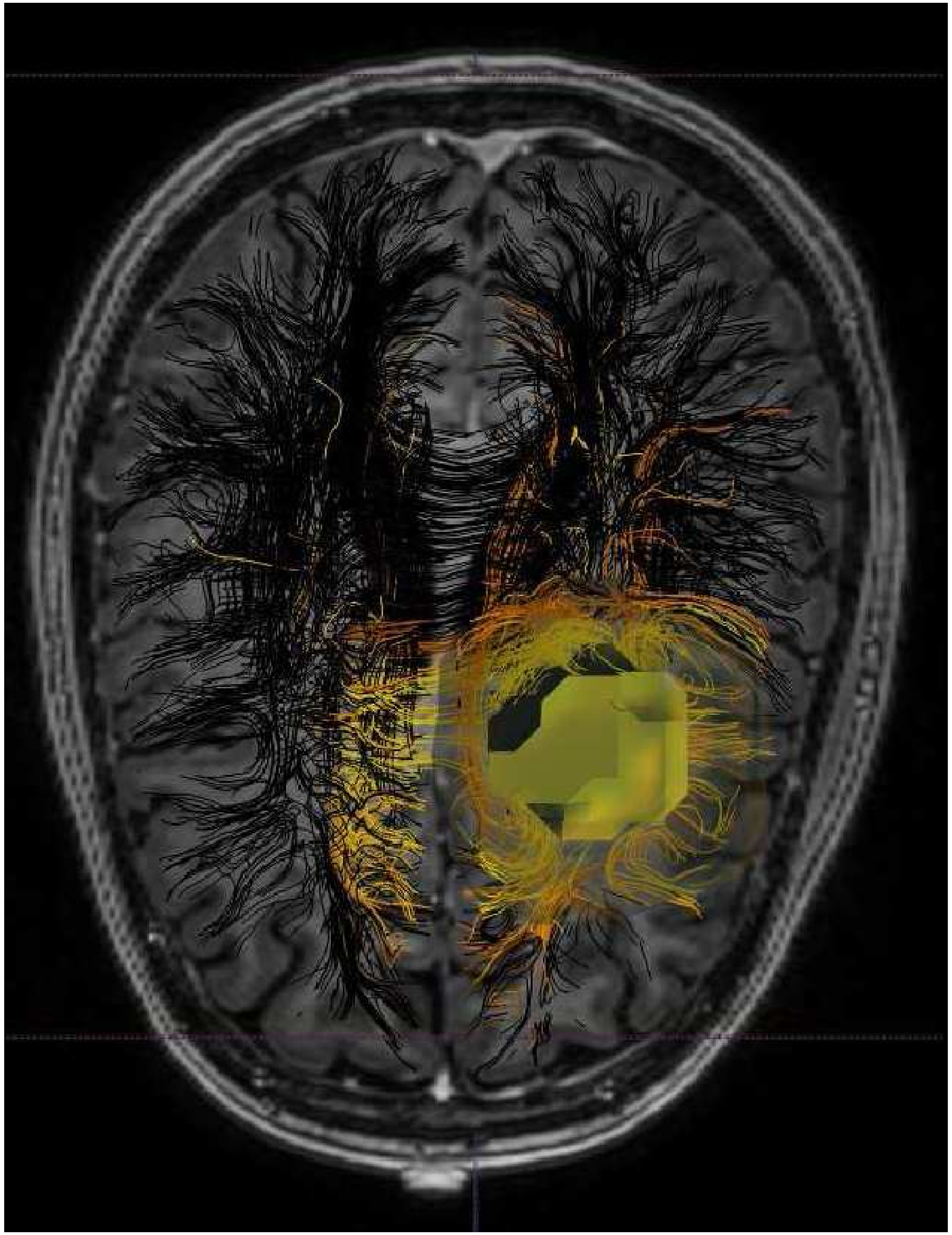


by activation zones

interactive queries:

- tumor vicinity
- activation zones
- fiber tract selection

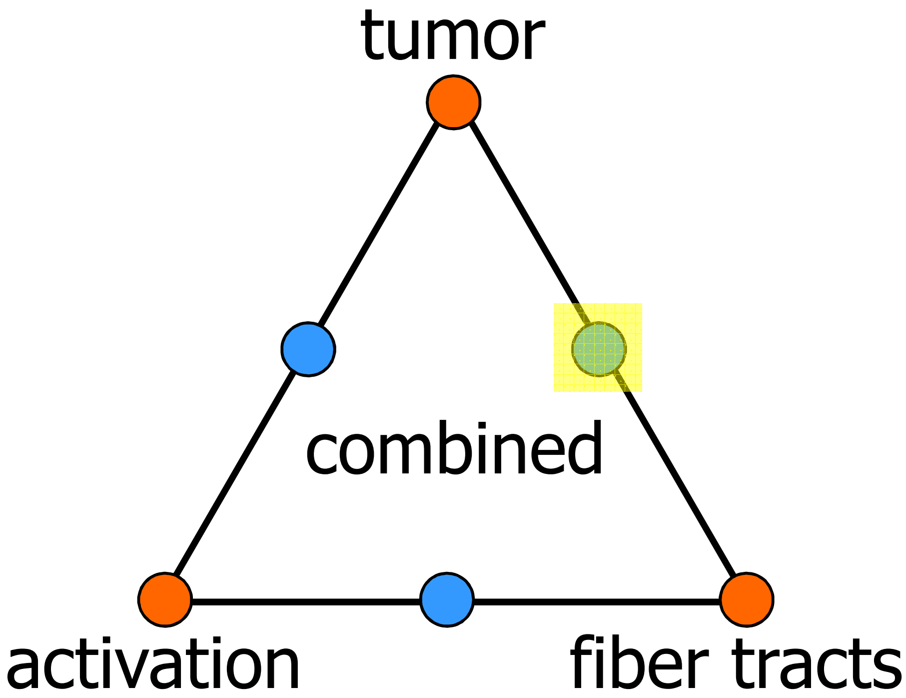


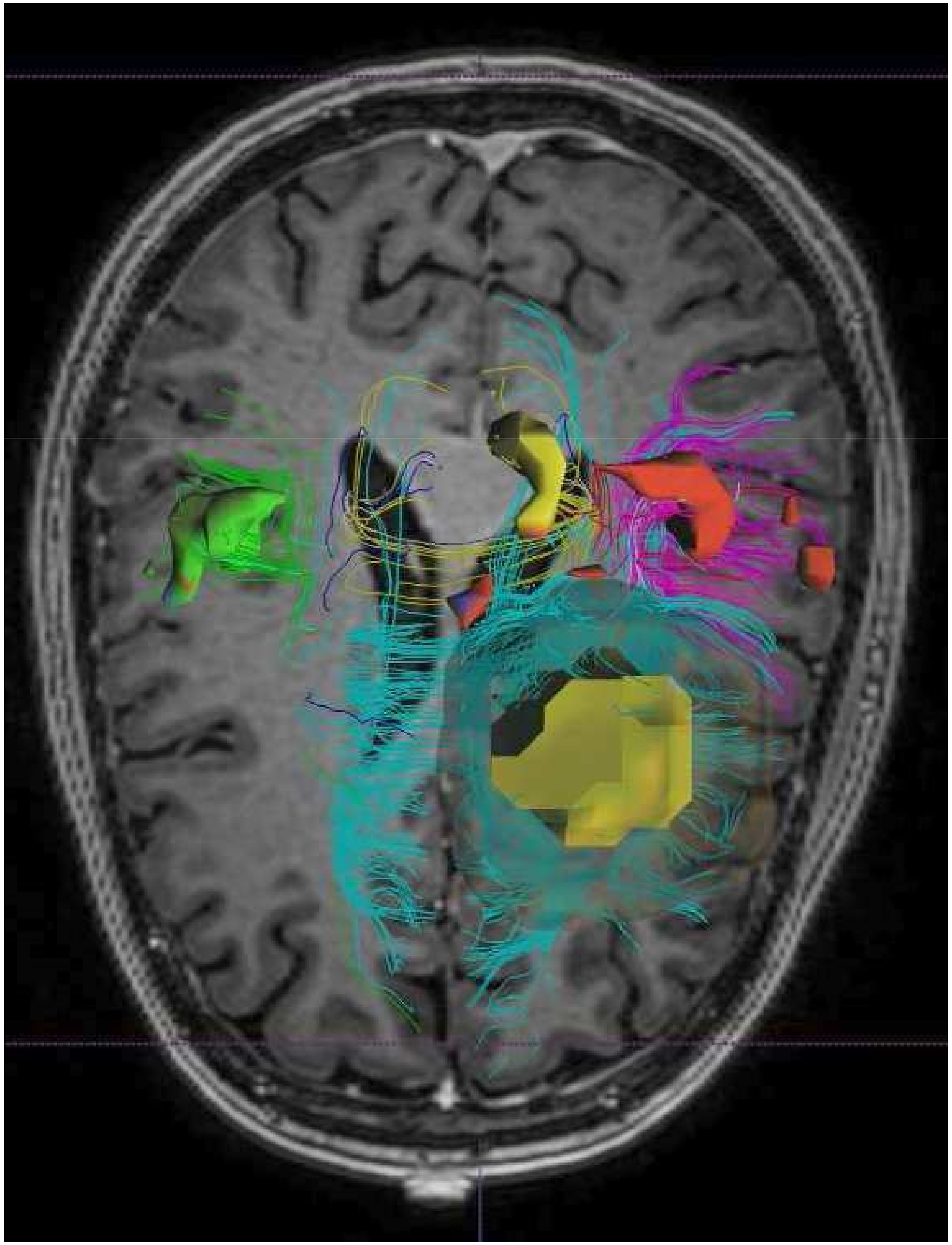


by tumor neighborhood

interactive queries:

- tumor vicinity
- activation zones
- fiber tract selection

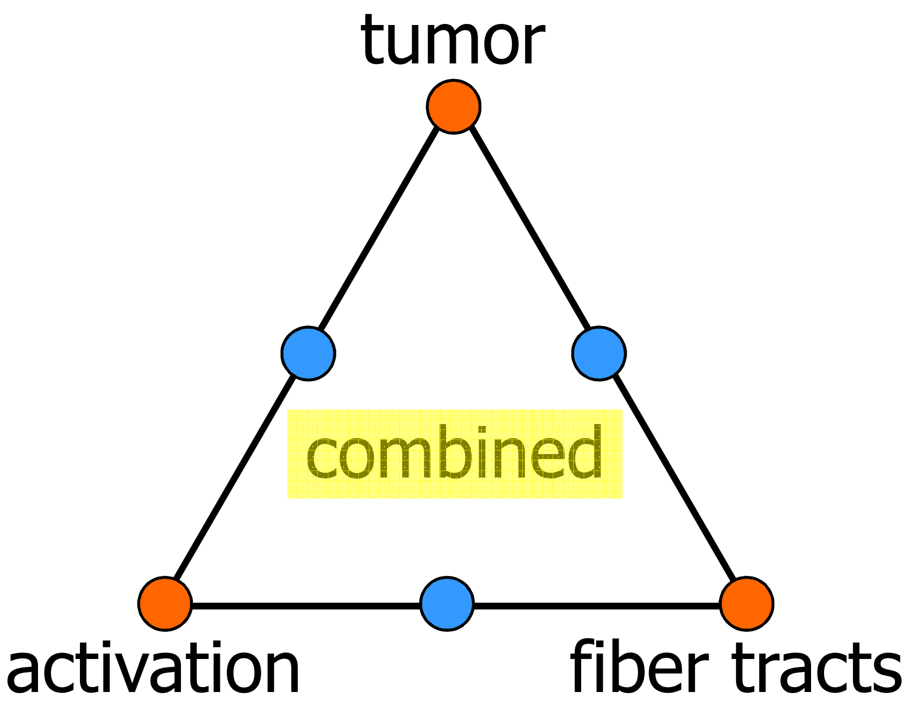




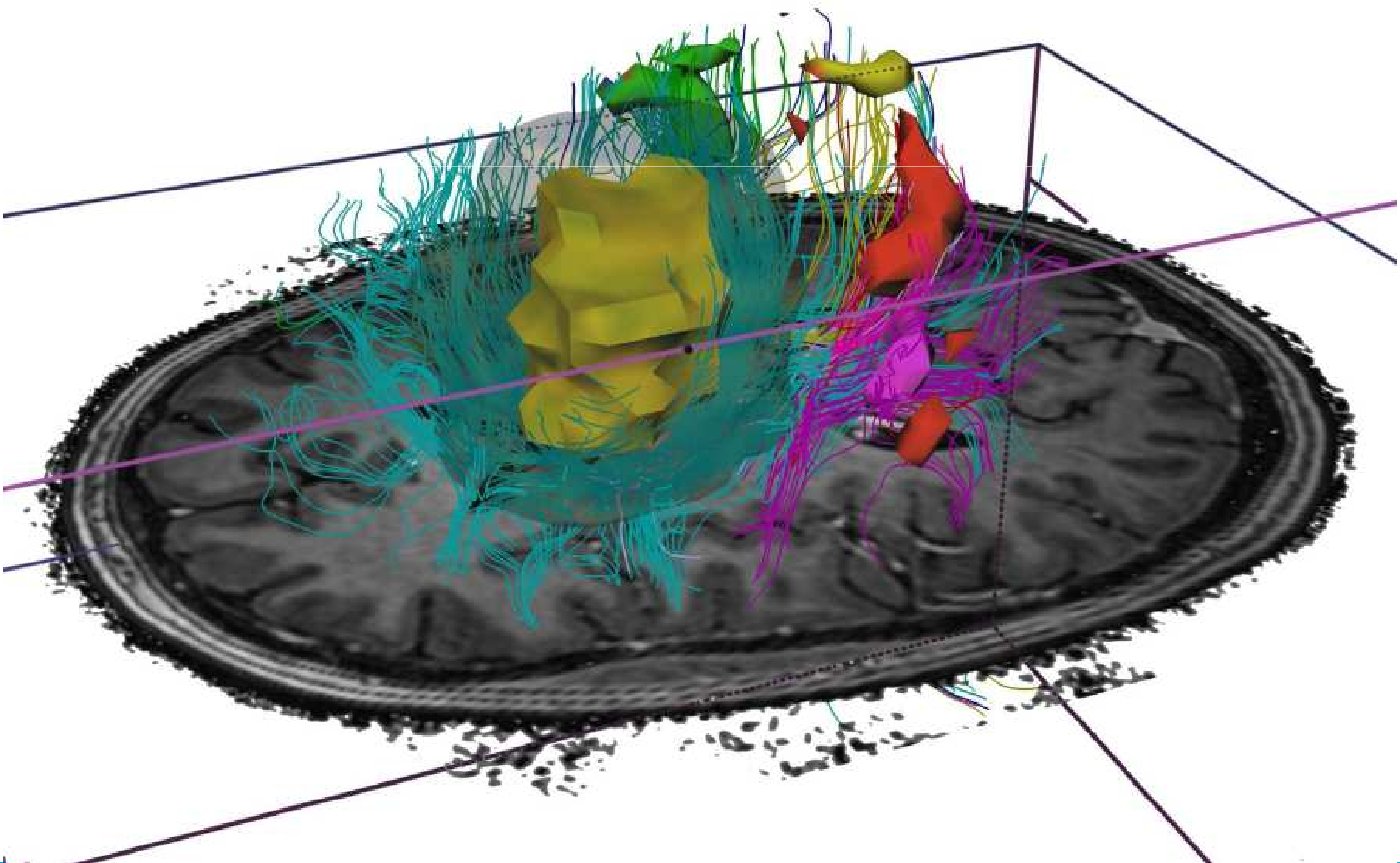
all modes combined

interactive queries:

- tumor vicinity
- activation zones
- fiber tract selection



Putting it all together



Discussion

- developed with clinicians, used in a clinical setting, positive responses…
- no formalized planning and guidance procedure
- no hard test data yet!
- evaluation is difficult to perform:
  - how to quantify resection damage?
  - how accurate is fiber tracking in a tumor zone?
  - can DTI be used to detect/visualize damaged tracts?

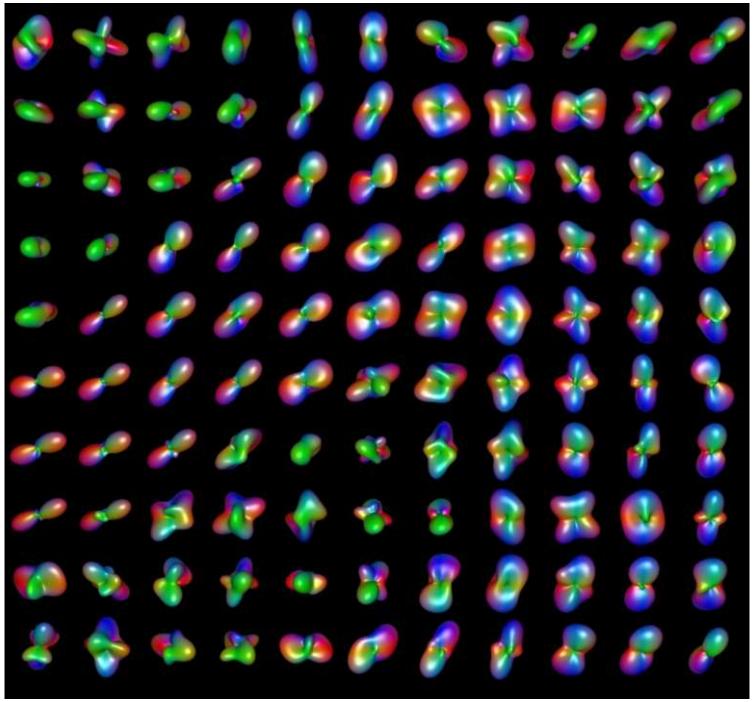
Summary / Future work

Summary

- DTI overview
- Fast selection for full-brain fibre tracking.
- Prototype combining MRI, DTI and fMRI for resection planning.

Current + Future Work

- Resection planning.
- HARDI.
- Stochastic fiber tracking.



Fast and sleek glyph rendering for interactive HARDI data explortation, Peeters et al.

Computer-assisted shoulder replacement

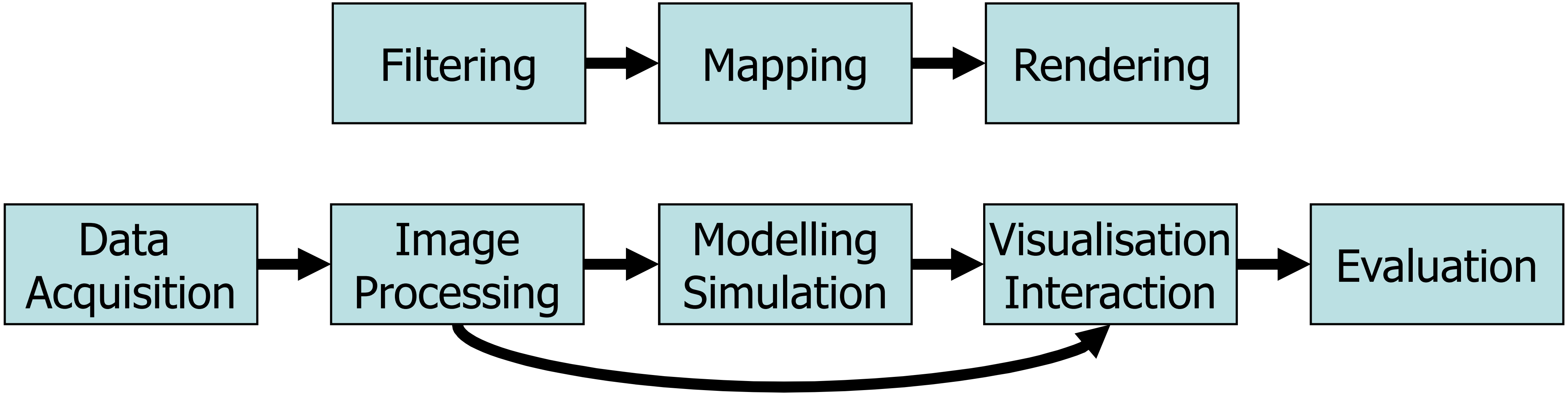
Dr. Charl Botha
TU Delft / Leiden University Medical Centre

http://visualisation.tudelft.nl/CharlBotha
http://visualisation.tudelft.nl/MedVis

Research by:
Peter Krekel
Charl Botha
Paul de Bruin
Edward Valstar
P.M. Rozing
Frits Post
Rob Nelissen

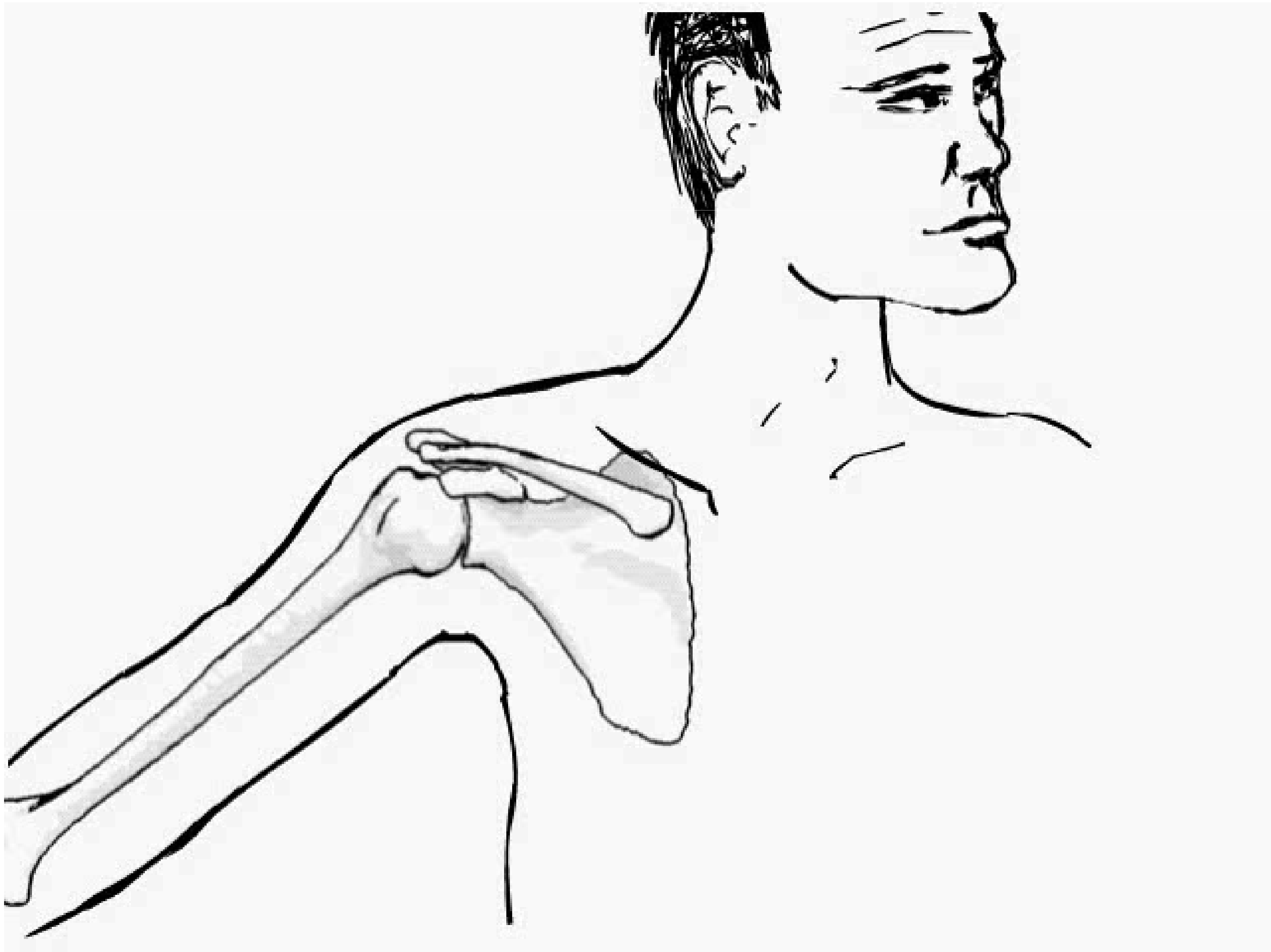
Delft University of Technology

Detour:
Medical Visualisation Pipeline

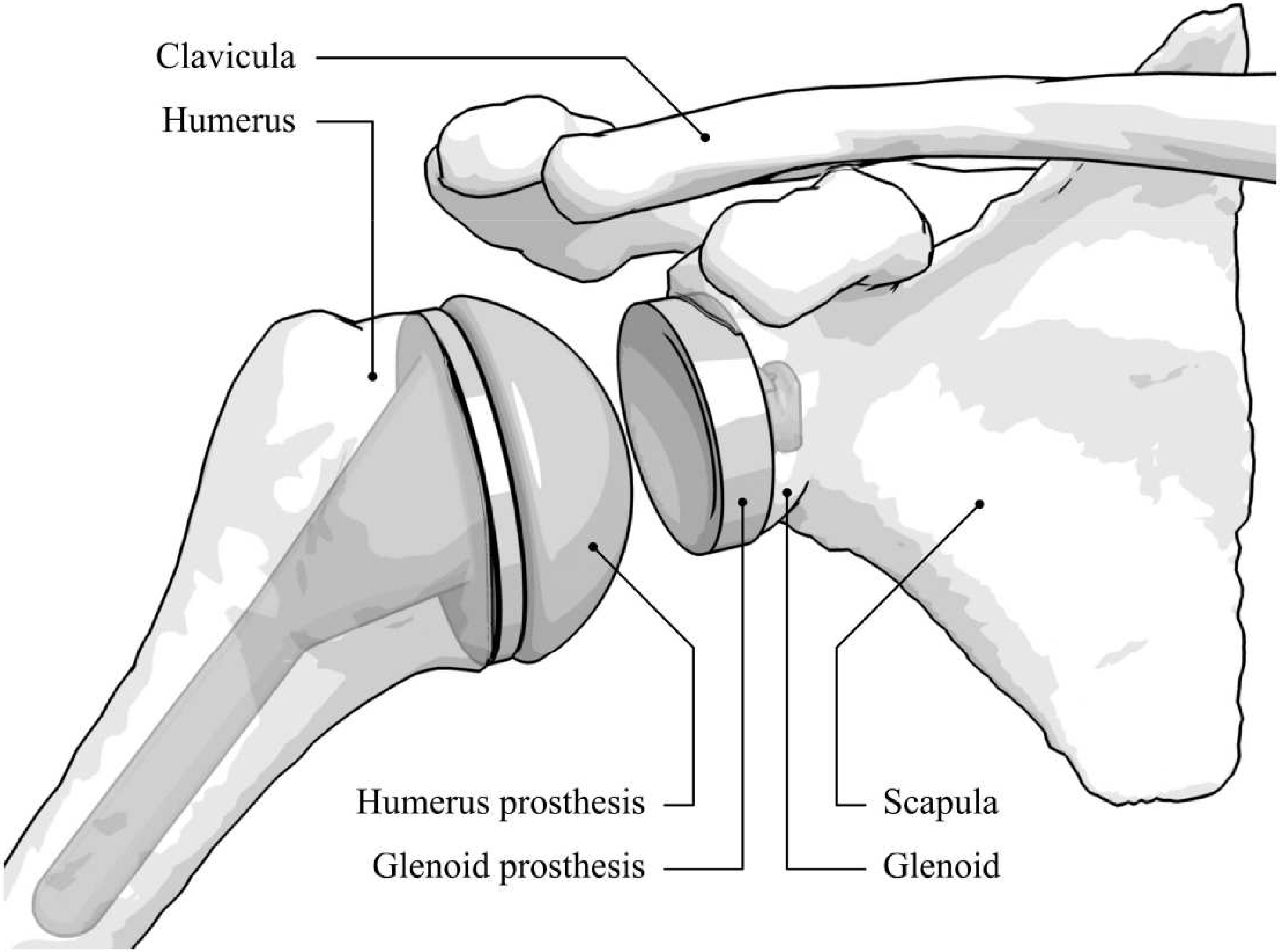


- Research
- Diagnostics
- Treatment planning
- Pre- and intra-operative guidance
- Medical training
- Post-operative evaluation

Shoulder replacement?

