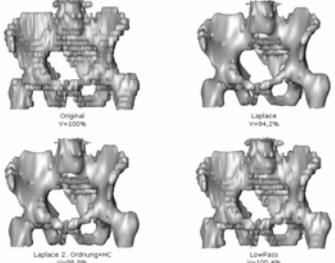
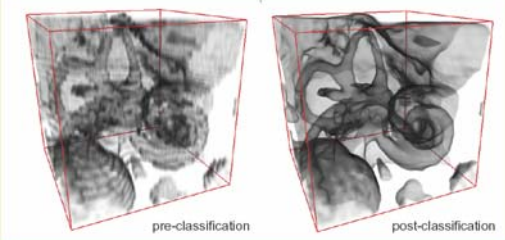




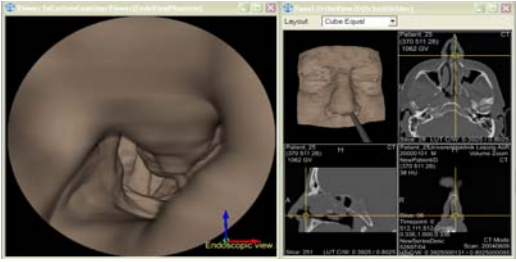
Virtual Reality and Visualization



Surface
visualization



Volume
visualization



Virtual
Endoscopy



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1



Content

2D and 3D Visualization for the Exploration of Medical Image Data, B. Preim	(15 min.)
Surface Visualization, B. Preim - Marching Cubes and its improvements - Smoothing of surface visualizations	(30 min.)
Direct Volume Visualization, D. Bartz - Ray casting and texture-based approaches - Projection methods	(30 min.)
3D Vessel Visualization, B. Preim	(35 min.)
Virtual Endoscopy, D. Bartz	(30 min.)
Virtual and Augmented Reality, D. Bartz	(20 min.)



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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

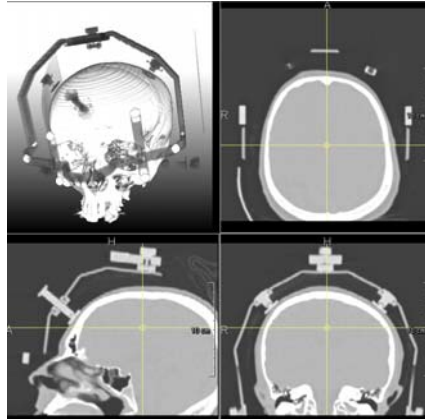


2D and 3D Visualization for the Exploration of Medical Image Data

- 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



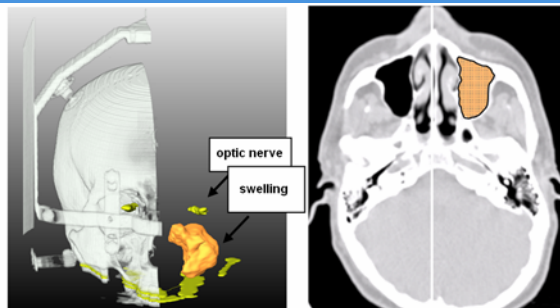
2D and 3D Visualization for the Exploration of Medical Image Data



- 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



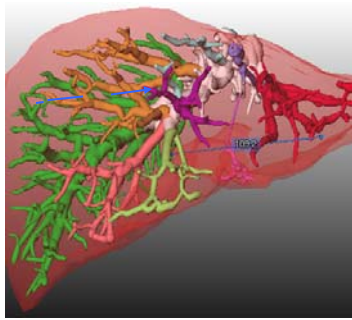
Images Dörte Apelt, MeVis Research

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.



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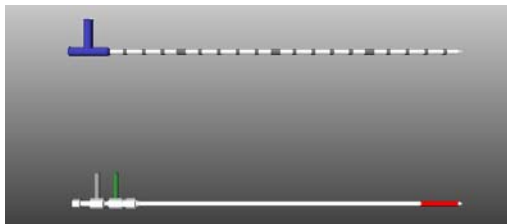
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2D and 3D Visualization: Placement of Applicators

- 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 thermal treatment of liver tumors.



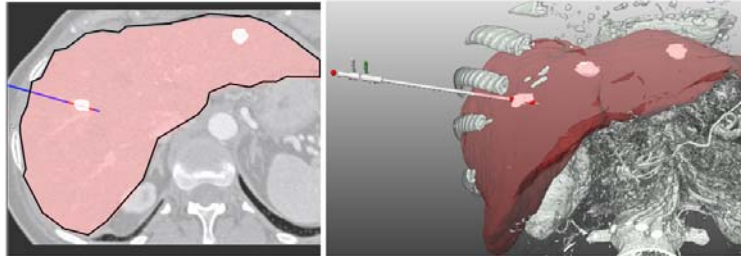
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2D and 3D Visualization: Placement of Applicators



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.



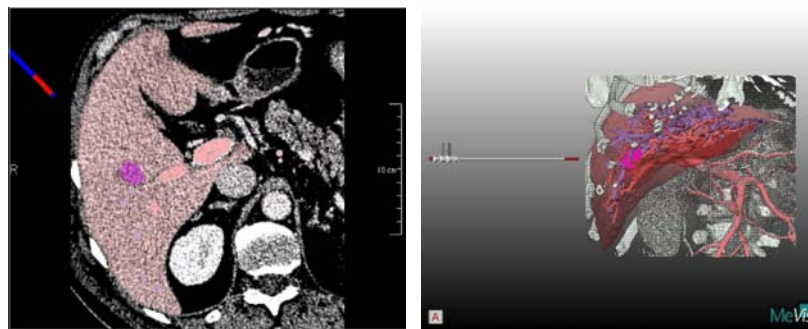
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2D and 3D Visualization: Placement of Applicators