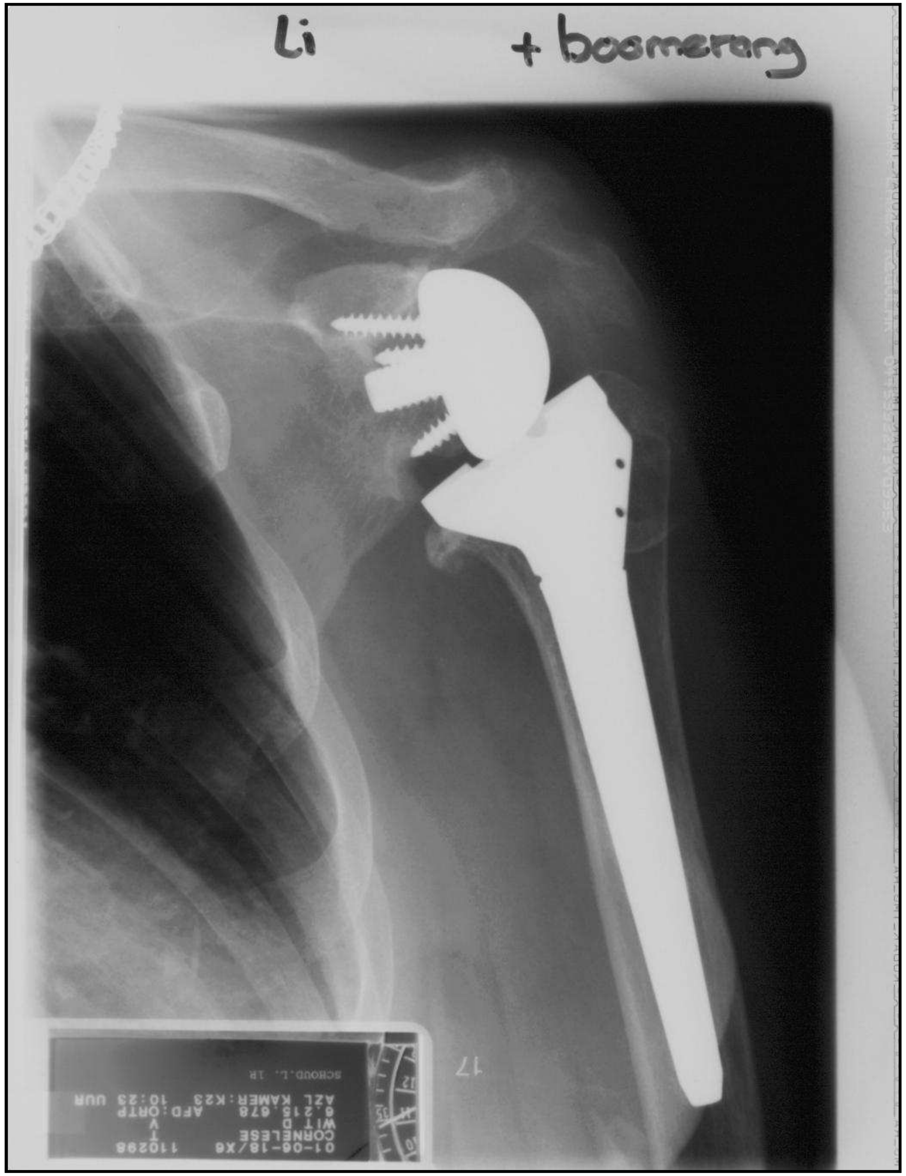


The Ideal Result

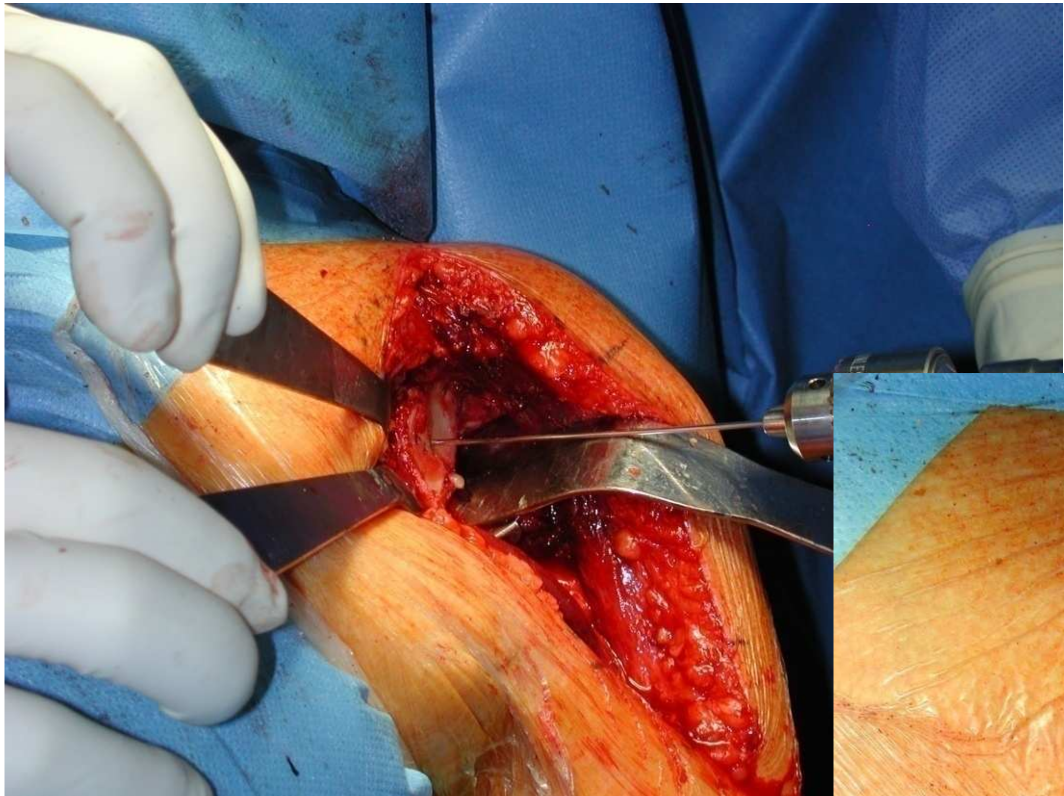


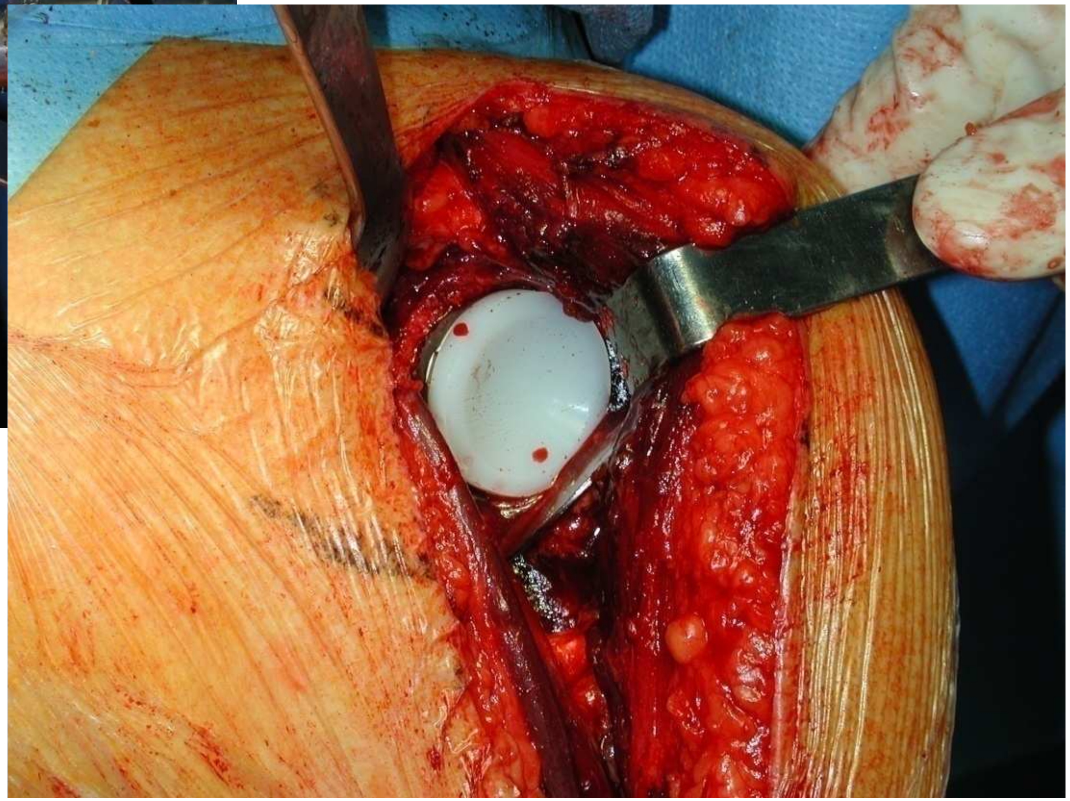
Reality

- Malpositioning 23%
  - (Hasan JSES 2002; n = 139)
- Leading to:
  - Loosening and wear
  - Instability
  - *Limited range of motion*
- Why is this?
  - Limited field of view
  - Complex joint
  - No guidance!



Reality

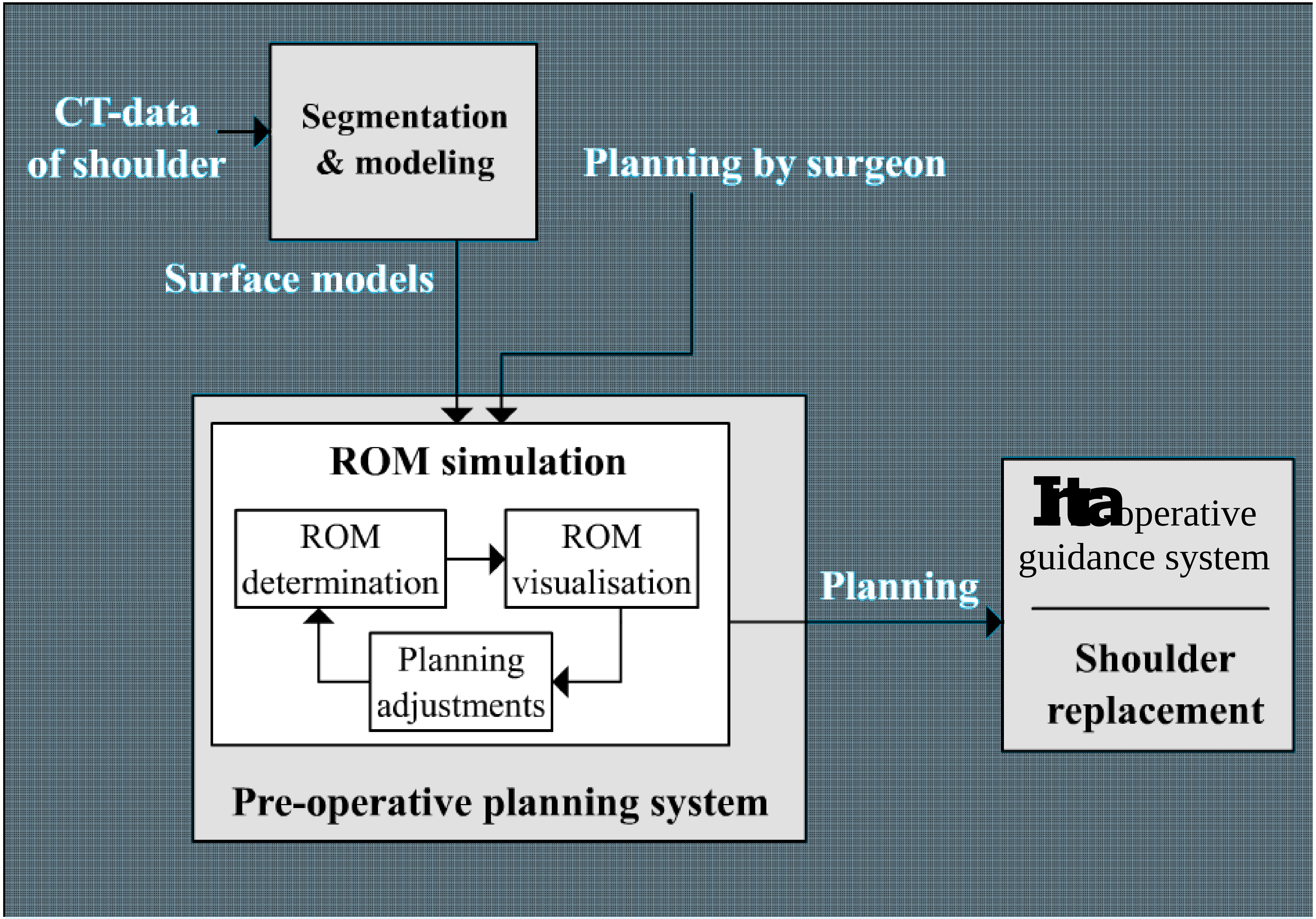




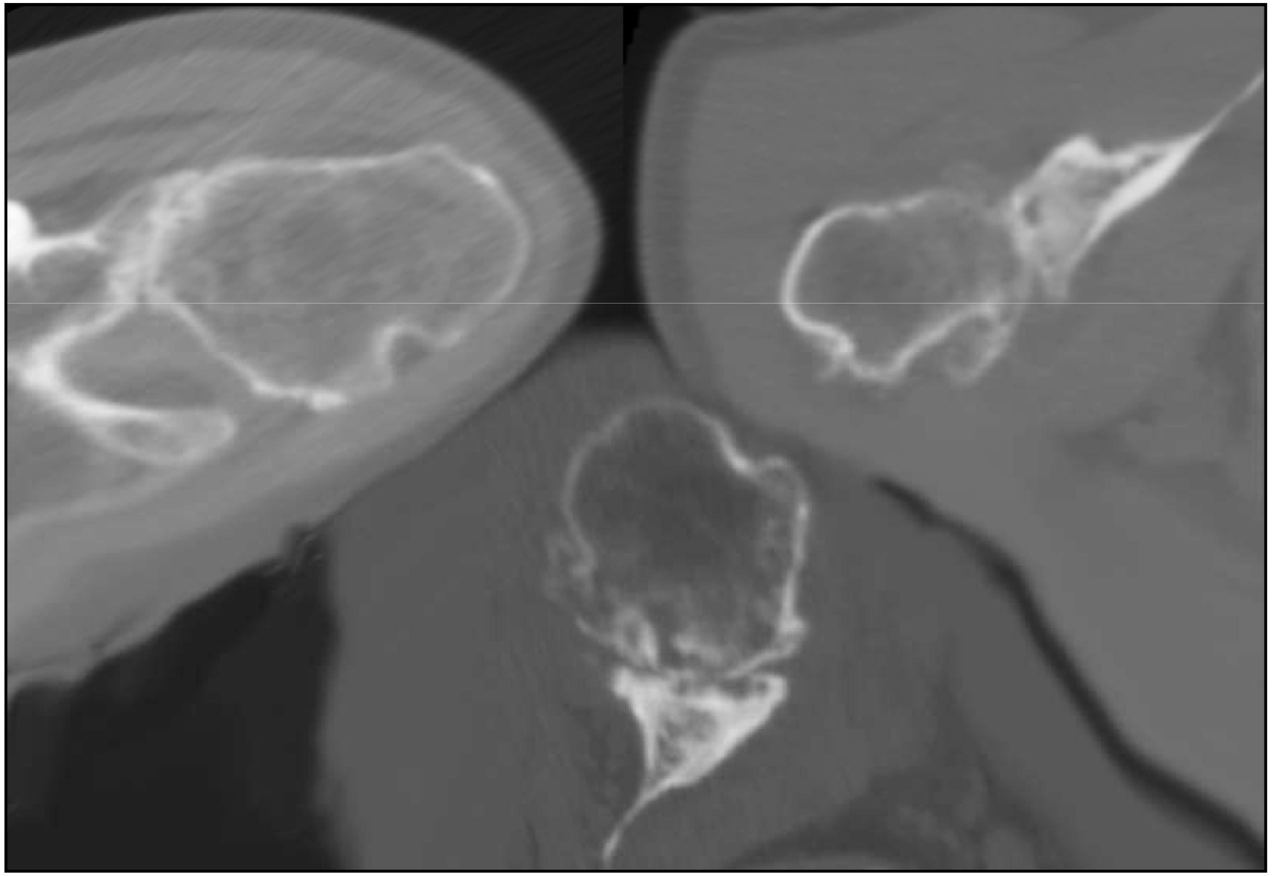
Reality

•State of the art: Template-over-x-ray planning

Improved shoulder replacement

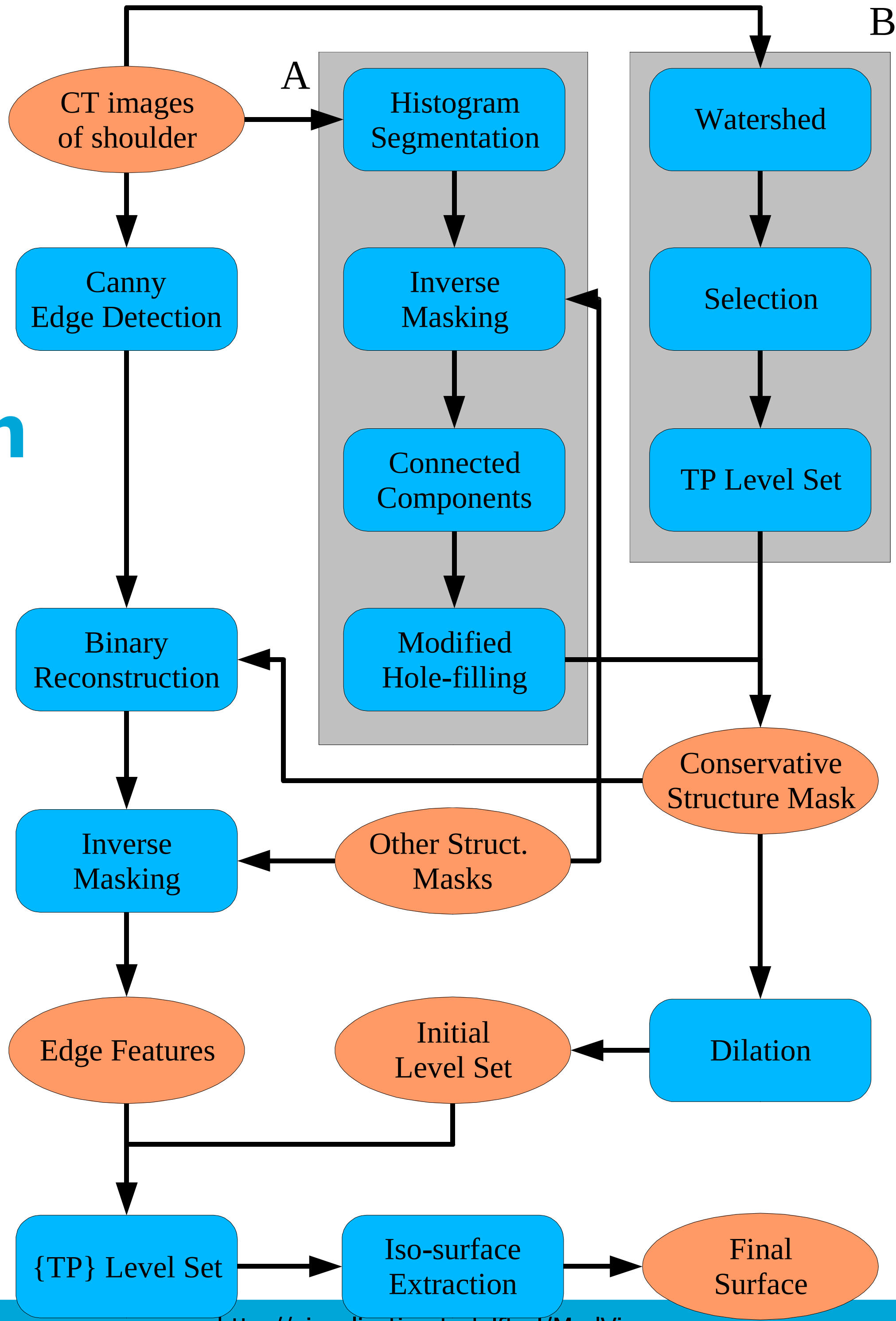


Shoulder segmentation is hard

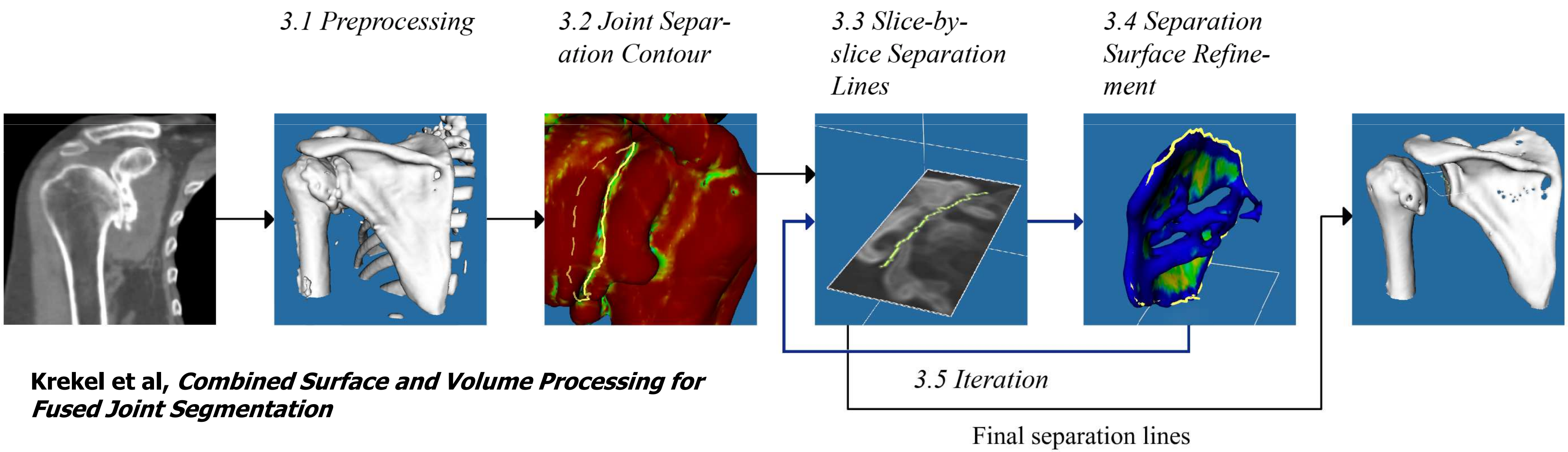


- Bone decalcification
- Joint space narrowing
- Osteophytes
- Destroyed cartilage

Segmentation Solution #1

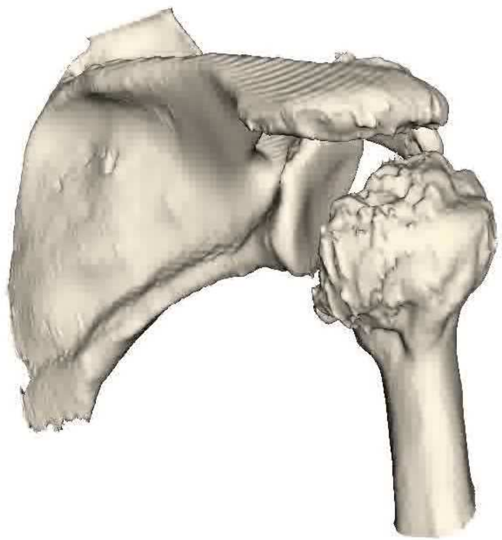


Practical segmentation of pathological shoulder data

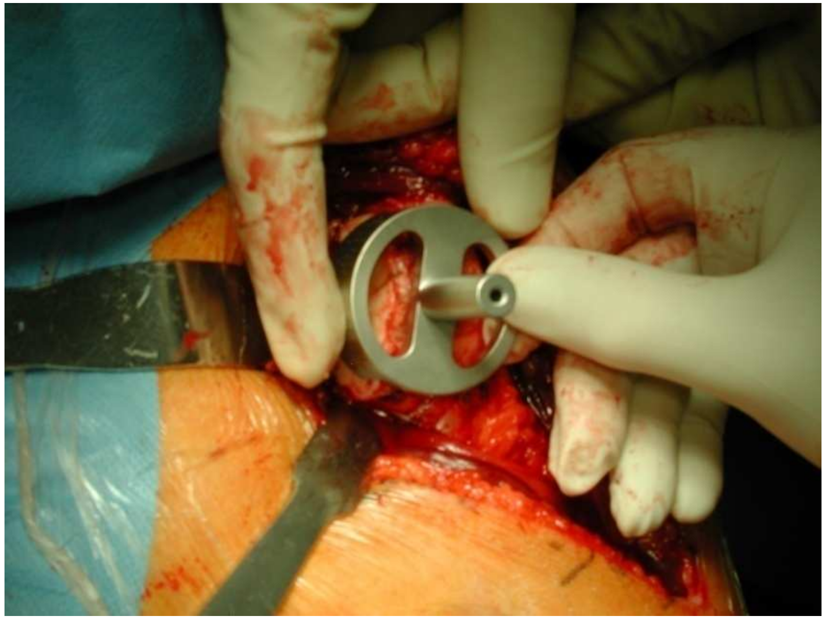
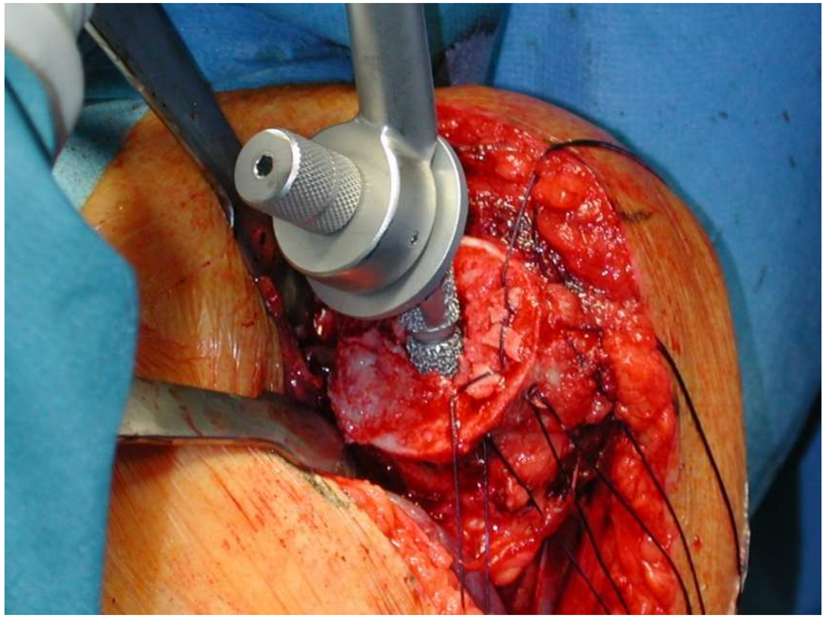
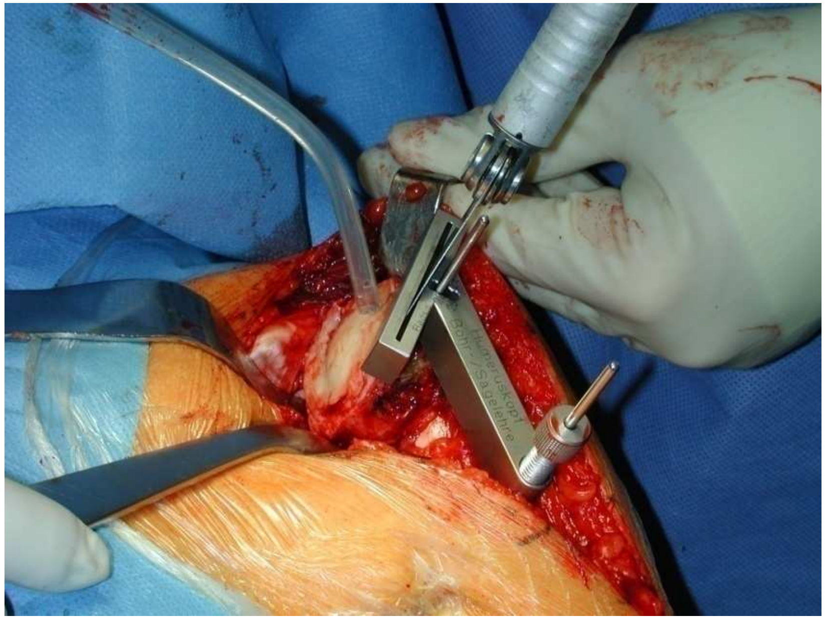
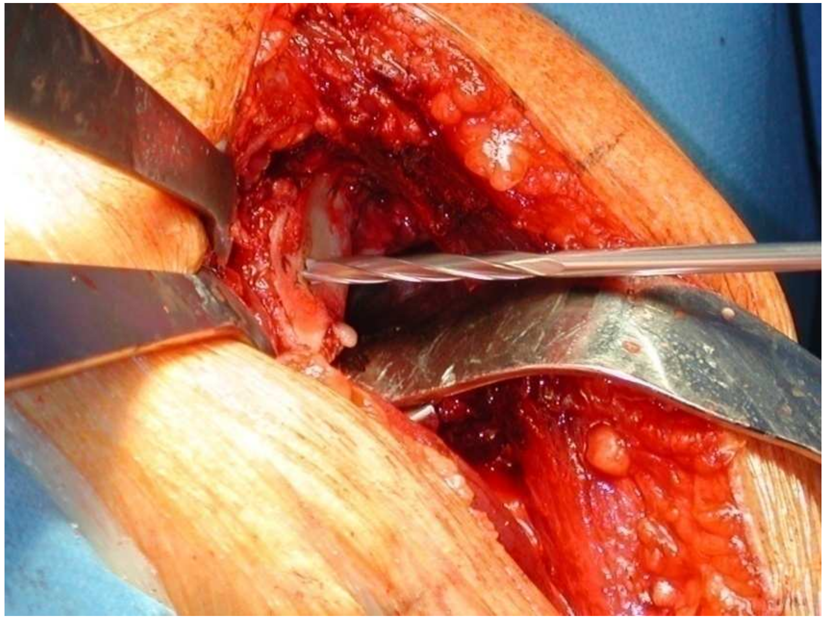


Krekel et al, *Combined Surface and Volume Processing for Fused Joint Segmentation*

- Surface curvature
- Joint separation contour
- Slice by slice separation lines
- Surface refinement

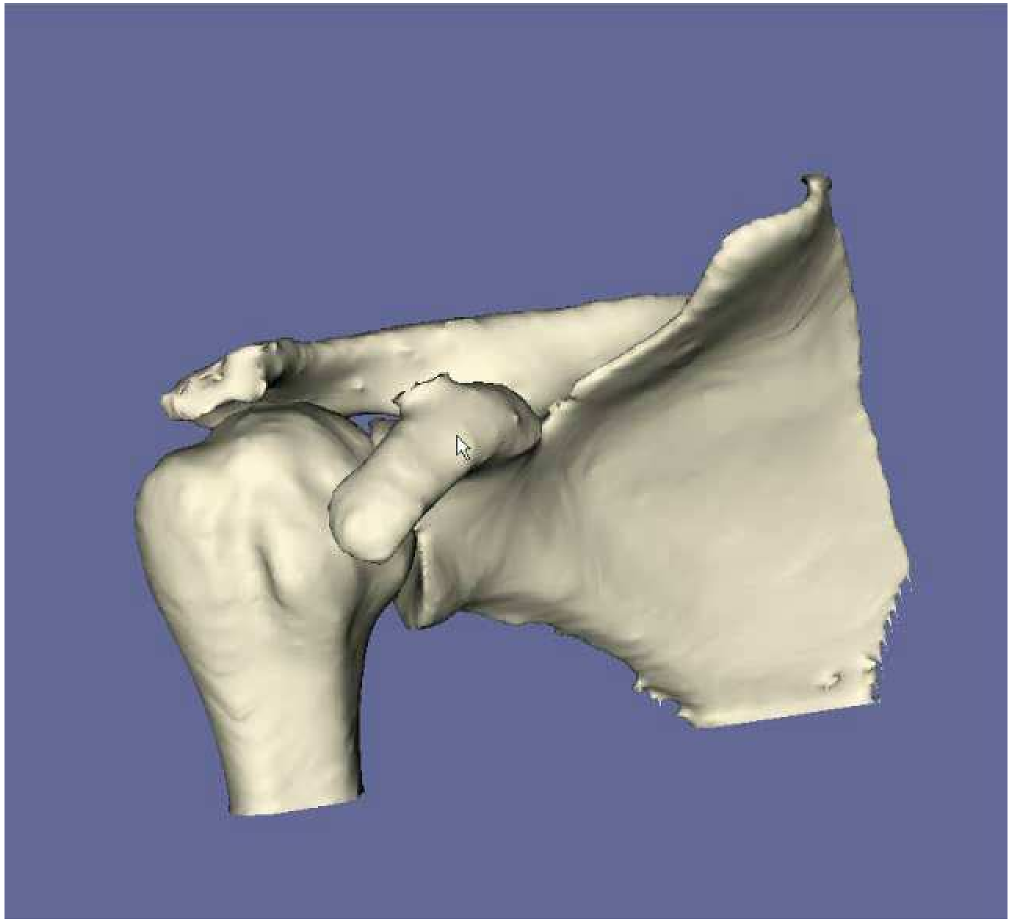


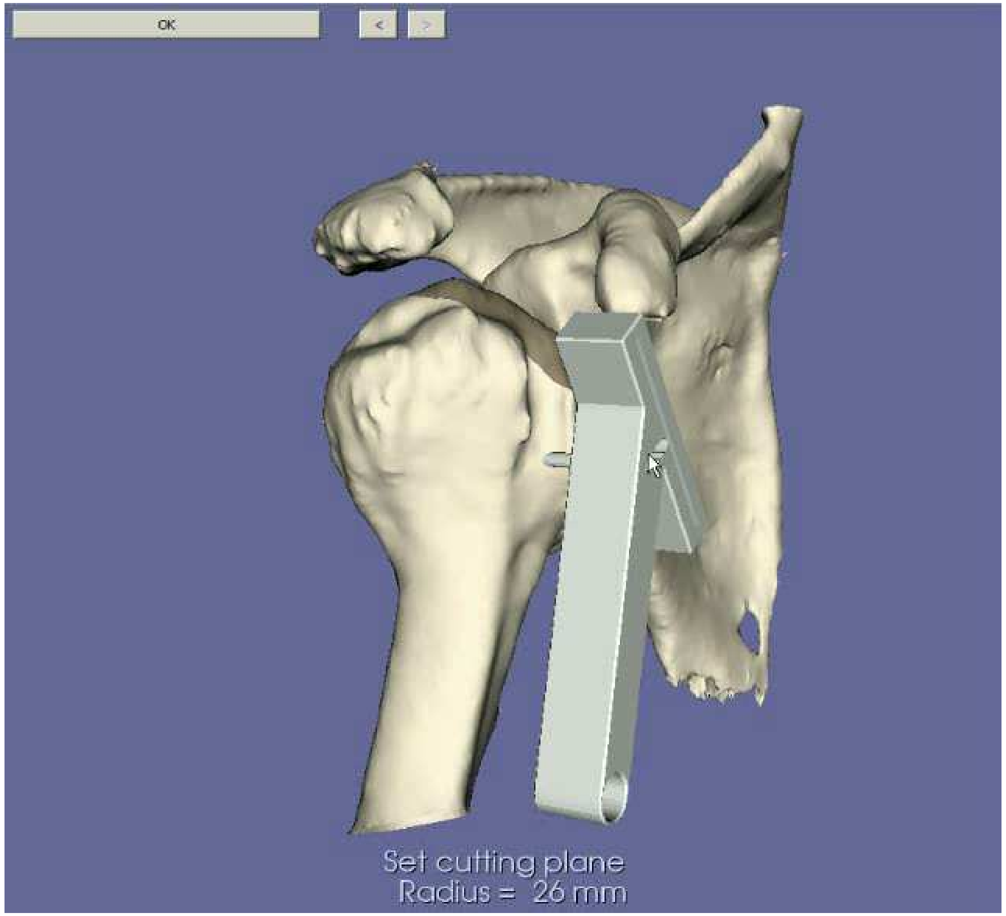
Pre-operative planning

Pre-operative planning

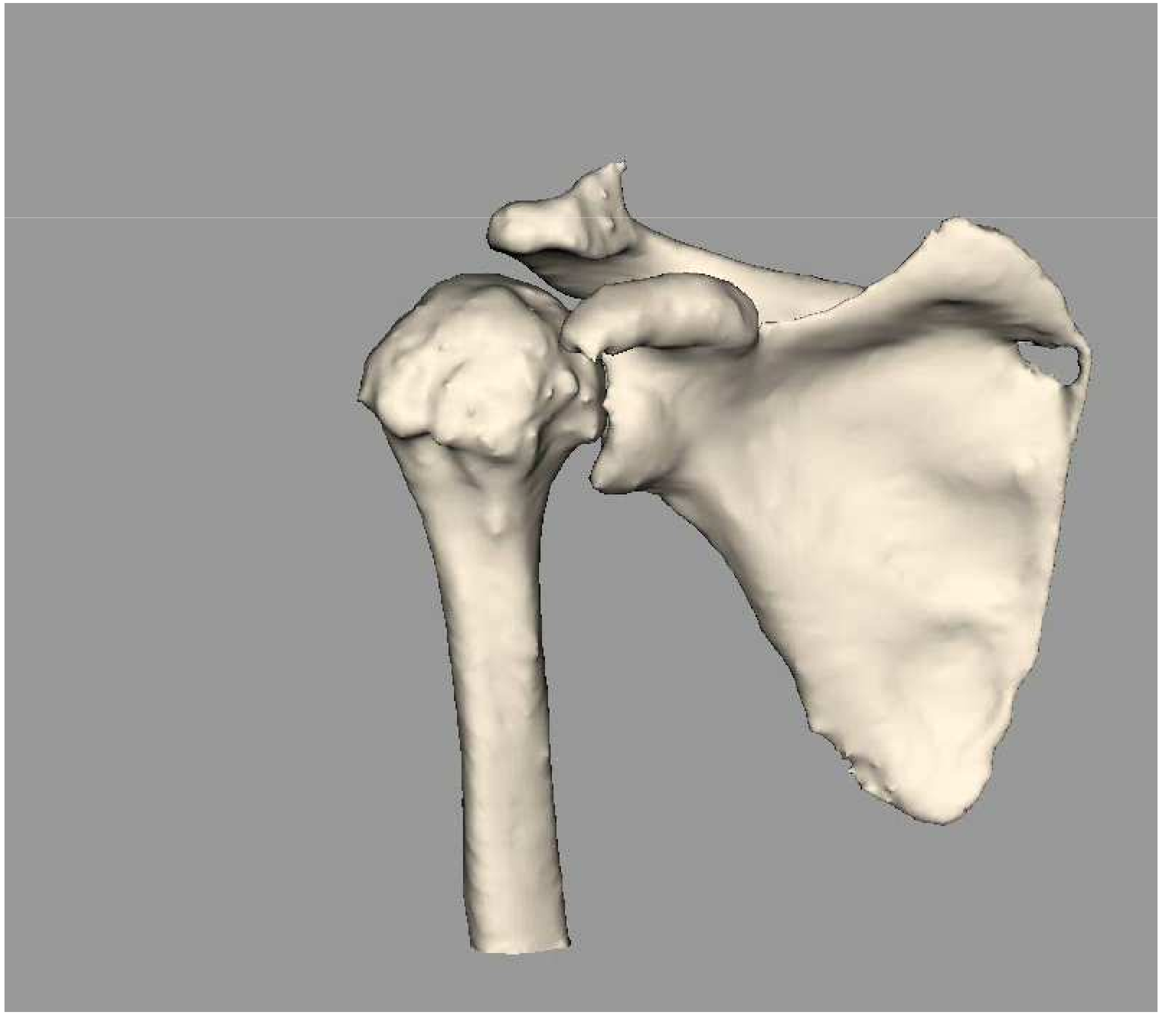
- Surgical instruments virtually reproduced.
- Center of rotation, humerus cutting plane.
- Familiar, well-received.



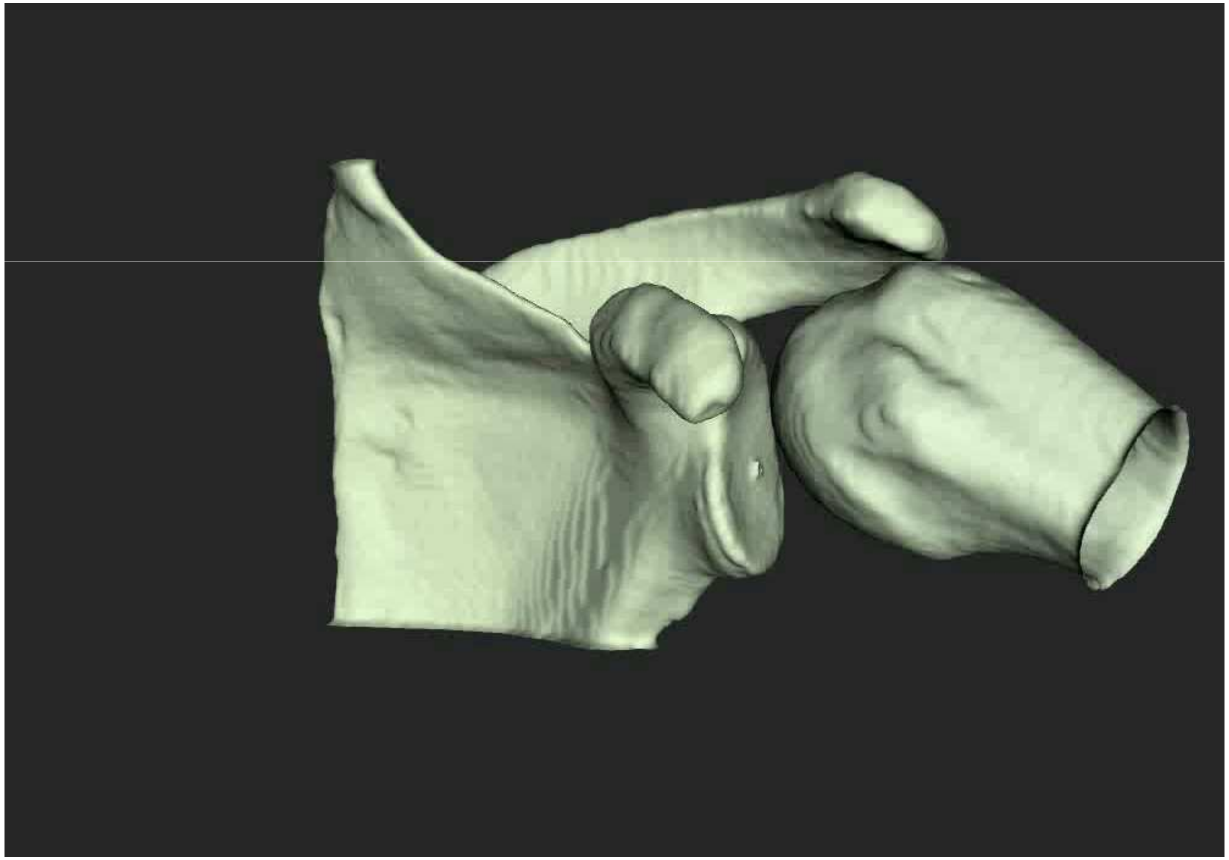


Pre-operative planning

- Initial placement automatic.
- Based on patient-specific features derived from shoulder geometry.
- Can be adjusted.
- 3D Template over X-Ray.

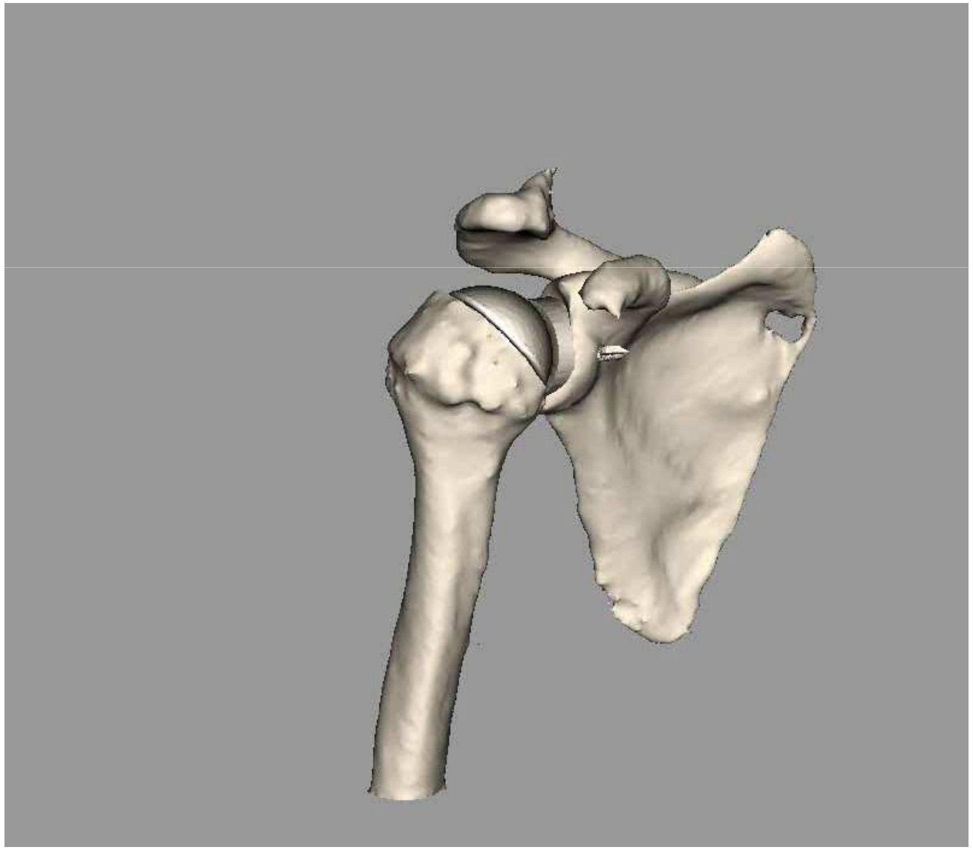


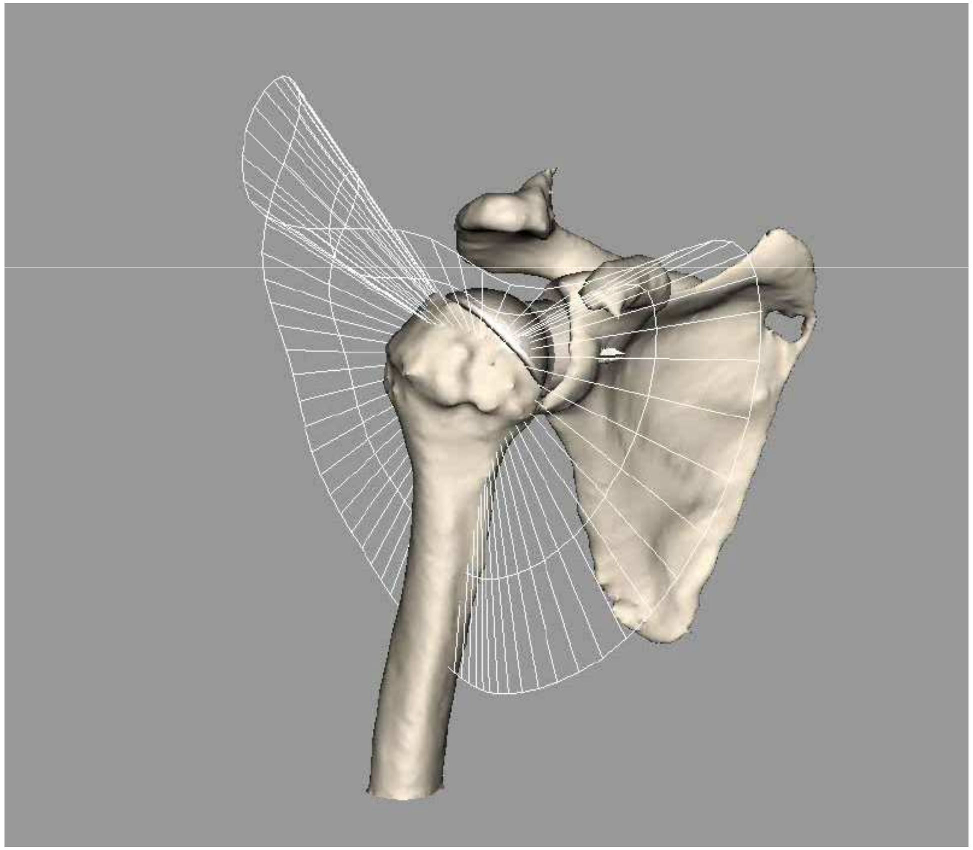
Pre-operative planning



- Combine adaptive / constrained ball-joint model with fast collision detection.
- Scan motion space to determine ROM.

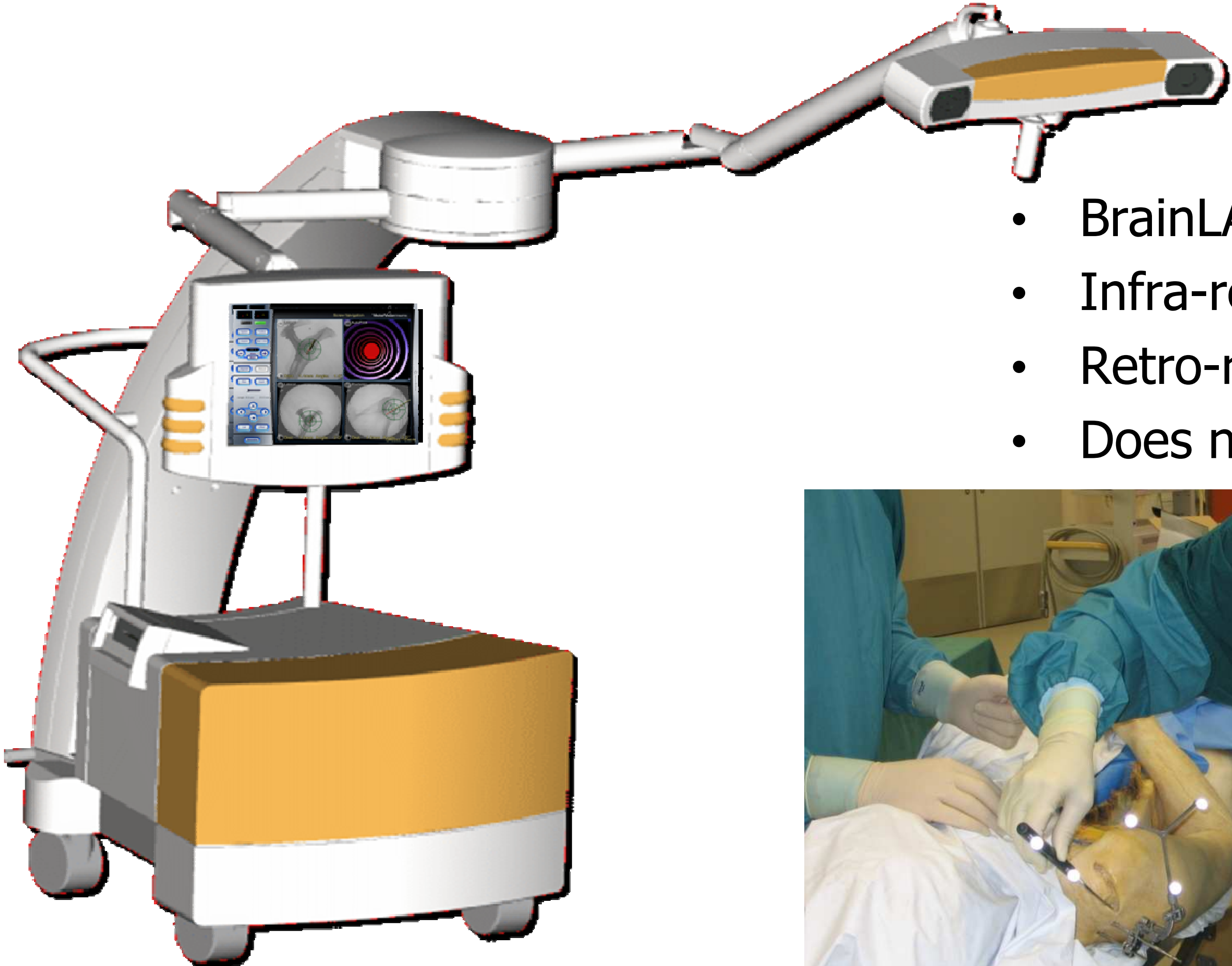
Pre-operative planning





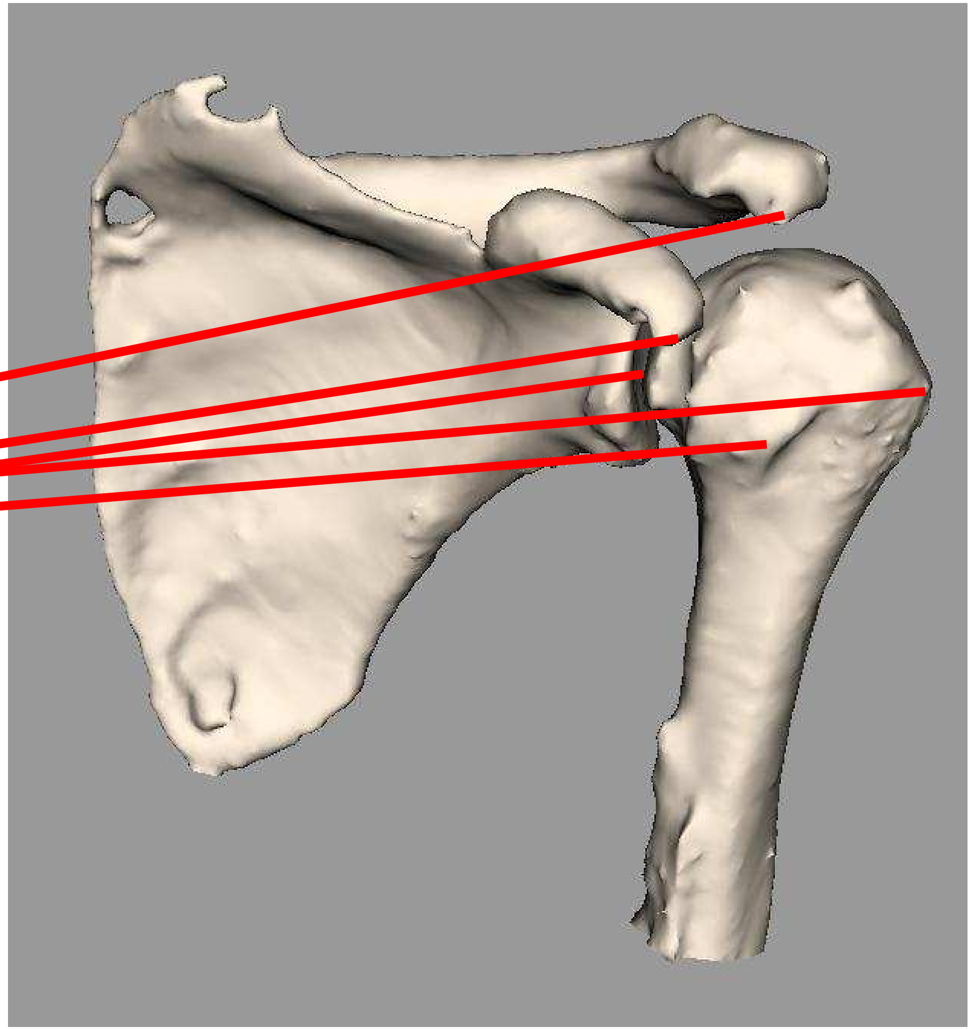
- Post-operative range of motion predicted.
- Surgeon gets real-time visual feedback trying different approaches.
- System explicitly shows improvement / deterioration in ROM.
- Surgeon converges rapidly on a suitable configuration.

Intra-operative guidance



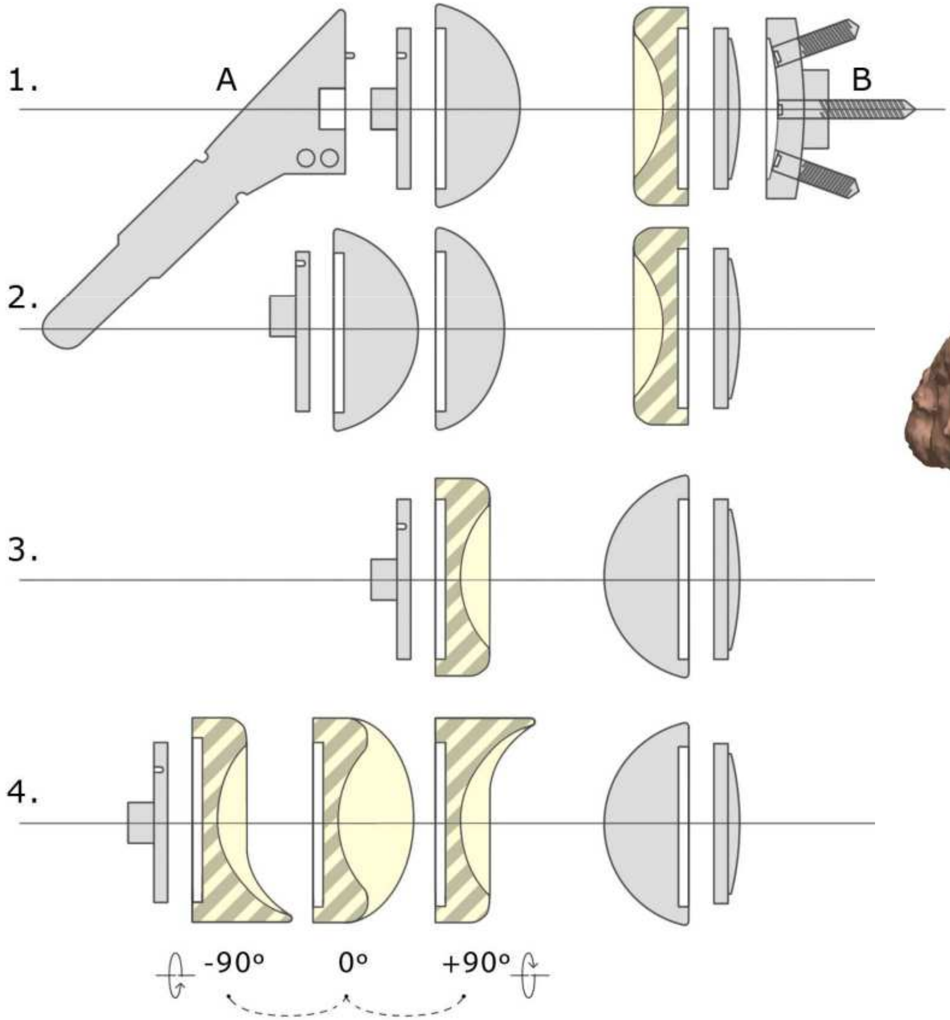
- BrainLAB VectorVision
- Infra-red camera system
- Retro-reflective markers
- Does not support shoulders.

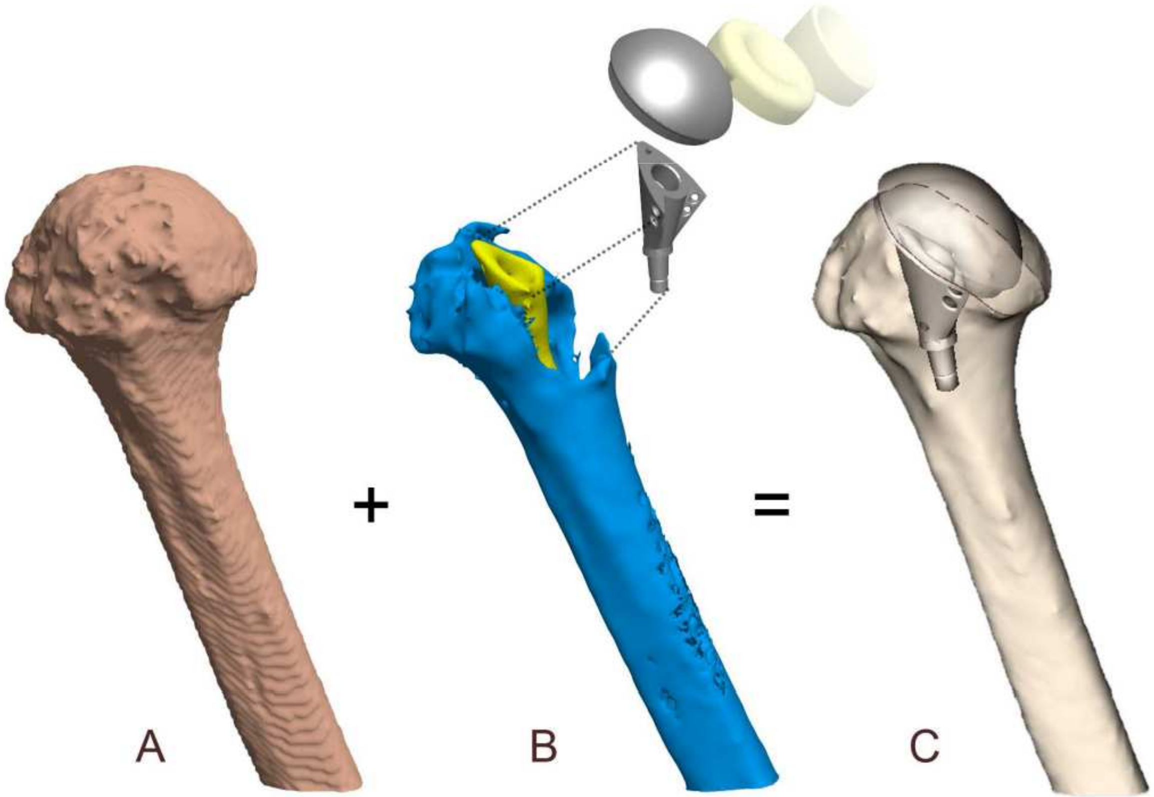
Intra-operative tracking



Intra-operative tracking

Evaluation





- Number of different prosthesis configurations tested on cadaver shoulders.
- Pre- and post-CT used to setup simulation.

Evaluation

Prosthesis configuration		Motion	Left shoulder				Right shoulder			
			Simulated impingement		Observed limitation		Simulated impingement		Observed limitation	
Humeral insert	Glenoid insert		Begin	End	Begin	End	Begin	End	Begin	End
Ball (h=14)	Cup	abduction	0	84	no	*63,5*	-6	56	no	*52,9*
		endorotation	-28	**71**	*16,6*	**69,2**	**-3,3**	**94**	**-5,5**	**95,7**
		anteflexion	0	90	no	*61,6*	-33	112	no	*42,1*
Ball (h=18)	Cup	abduction	0	91	no	*62,7*	-6	56	no	*52,8*
		endorotation	-27	**72**	*27,3*	**69,6**	-43	**101**	*-3,2*	**98,6**
		anteflexion	0	87	no	*67,5*	-35	111	no	*43,2*
Ball (h=14) eccentric	Cup	abduction	2	85	no	*64,5*	-4	54	no	*52,7*
		endorotation	-16	**52**	*16,4*	**59,1**	-18	**105**	*9,7*	**111,8**
		anteflexion	4	**79**	no	**70,7**	-30	112	no	*41,0*
Ball (h=18) eccentric	Cup	abduction	3	84	no	*56,2*	-5	53	no	*49,5*
		endorotation	-13	**39**	*6,5*	**42,8**	-39	**94**	*13,7*	**96,0**
		anteflexion	3	82	no	*66,1*	-28	112	no	*36,6*
Cup eccentric	Ball (h=14)	abduction	21	**75**	no	**72,5**	7	**49**	no	**55,3**
		endorotation	**16**	**69**	**11,6**	**71,5**	**-8**	**63**	**-6,5**	**62,2**
		anteflexion	17	**56**	no	**62,7**	7	88	no	*37,2*
Cup proximal slope	Ball (h=14)	abduction	19	**71**	no	**68,5**	**7**	**47**	**6,1**	**46,1**
		endorotation	**-5**	**44**	**-2,2**	**48,9**	**-10**	**63**	**-6,9**	**67,4**
		anteflexion	**23**	**61**	**25,1**	**58,8**	**7**	55	**10,4**	*41,0*
Cup anterior slope	Ball (h=14)	abduction	18	**68**	no	**68,3**	**11**	**50**	**10,0**	**52,6**
		endorotation	**18**	**70**	**15,0**	**72,1**	-14	**46**	*-2,9*	**49,9**
		anteflexion	23	**61**	no	**60,0**	**18**	66	**19,5**	*36,4*
Cup distal slope	Ball (h=14)	abduction	**33**	**73**	**31,5**	**68,4**	**26**	**51**	**26,2**	**49,7**
		endorotation	**-1**	**57**	**-2,6**	**63,9**	-7	**63**	*-9,2*	**70,8**
		anteflexion	28	59	no	*56,9*	**26**	75	**25,7**	*39,3*

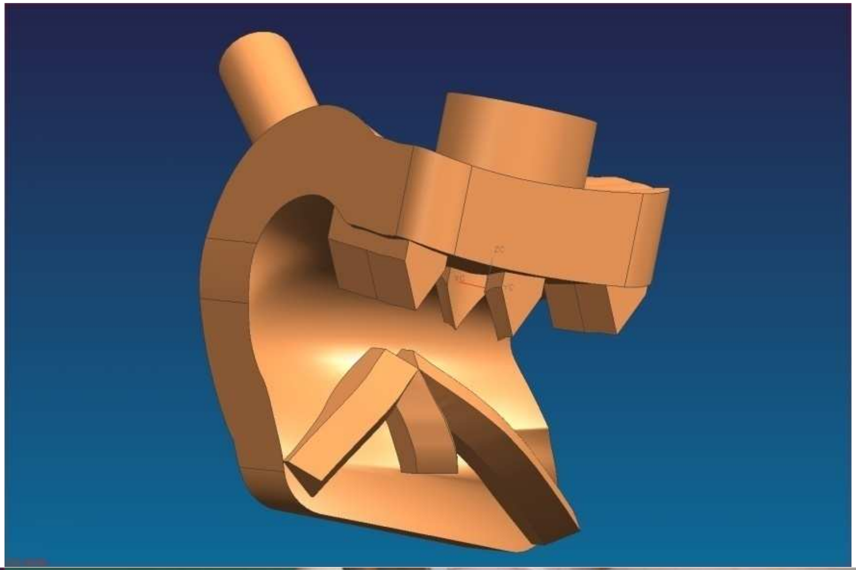
Median deviation between observed and predicted impingement: 0.3 degrees
Krekel et al: *Evaluation of Bone Impingement Prediction in Pre-operative Planning for Shoulder Arthroplasty*, Journal of Engineering in Medicine

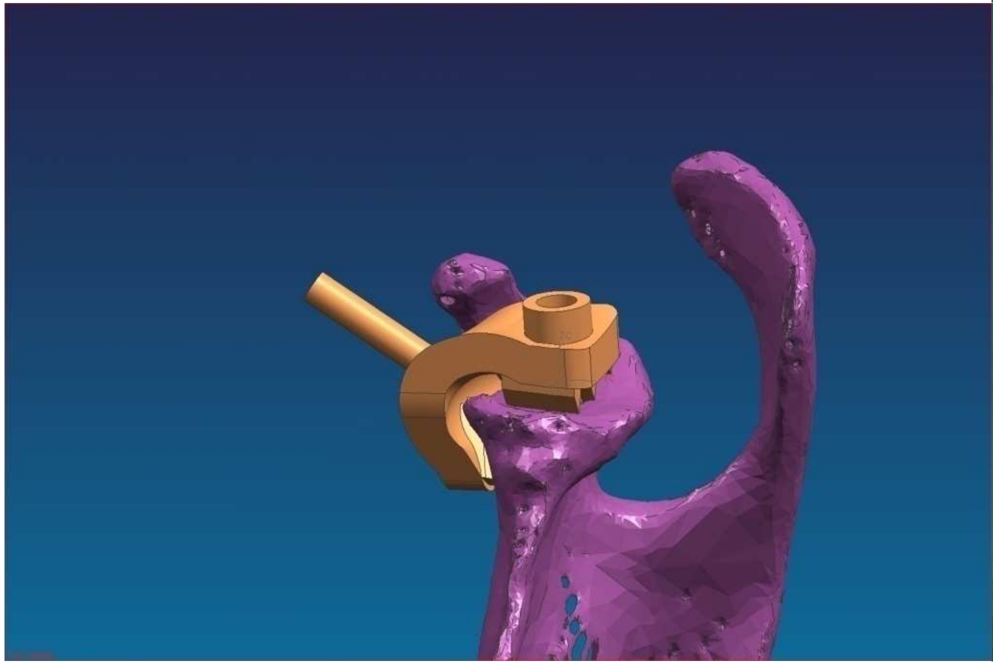
Mechanical Guidance Devices

- Sometimes a computer-free solution is better!
  - No equipment required in OR
- Virtual prosthesis placement parameters can be used to design mechanical guidance device automatically.
- Guidance device encapsulates all knowledge gained pre-operatively in a compact, robust and cost-effective fashion.

Mechanical Guidance Devices

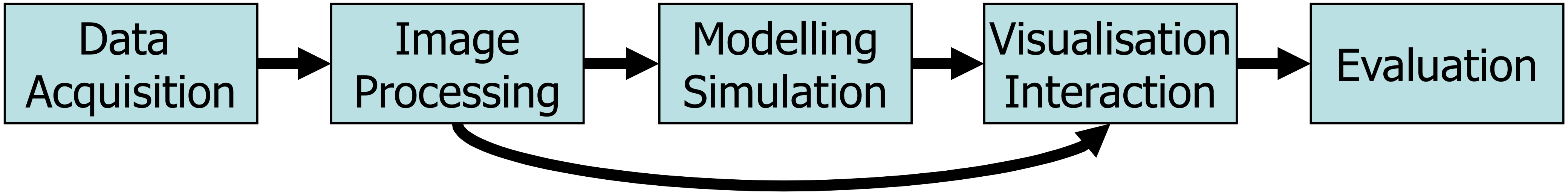
- First trials on cadaver scapulae with manually designed devices.
- Currently working on automatic designs.





Conclusions & Future Work

- Pre-operative planning system
- Range of motion simulation and visualisation
- Intra-operative guidance
- Results of first evaluation are positive

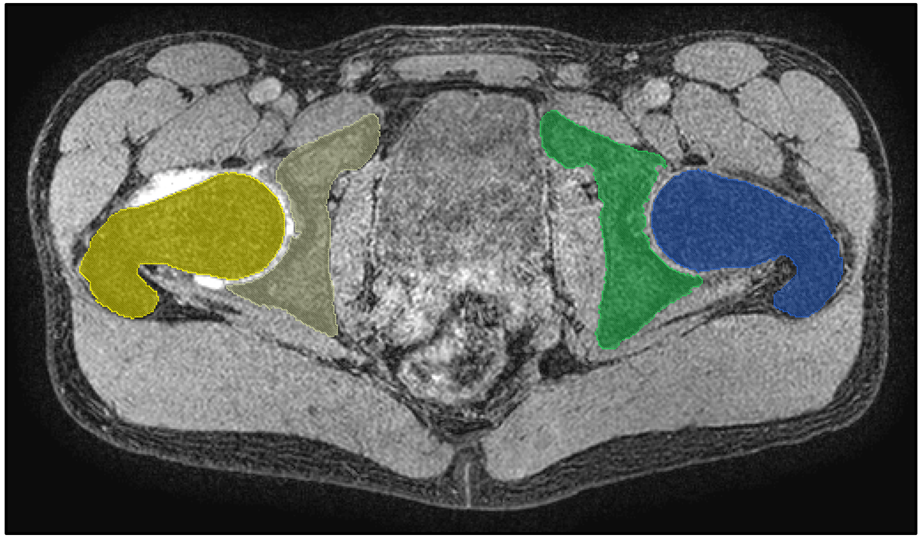


Future Work:

- Guidance devices
- Instrument navigation
- Soft tissue simulation
- Shoulder kinematics analysis and visualisation
- Analysis of other joint pathologies

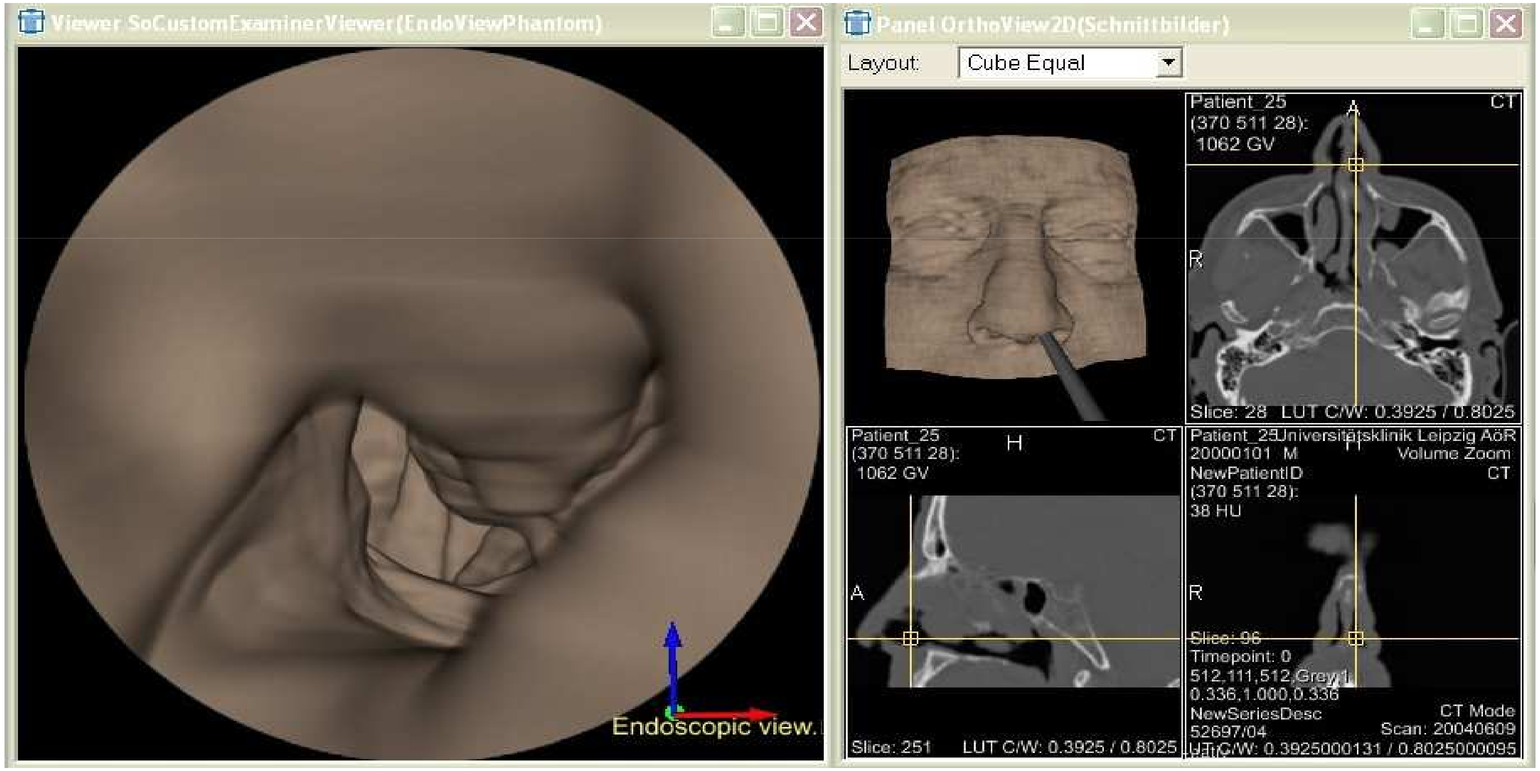
Recent progress: Hip impingement

- Using the ROM simulator, bone-determined hip impingement can also be studied.



Krekel et al., RANGE OF MOTION SIMULATION FOR DIAGNOSIS OF FEMOROACETABULAR IMPINGEMENT, ISB 2009

Virtual Endoscopy



Outline

- Introduction and Motivation
- Rendering Techniques
- Navigation and Interaction Concepts
- Application Areas
  - Virtual Colonoscopy (Diagnosis)
  - Virtual Bronchoscopy (Diagnosis)
  - Virtual Endoscopy for Sinus Surgery (Intervention Planning and Training)
  - Virtual Endoscopy for Minimally-Invasive Surgery of the Pituitary Gland (Intervention Planning)
- Commercial Systems
- Conclusion

Introduction

- Virtual Endoscopy is based on high-resolution medical image data (often CT) and is a viewing and exploration mode derived from optical endoscopy.
- In optical endoscopy a thin (flexible or stiff) fiber optic is moved to the target area.
- Virtual endoscopy: Virtual camera is moved along air- or fluid filled structures.
- Optical properties of endoscopes are mapped to the virtual camera.

Introduction

- Endoscopy is used as diagnostic tool and can be combined with interventions, e.g., removal of polyps or taking biopsies.
- Virtual endoscopy is limited to applications without interventions.
- Requirements for virtual endoscopy:
  - Sufficient accuracy
  - Identifiable (segmentable) structures of interest
  - Interactivity (high frame rate)
    - Large amounts of data and interactivity – these aspects are difficult to achieve at the same time. Special emphasis is needed!

Introduction

Major applications for virtual endoscopy

- Diagnosis: virtual bronchoscopy
- Diagnosis: vascular diseases, such as aneurysms
- Screening for colon cancer prevention (or early detection)
- Treatment planning with respect to endoscopic procedures, such as Functional Endoscopic Sinus Surgery
- Training for endoscopic interventions. Due to the limited visual access there is a high demand for training these procedures.

Introduction

Instruments for optical endoscopy:

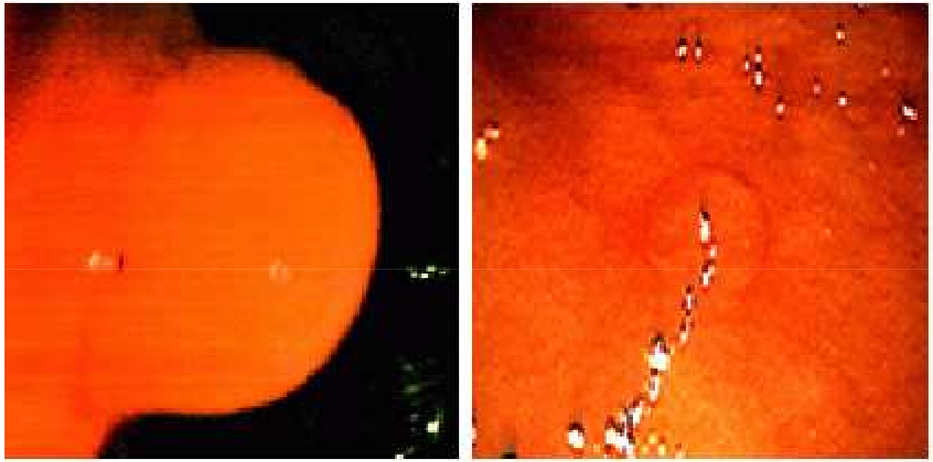
Brochoscope,
Coloscope

Light source,
Video processor

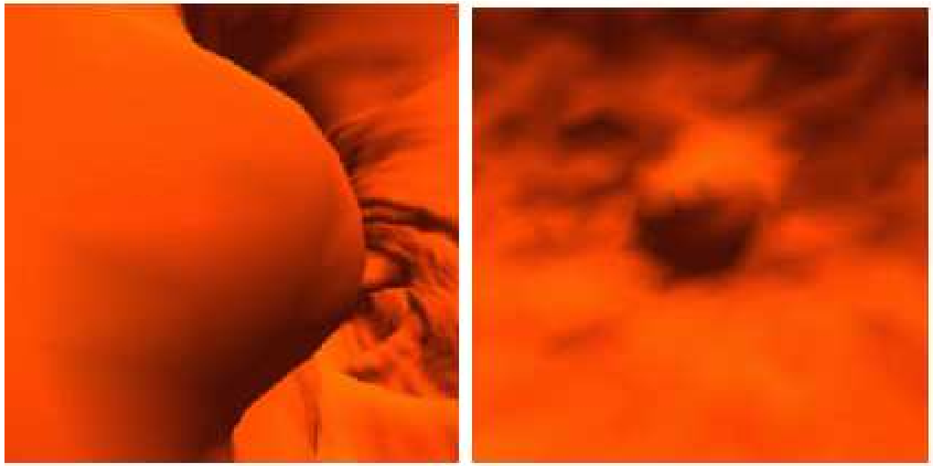
Sources: above – http://www.olympus.de/endo
below – http://www.info-endoskopie.de

Nooses,
Forceps

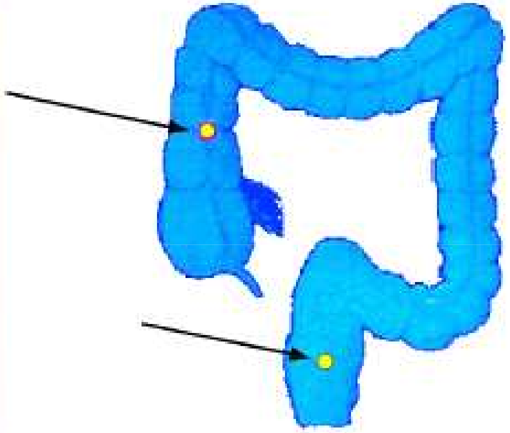
Introduction



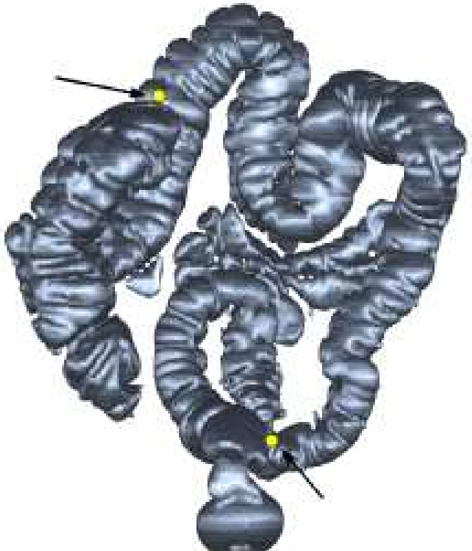
Optical Endoscopy



Virtual Endoscopy



8 mm polyp



4 mm polyp

Image Courtesy Dirk Bartz,
Univ. of Leipzig

Motivation

- In contrast to optical endoscopy, virtual endoscopy allows
  – to „look behind the walls“
  – to reduce risks and costs associated with optical endoscopy

- However, virtual endoscopy
  – cannot be combined with interventions
  – does not provide realistic colour and texture information and
  – does not allow physical contact
  – is of limited value if the structure of interest has changed since acquisition, e.g. „brain shift“

Concept

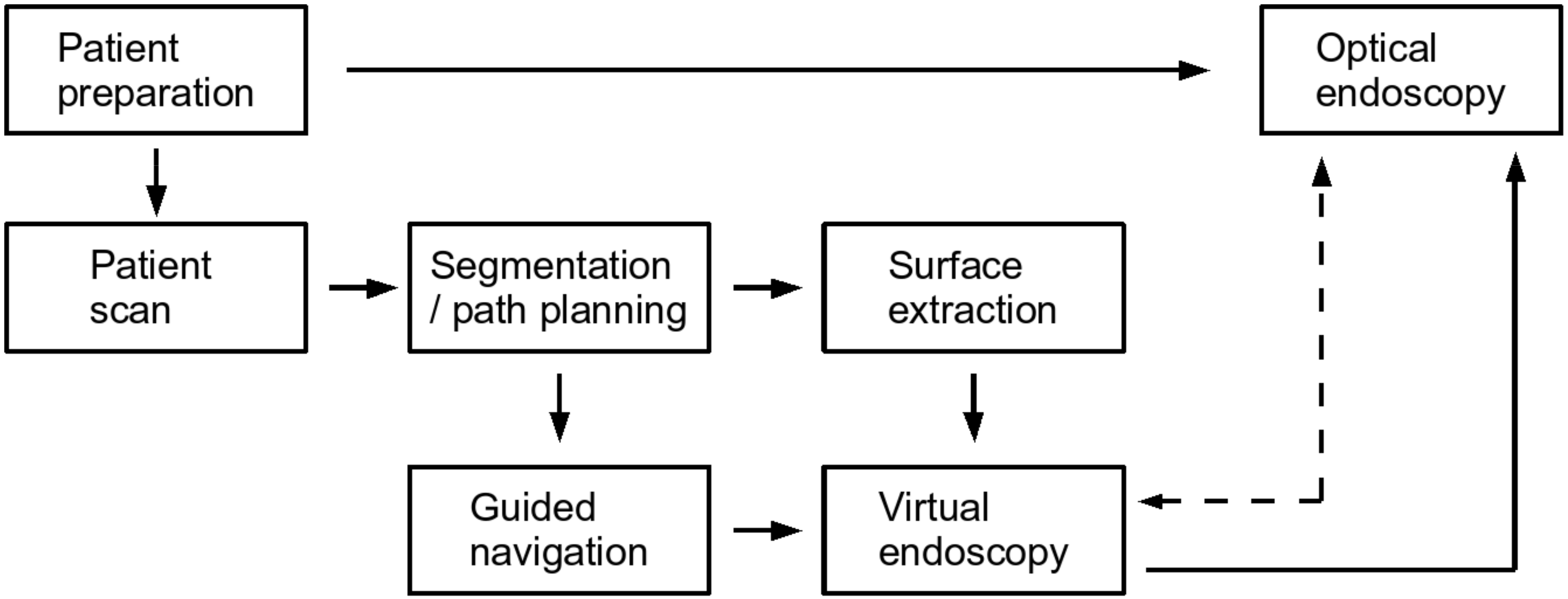
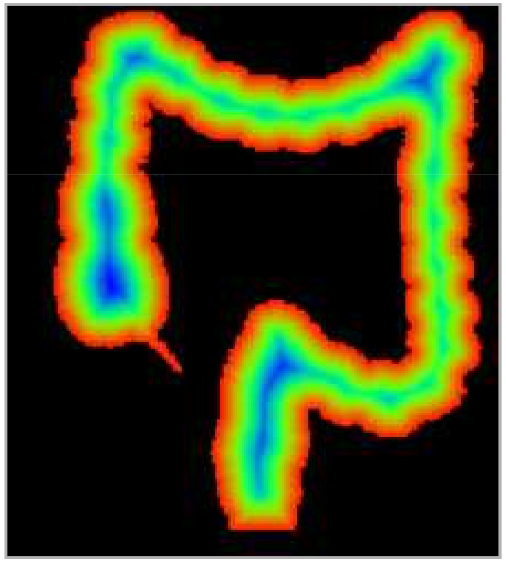


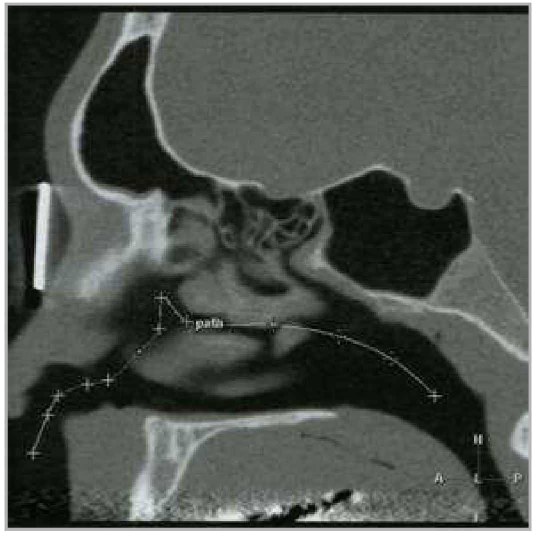
Image Courtesy Dirk Bartz, Univ. of Leipzig

Segmentation/Path Planning

- Accuracy and value of virtual endoscopy depends on segmentation quality.
- Reliable, fast and automatic segmentation in general is very difficult.
- Good results are achieved in case of air-filled structures in CT, such as the colon.
- Path planning often based on the skeleton and/or the distance field of the target structure.

Segmentation/Path Planning





The distance field in the colon may be used for path computation and supporting guided navigation.

(From: Hong et al. 1997)

Interactive path specification based on coronal slices.

Rendering Techniques

Surface visualization and Direct Volume Rendering

- Surface visualization requires pre-processing (segmentation).
- Segmentation result is converted to a polygonal mesh, post-processed (smoothing) and efficiently rendered using graphics hardware.
- Perspective rendering is preferred
- Acceleration Techniques:
  - Occlusion culling (restrict rendering to the small visible portion)
  - Empty-Space-Leaping

Rendering Techniques

Image Courtesy Dirk Bartz, Univ. of Leipzig

Typical artifacts of surface models generated by means of Marching Cubes for virtual endoscopy.

Rendering Techniques

Occlusion Culling:

Specific possibilities of endoscopic views:

- Endoscopic views have very limited visibility
- Removal of occluded geometry (occlusion culling)
- Frequently achieves culling of 90%

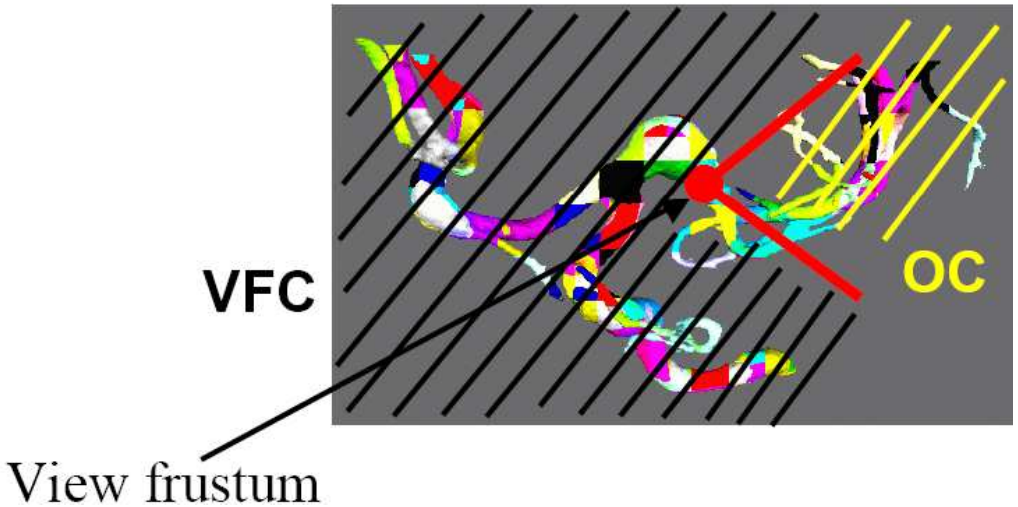
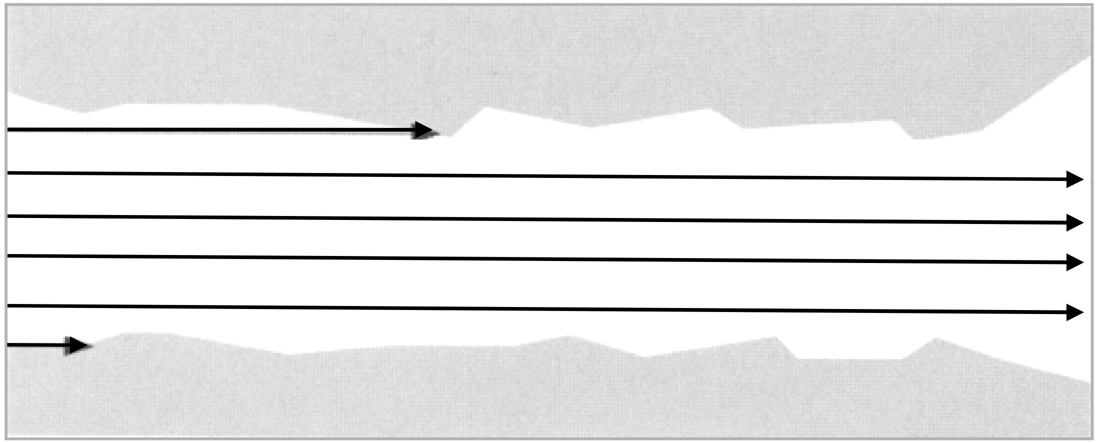


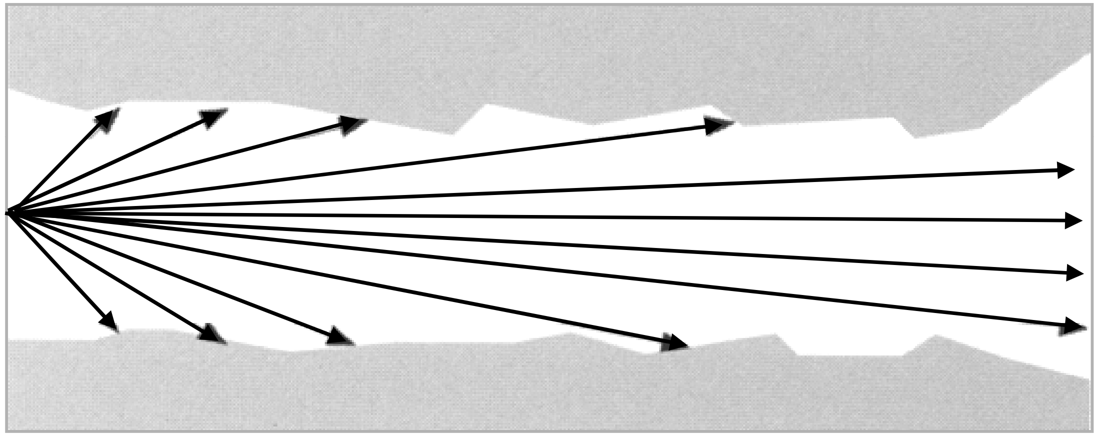
Image Courtesy Dirk Bartz, Univ. of Leipzig

Rendering Techniques

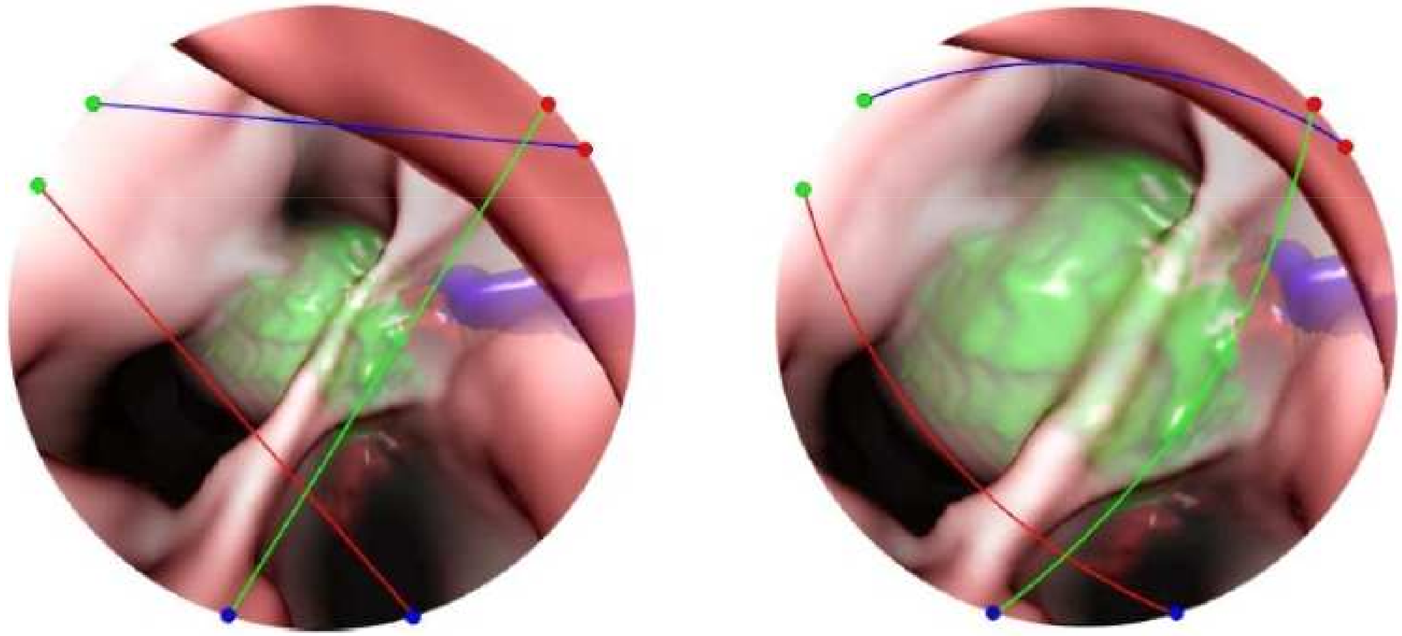
Parallel versus Perspective Rendering

More structures are visible with perspective rendering. Although parallel rendering is faster, perspective rendering is preferred.





Rendering Techniques



For intervention planning and training, it is essential to simulate the distorted view of virtual endoscopy.

To provide a sufficient overview, lenses at the tip of endoscopes use large opening angles (30°, 70°).

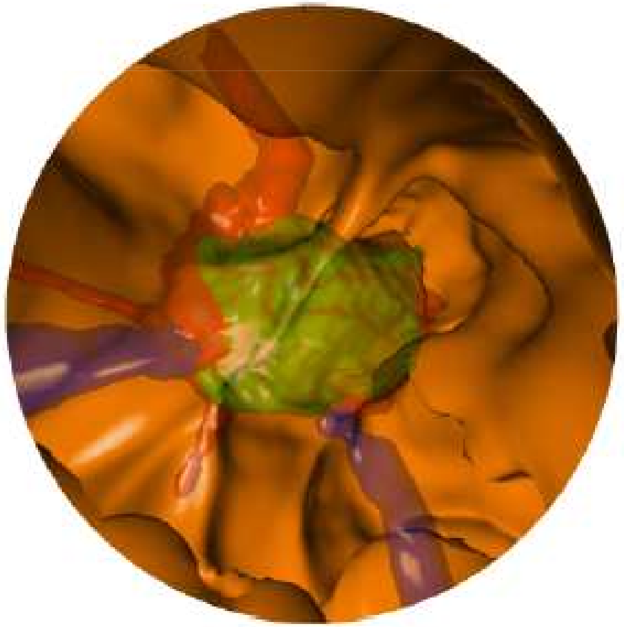
View from the sphenoid sinus to the pituitary gland

Images are courtesy of André Neubauer, VR Vis Vienna

Rendering Techniques

„Look behind the wall“

Provide additional information compared to optical endoscopy



constant blending parameter

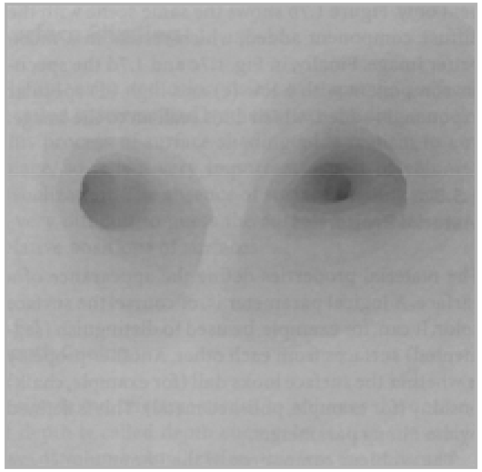
Modified blending considering the distance between fore- and background

Blended fore- and background images for first-hit ray casting. Images are courtesy of André Neubauer, VRVis Wien.

Rendering Techniques

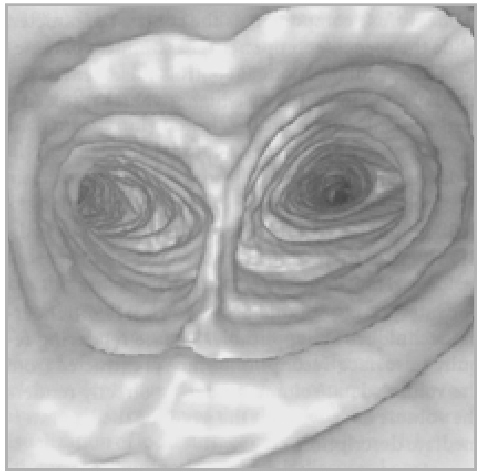
Illumination

ambient

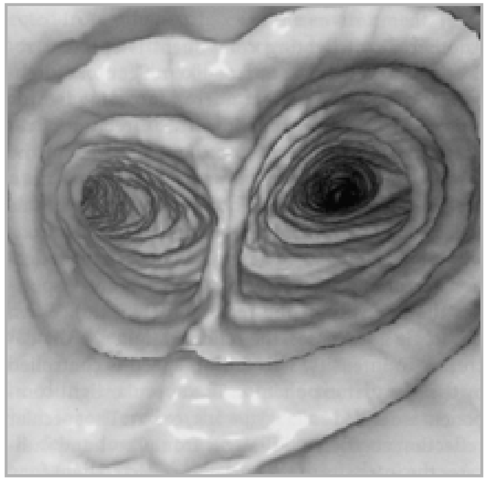


diffuse

diffuse
+
low specular



diffuse
+
high specular



Source: Virtual Endoscopy and Related 3D Techniques, Springer 2001

Rendering Techniques

Direct volume rendering

- Trilinear interpolation (better than linear interpolation, used in Marching Cubes)
- Special variant of ray-casting, first hit raycasting (Neubauer, 2004), where a predefined number of surfaces along each ray are located.

Interaction and Navigation

Navigation Models - Paradigms

- Planned Navigation (“Autopilot“)
  - Specification of a camera path
  - Camera is more or less fixed to that path
  - VCR-like interaction
  - Costly refinement
  - Some observations: only 70% of all polyps are visible in a typical flight through the colon. 95 % are visible if the flight is also shown in the reverse direction.

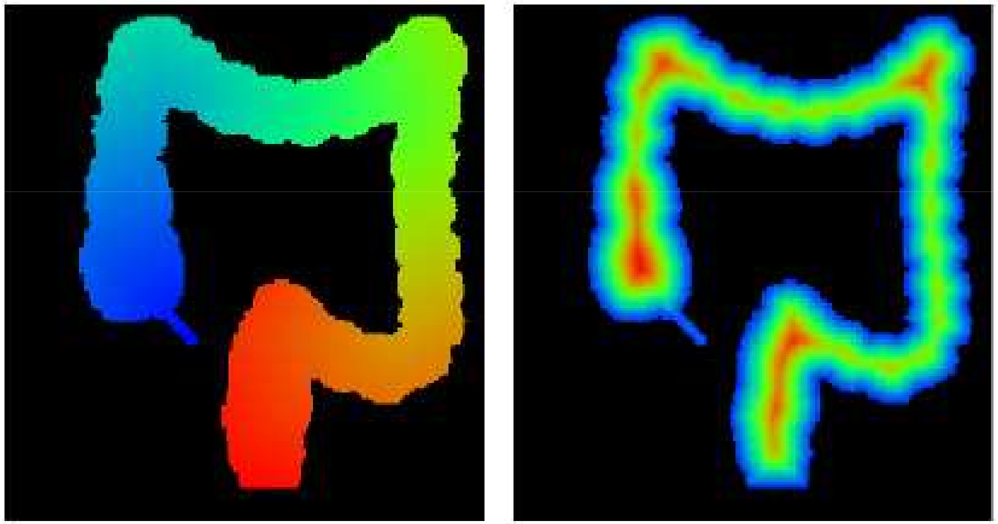
- Manual/free Navigation
  - Often difficult to control
  - Requires heavy 3D interaction

Interaction and Navigation

Guided Navigation:

- Combines flexibility and guidance
- Interactive and intuitive
- Camera dives through scene like submarine
- Current and thrust through distance fields and kinematic rules
- Principles have been invented in the Vivendi-System (Bartz, 2003)

Interaction and Navigation



Distance to the target and distance to the vessel wall are employed for guided navigation (Hong, 1997). Images courtesy of Shigeru Muraki, AIST Japan

Interaction and Navigation

Besides „traditional“ input devices, graphics tablets, force feedback devices as well as tactile input may be employed.

Sources: http://www.wacom.com

http://www.sensable.com

Interaction and Navigation

Comparison of different input devices

(From: [Krüger, 2007])

- Input devices
  - SpaceMouse
  - PHANToM without force feedback
  - PHANToM with force feedback
- Subjective Evaluation
  - Ease of learning, ease of use, spatial orientation
  - Satisfaction and level of fatigue
- PHANToM with force feedback yielded best results

Applications: Virtual Colonoscopy

Cancer of the colon is a leading cause of death → prevention and early detection is crucial.

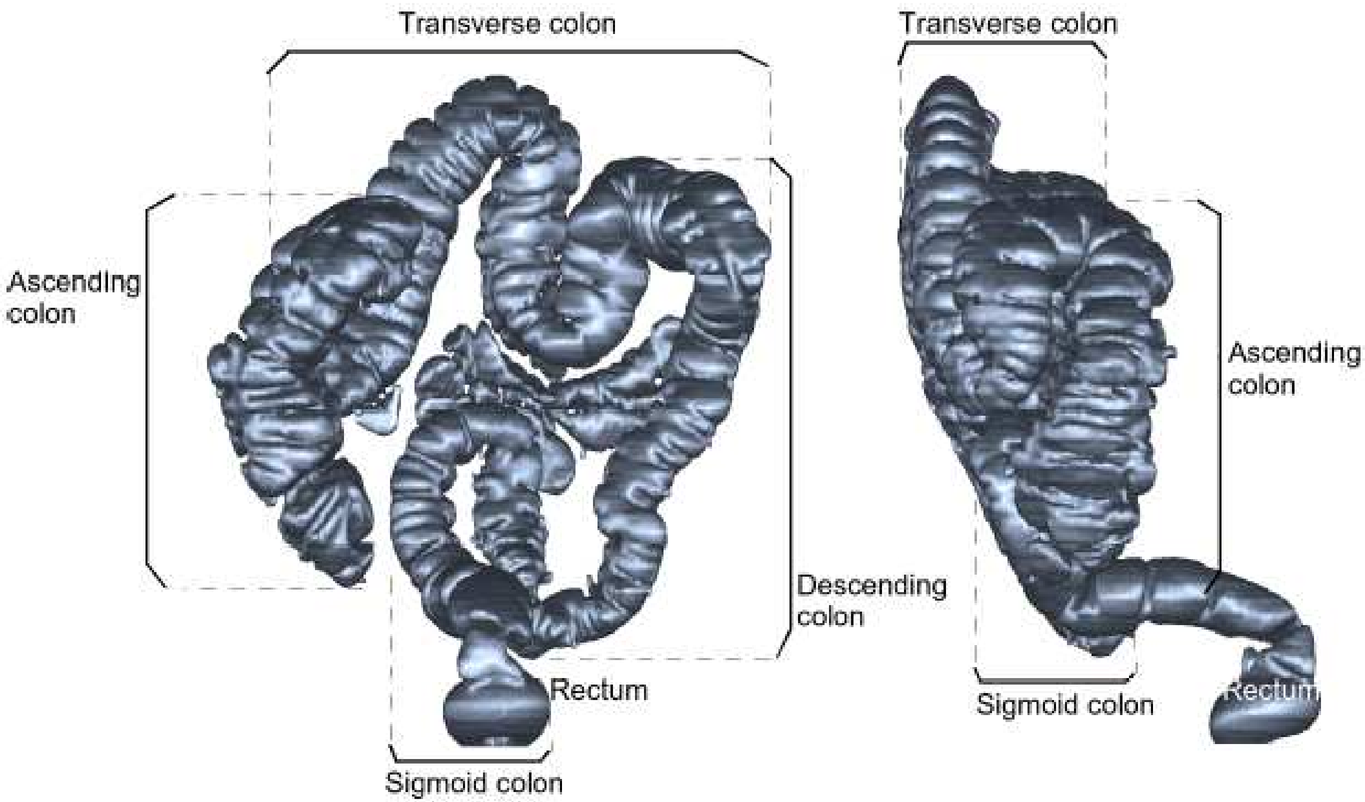
Optical endoscopy is an effective diagnostic procedure to inspect the colon wall for pathologies.

However, it is expensive (sedation of the patient) and suffers from low patient acceptance. → Virtual Endoscopy

Major goals:

- Reliable identification of polyps > 5 mm
- Low rate of false positives (e.g., residual fluid or remaining stool)
- Efficient processing of data for mass screening application of a whole age group

Applications: Virtual Colonoscopy



Coronal (left) and sagittal (right) view of the colon.

Applications: Virtual Colonoscopy

Results:

- The diagnostic performance (sensitivity, specificity) depends on many factors.
- Similar results to optical endoscopy are feasible (high quality data, experienced radiologists).
- It is essential that every part of the colon was inspected. Visibility maps indicate which regions have not been visited.

Applications: Virtual Brochoscopy

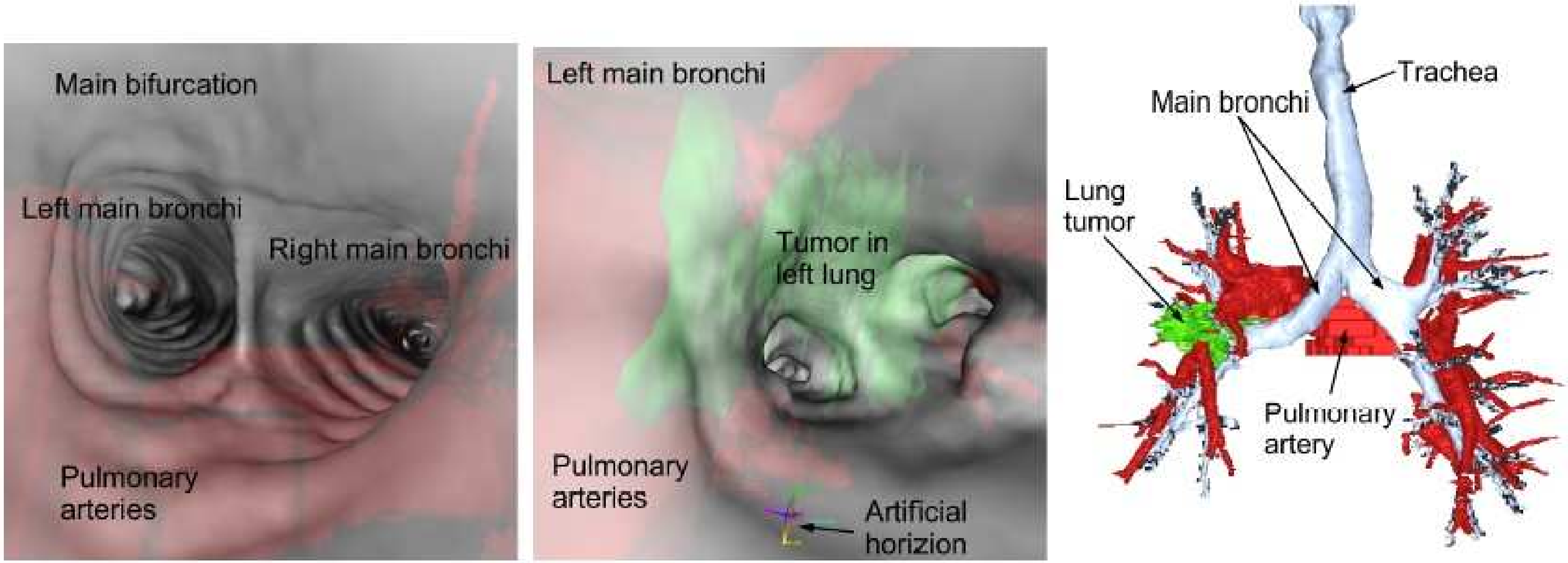
Diagnostic and therapy planning related to diseases of the tracheo-bronchial system, e.g., lung cancer, emphysema, …

Based on high resolution CT data (300 slices, 512x512)

Target structures: Airways, blood vessels, tumors

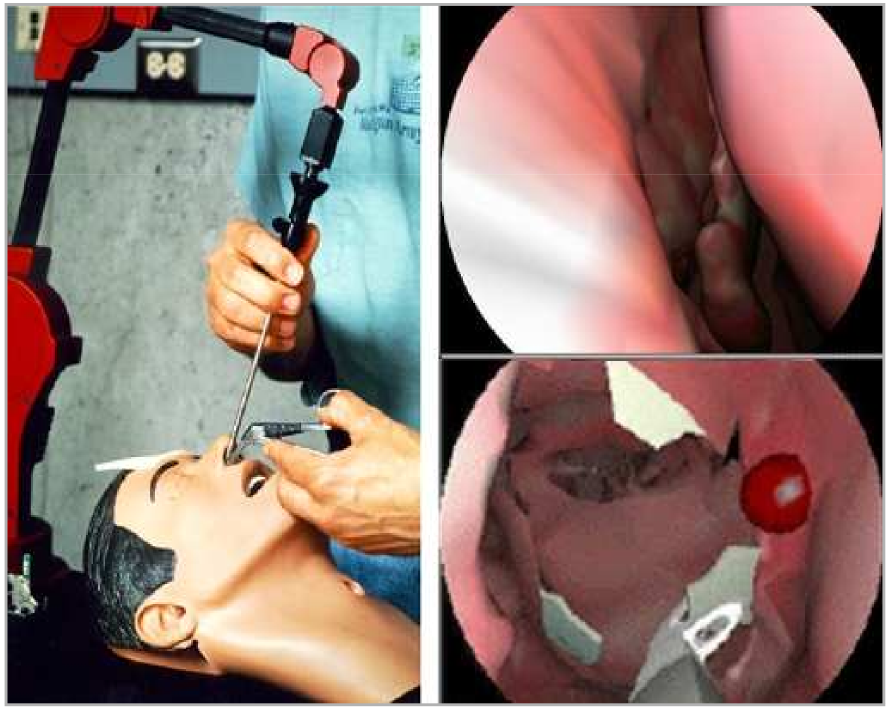
Segmentation of all structures requires a complex pipeline [Bartz, 2003]. In particular, reliable identification of the 5th and 6th generation of inner airways is difficult to accomplish.

Applications: Virtual Brochoscopy



Virtual bronchoscopy for surgery planning. Blended visualization of objects is crucial. (From: Bartz et al., 2003)

Applications: Training



Endoscopic Sinus Surgery Simulator
[Weghorst, 1997]

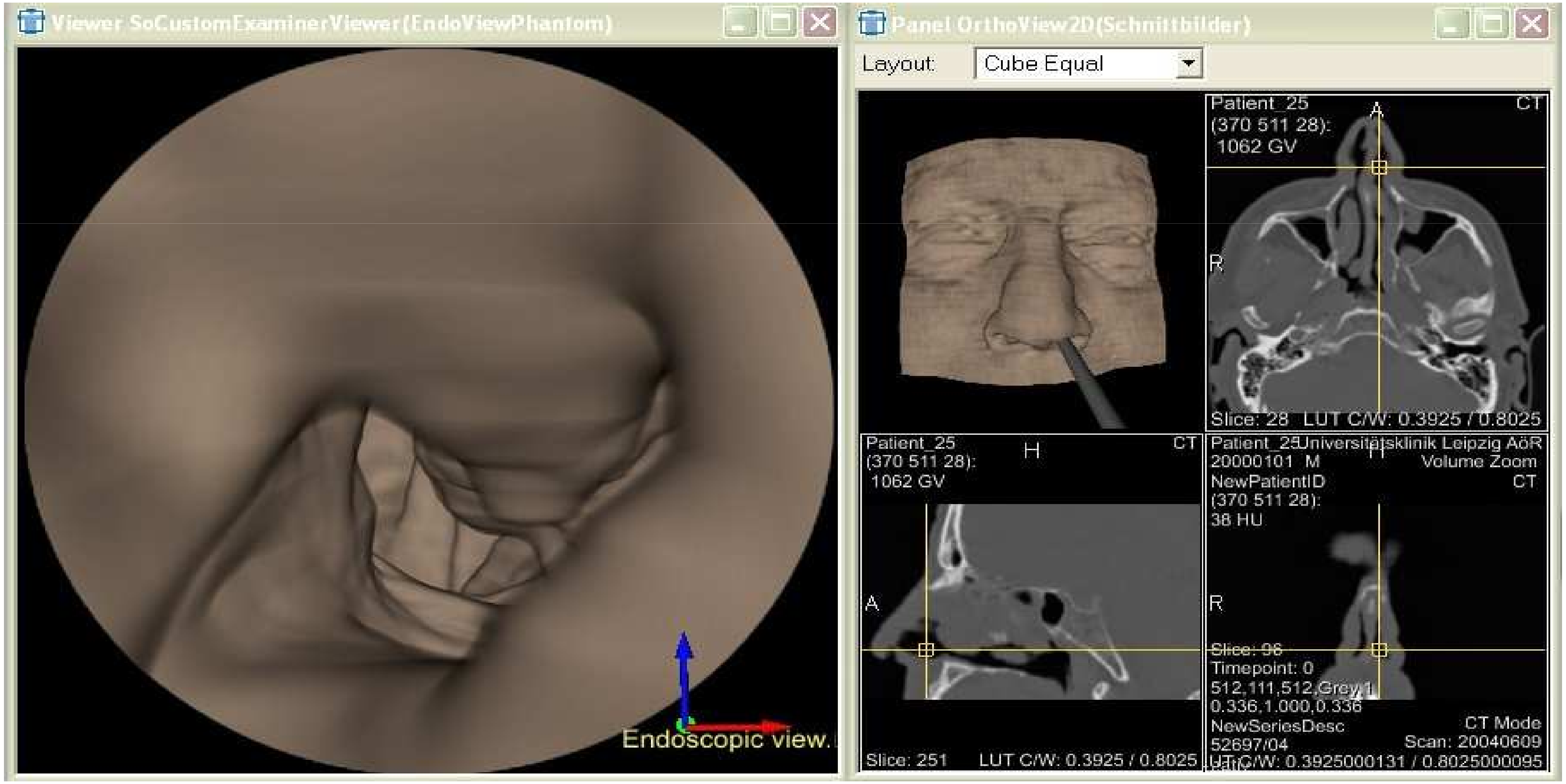
- Teaching anatomy of patients from interior viewpoints.
- Simulating endoscopic interventions, e.g. sinus surgery.
- Challenging application area since instrument-tissue interaction as well as soft tissue deformation must be simulated.

Applications: Functional Sinus Surgery

Major goals:

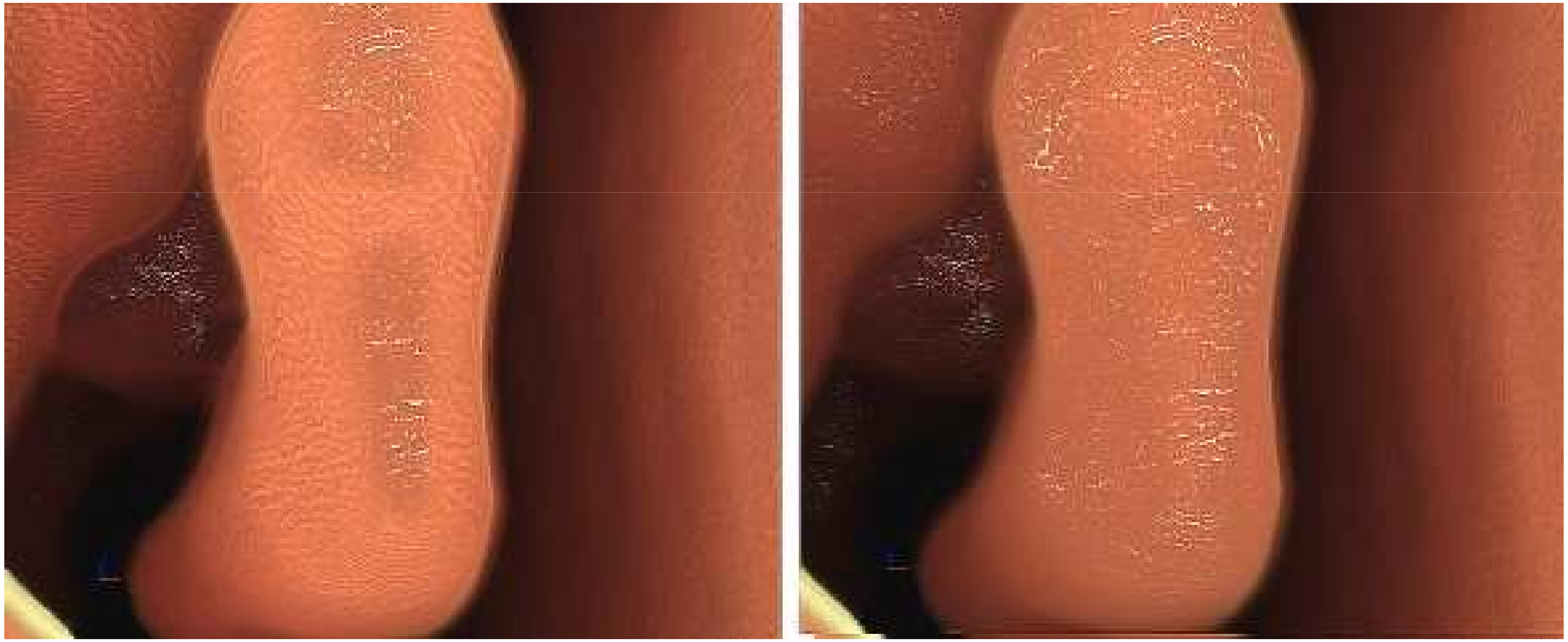
- 3D visualization of relevant structures
- Evaluation of spatial relations, e.g. with respect to risk structures, such as the optical nerve
- Measurement (e.g. to evaluate whether certain structures may be reached)
- Access planning
- Documentation of treatment planning

Applications: Functional Sinus Surgery



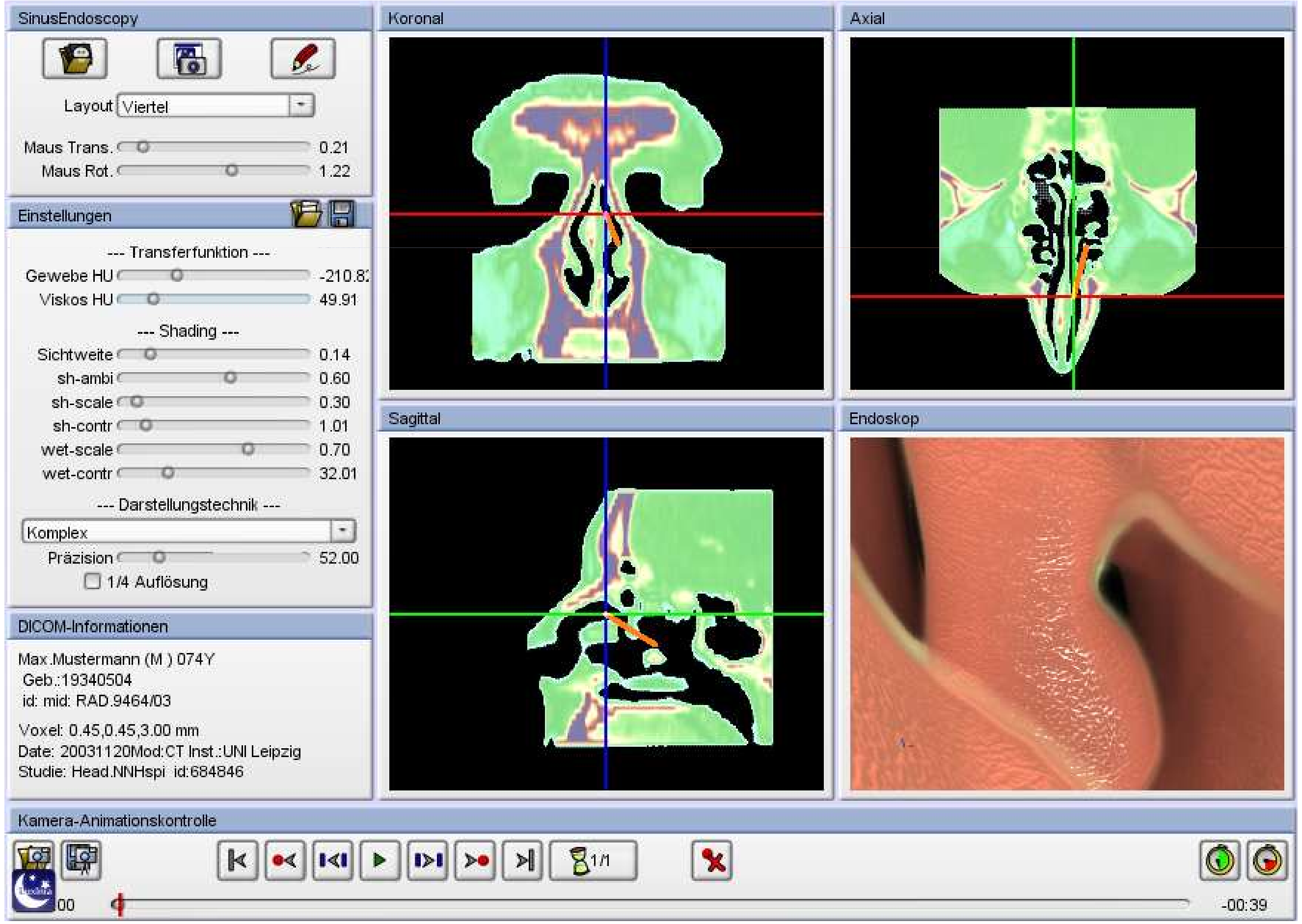
Endoscopic Sinus Surgery Planning System (From: [Krüger, 2007])
Segmentation and path planning is easy as long as cavities are filled with air. The more extended pathologic swellings are, the more difficult is the segmentation.

Applications: Functional Sinus Surgery



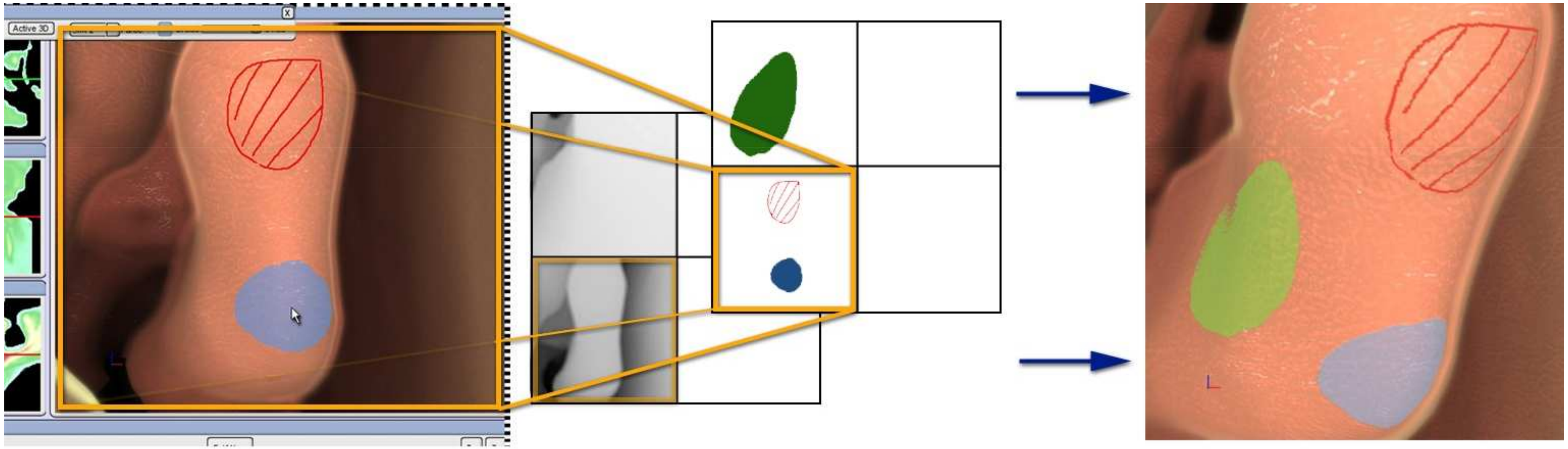
Endoscopic Sinus Surgery Planning System (From: [Krüger, 2008])
Realistic visualization of wetness effects for maximum similarity to intraoperative views

Applications: Functional Sinus Surgery



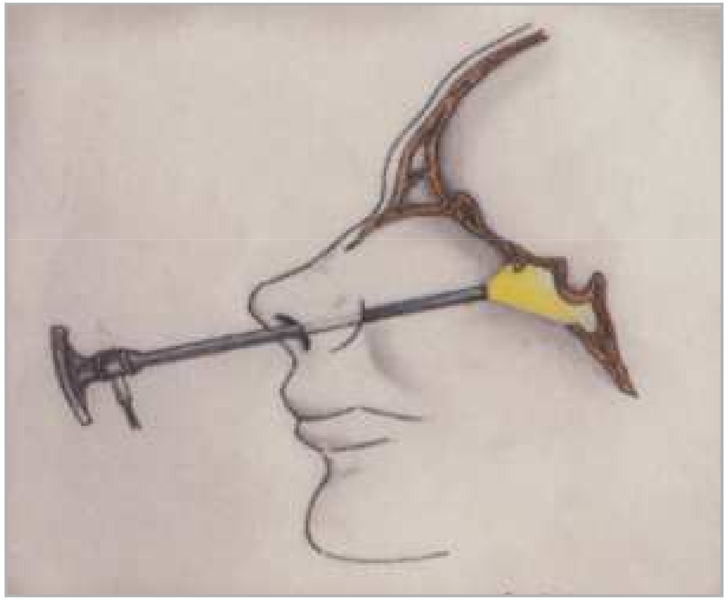
First user interface: too complex, too many settings and parameters. Improved UI applied to 125 patients (Krüger et al., 2008)

Applications: Functional Sinus Surgery



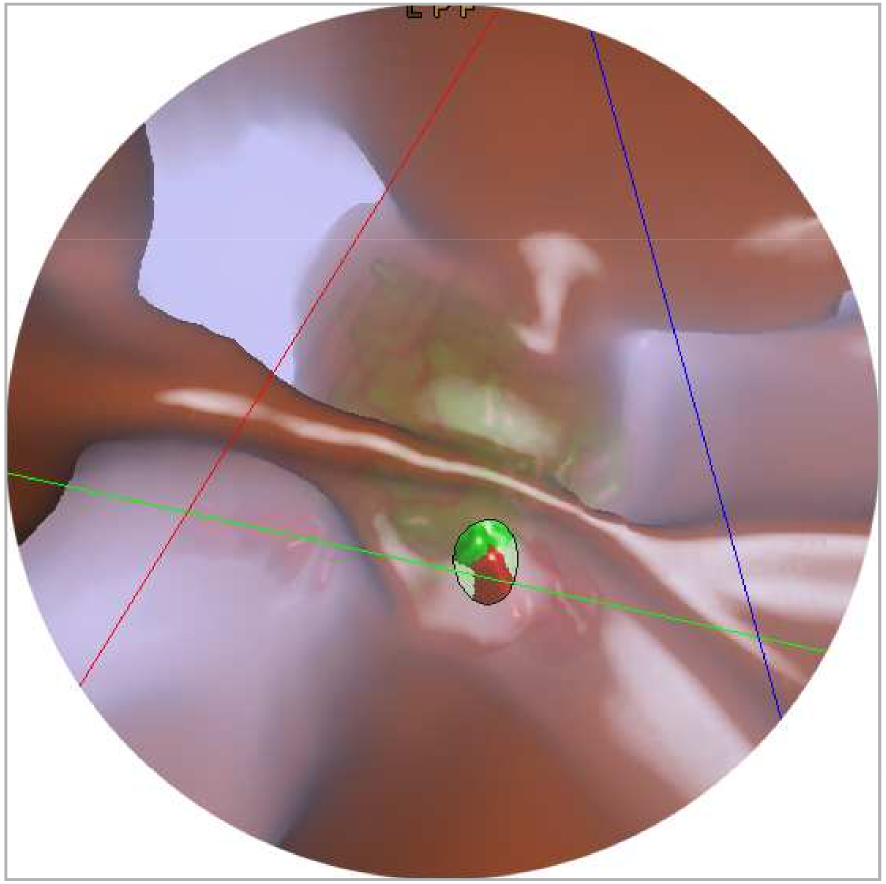
Feedback: Drawing and annotation facility is crucial for surgical planning and collaborative discussions.

Applications



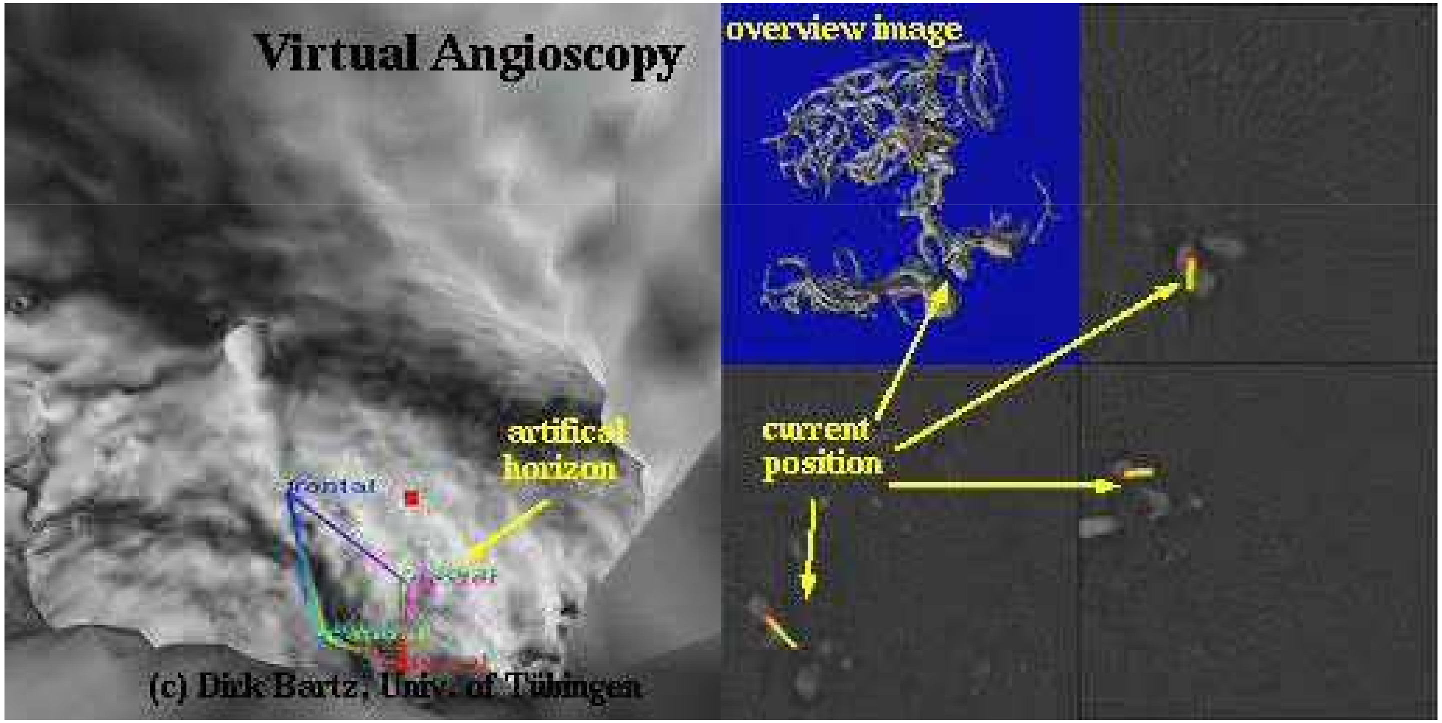
Virtual Endoscopy for Minimally-Invasive Surgery of the Pituitary Gland.

Benign tumors in this region are frequent and minimally-invasive removal is the state-of-the-art treatment. Several risk structures have to be considered.



Images are courtesy of André Neubauer, VRVis Wien.

Applications



Virtual endoscopy for diagnosis of cerebral aneurysms and planning neurointerventions (From: [Bartz et al. 2001])

Commercial Systems

Rendering, interaction and navigation techniques are similar to research prototypes. Careful integration in hospital information systems and clinical workflows are essential.

In particular, for virtual colonoscopy

- Philips EasyVision Endo 3D
- Viatroxnix V3D Viewer/Colon
- GE Advantage Winodws
- Vital Images Vitrea2/CT Colonography

Most of them

- use raycasting as rendering mode,
- provide (semi-)automatic path planning and
- guided as well as manual navigation

Conclusion

- Virtual endoscopy for intervention planning has great potential. However, the added planning time hampered wide-spread use so far.
- Requirements, with respect to accuracy, strongly depend on application area.
- Virtual endoscopy cannot be used when examination of tissue sample is necessary.
- Validation and clinical evaluation are crucial aspects. The book by Rogalla et al. (Virtual Endoscopy and Related 3D Techniques) provides an excellent overview on these aspects.

Acknowledgement

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- André Neubauer, Katja Bühler, VR Vis Wien
- Arno Krüger, Univ. of Magdeburg
- Christoph Kubisch, Univ. of Magdeburg

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Augmented Reality and Intraoperative Visualization

Augmented Reality:

- Overlay of real data („patient“) and virtual data (geometric patient model)
- AR in Intraoperative Visualization:
  - Live-data (Op-Video) combined with pre-op. Patient model

Prerequisites:

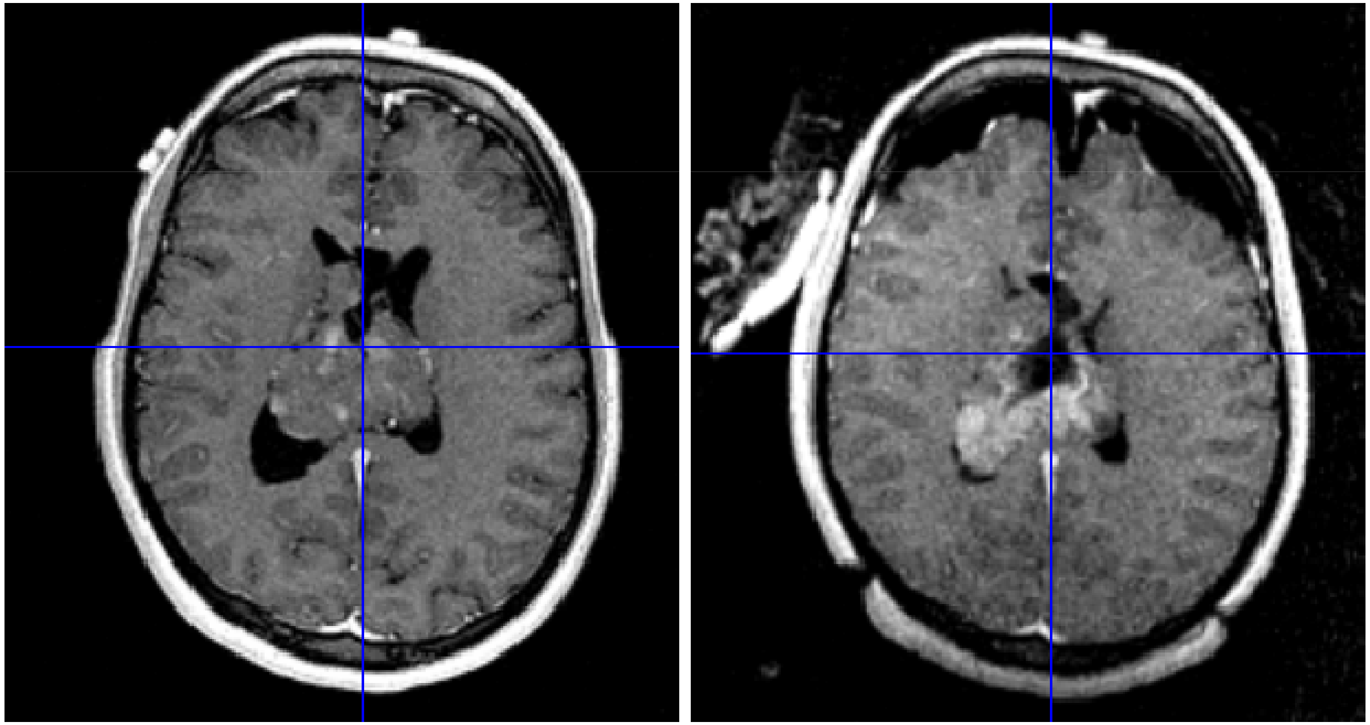
- Appropriate dataset (not too old)
- Preprocessing (Segmentation, …)
- Registration (Mapping: Pre-Op – Intra-Op.)
- Tracking of surgical instruments
- Update during surgery
- Appropriate output devices

Augmented Reality and Intraoperative Visualization

Brain shift and tissue deformation:

- Due to influence of surgical instruments and forces exercted on the tissue deformations occur
- Brain shift: Movement of (parts of the brain) after the skull is opened
- Initial registration is still valid in some portions of the brain.

Augmented Reality and Intraoperative Visualization



Images Courtesy Peter Hastreiter, Univ. Erlangen

Tissue deformation due to brain shift.

Augmented Reality and Intraoperative Visualization

Registration:

- Mapping of patient data to intraoperative position/orientation

  Optimization process guided by landmarks
  - Anatomic landmarks (difficult to locate them reliably and precisely)
  - Fiducial markers attached to the patient at known positions
  - Point cloud of the skin derived with a laser pointer
- Fiducial markers enable highest accuracy
- Point cloud sufficiently precise for a variety of interventions

Augmented Reality and Intraoperative Visualization

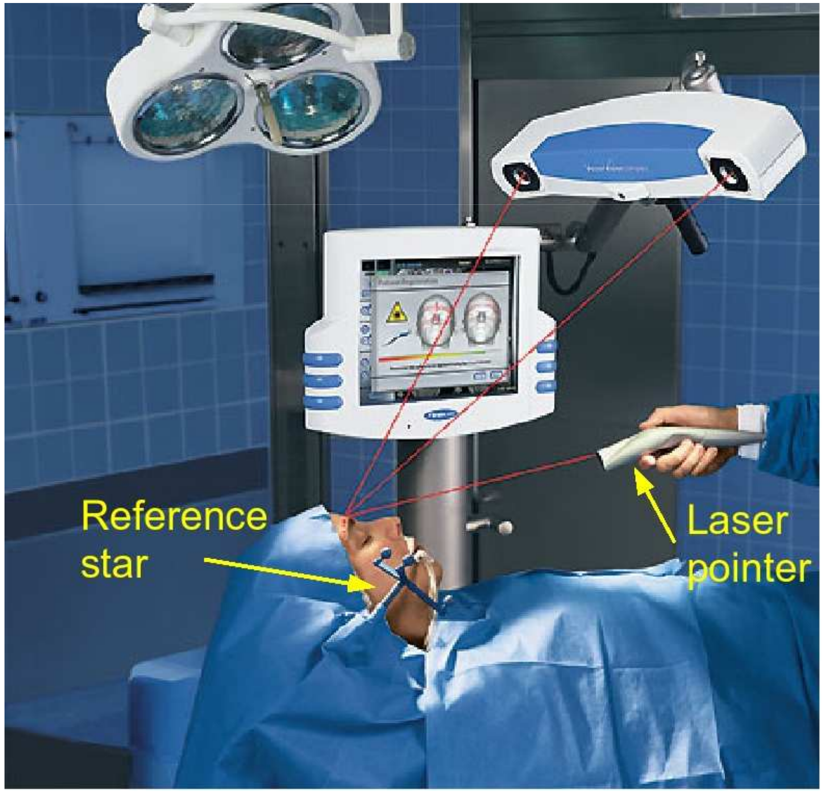


Image Courtesy Jürgen Hoffmann, Univ. Tübingen

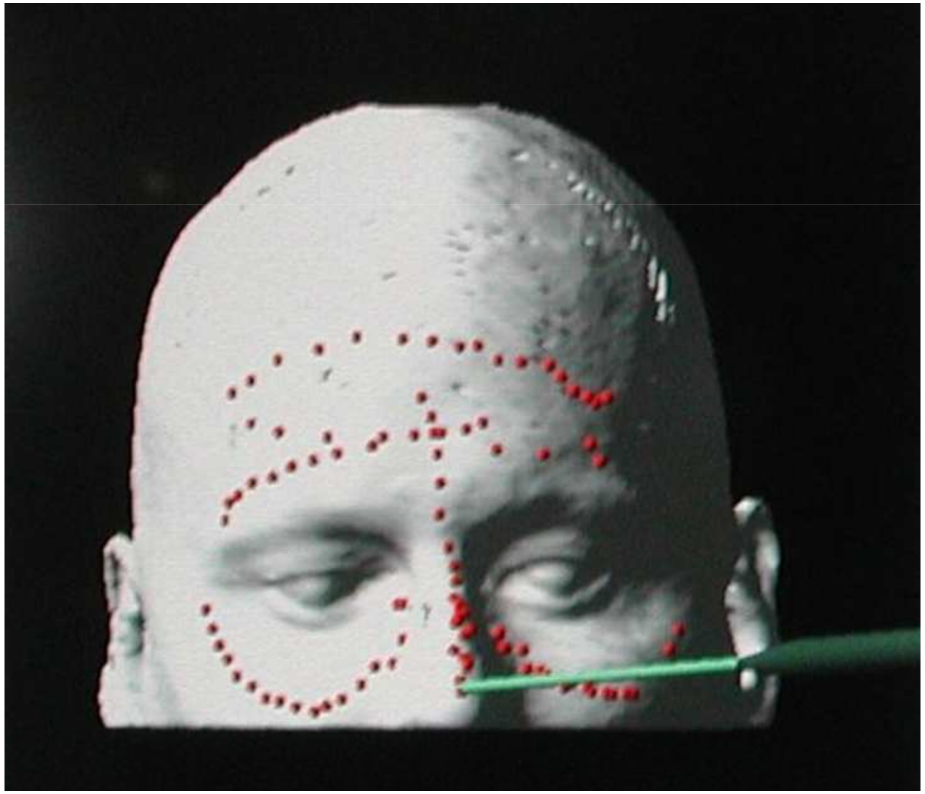


Image Courtesy BrainLab AG Feldkirchen

ICP-based registration of a point cloud

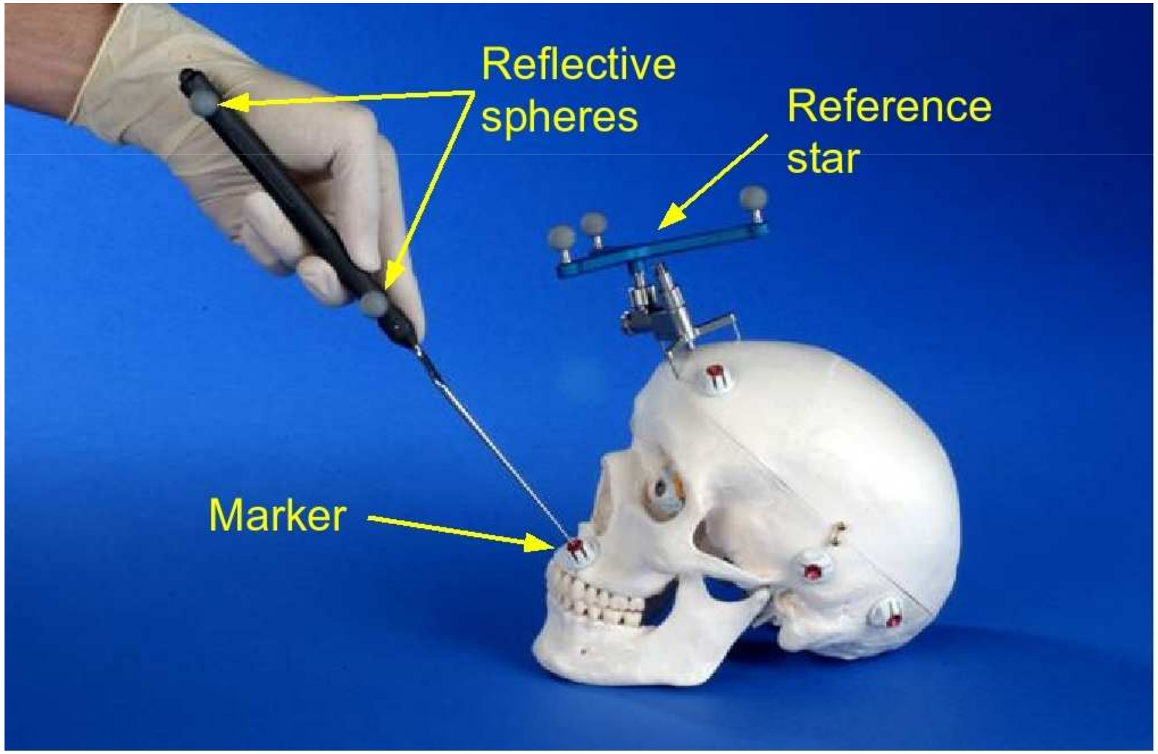
Tracking surgical instruments:

- Instruments attached with reflective spheres
- Optical tracking:
  - The instruments are seen by two cameras.
  - -> requires direct line of sight
- Electromagnetic tracking
  - No direct line of sight required. Lower accuracy compared to optical tracking. Magnetic field must not be disturbed.

Optical tracking with the Polaris Spectra

Image Courtesy NDI

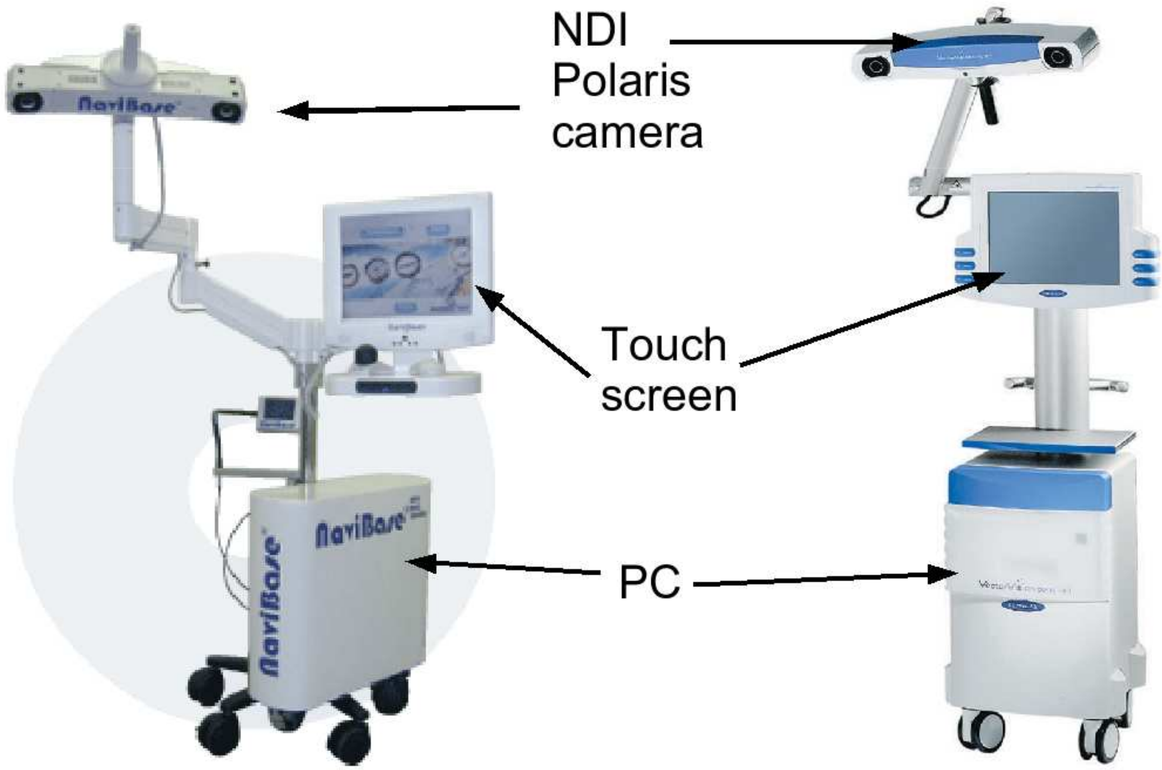
Augmented Reality and Intraoperative Visualization



Images Courtesy Jürgen Hoffmann, Univ. Tübingen

Tracked pointer tool to identify fiducial positions. A reference star is connected to the forehead.

Augmented Reality and Intraoperative Visualization

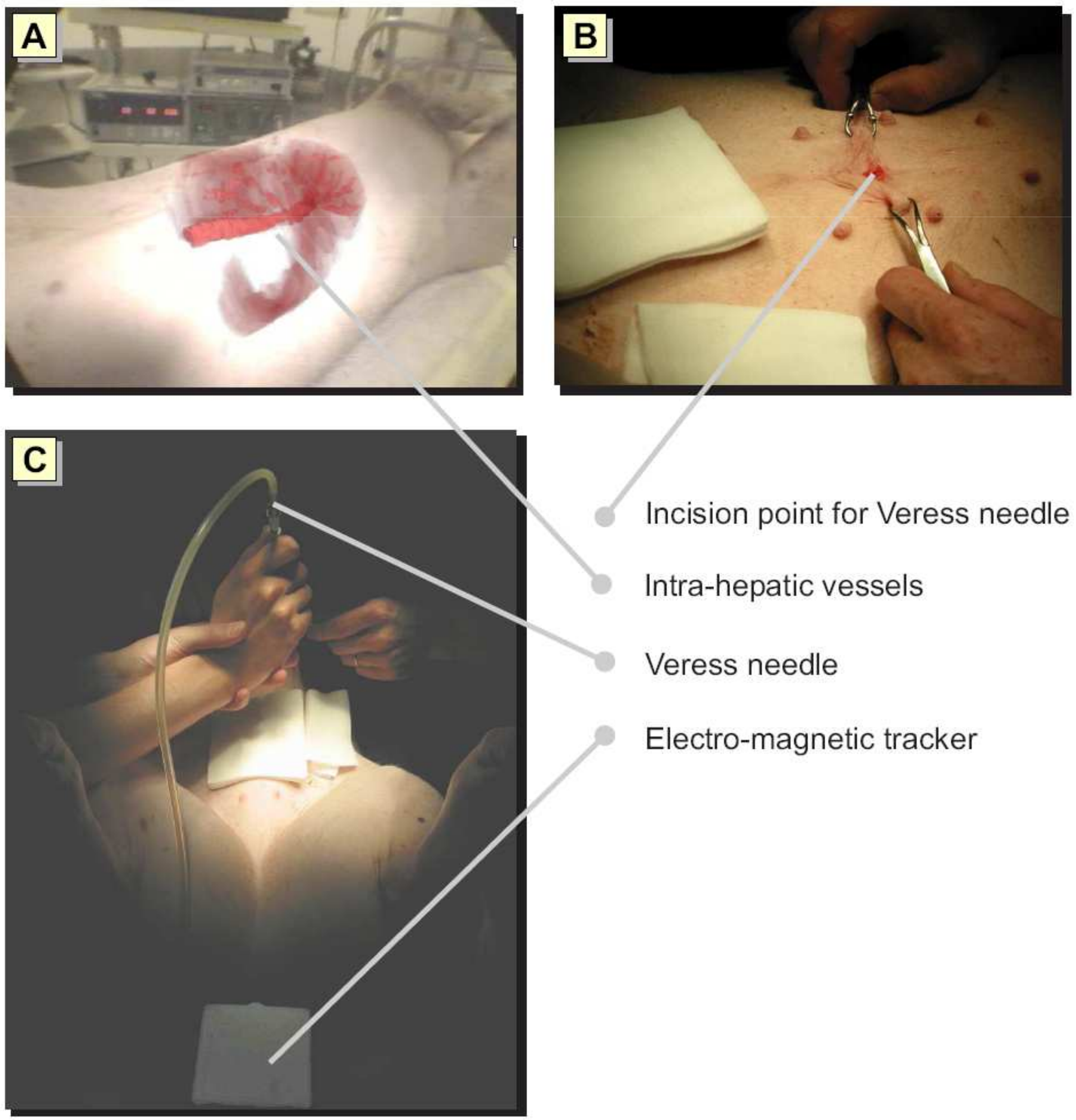


Augmented Reality and Intraoperative Visualization

Intraoperative visualization options:

- Data are projected on a special fixed monitor
- Data are projected on a small flexible display in the surgeons hand. Display is tracked.
- Data are included in the endoscope view.
- Data are projected directly onto the patient.

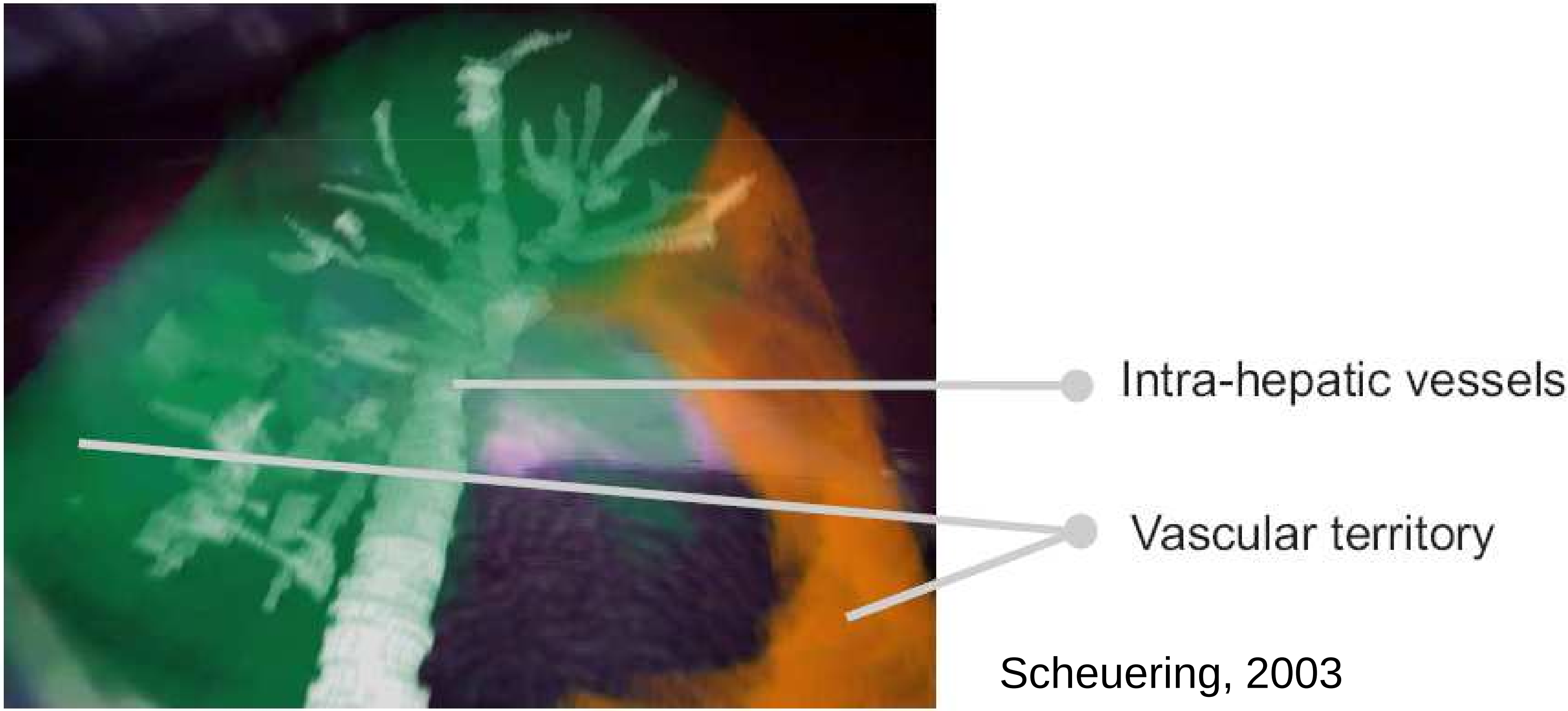
Augmented Reality and Intraoperative Visualization



- Augmented Reality in Liver Surgery
- Animal Experiment

  (Scheuering, 2003)

Augmented Reality and Intraoperative Visualization



Scheuering, 2003

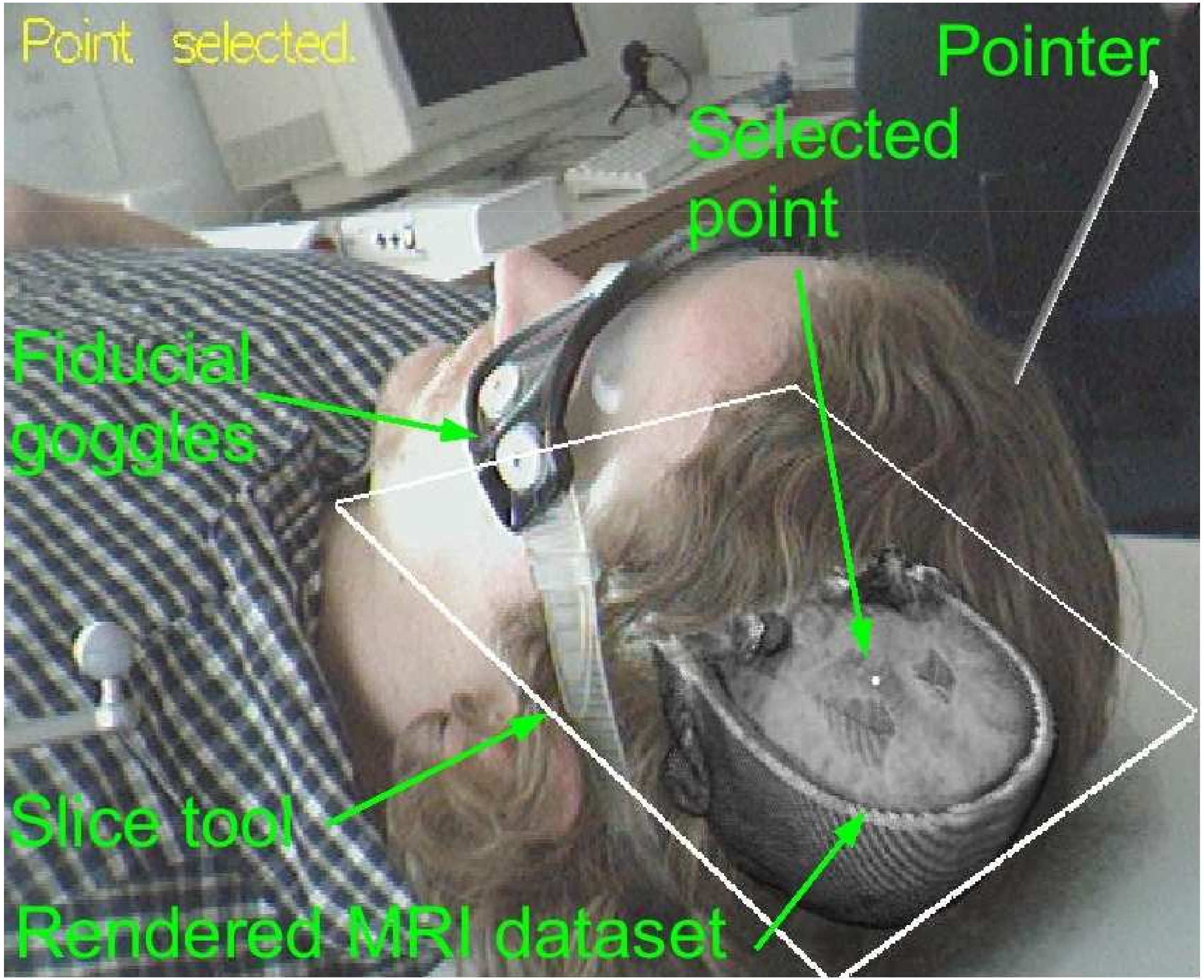
Video overlay of a laparoscopic liver image with 3D renderings from pre-planning.

Augmented Reality and Intraoperative Visualization

Image Courtesy
Thomas Lange,
Charite Berlin

Intraoperative 3D ultrasound in the OR. Preoperative imaging.

Augmented Reality and Intraoperative Visualization



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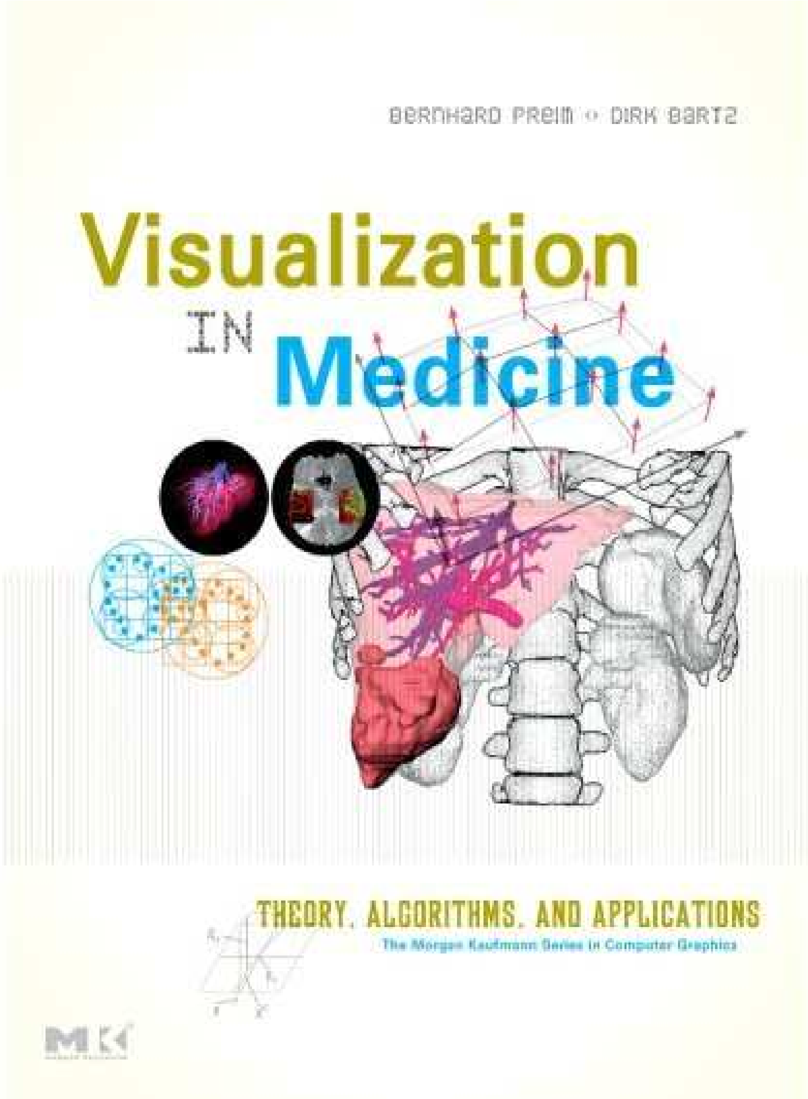
More detail on all this



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