Videos from Arne Littmann,
MeVis Research



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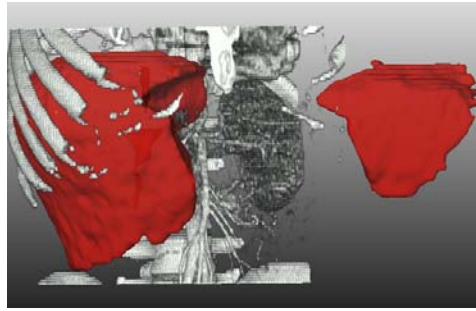
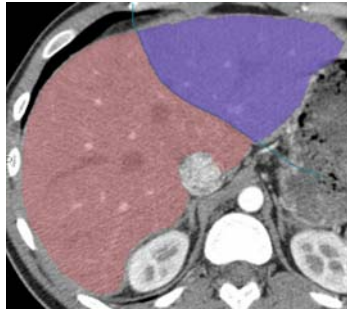
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2D and 3D Visualization: Virtual Resection

- Virtual resection by drawing into the slices and shape-based interpolation
- Interaction in 2D (precise), evaluation in 3D



Preim et al., *Proc. of SimVis*, 2003



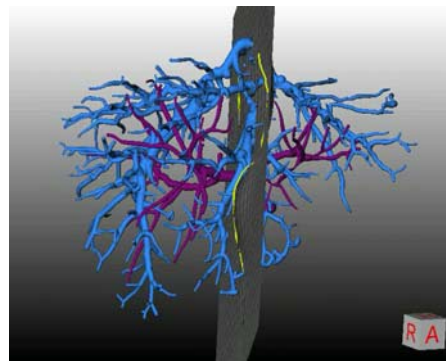
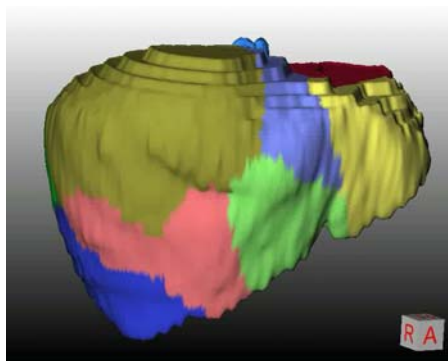
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2D and 3D Visualization: Virtual Resection



Videos Milo Hindennach, MeVis Research



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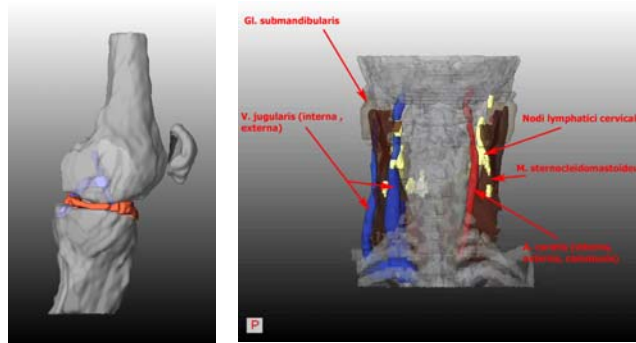
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Surface Visualization

Visualization of isosurfaces and segmentation results

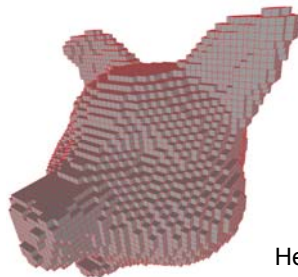


Surface Visualization: Introduction

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?

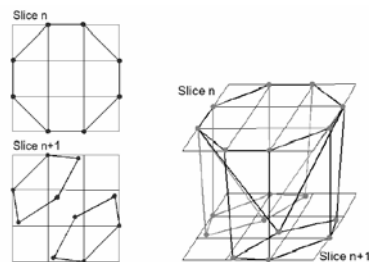
- follow the outlines
 - very difficult in 3D, many case distinctions
- Locally independent inspection of the cells. Determine how the cell is cut from the surface.
 - basic idea of Marching Cubes (patented in 1985, published in 1987)



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)*. Assume that C_1 and C_2 are corresponding contours. How shall these contours be connected through triangulation nets?
- *Branching problem*. If the number of contours in one slice S_n is different to the number of contours in the neighbor slice S_{n+1} .



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



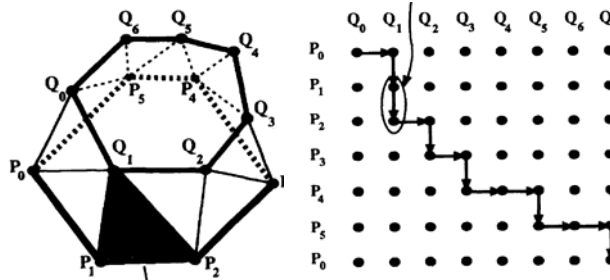
From Contours in slices to Surfaces

- *Correspondence problem*. Comes up, if the following applies:
The contours $C_i(S_n)$ and $C_j(S_{n+1})$ belonging to an object do not overlap themselves, and the number of contours belonging to one object is > 1 in S_n and/or S_{n+1} .
- What does Marching Cubes do?
 - An overlapping of contours in neighbored slices is assumed.
 - When does this procedure not work? 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.



From Contours in slices to Surfaces

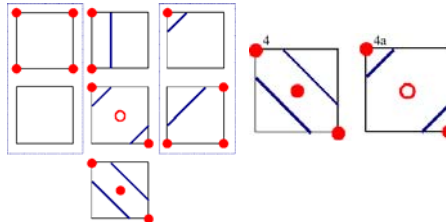
- “Tiling” problem. Connect n endpoints of the contour in a slice P_i with m endpoints of the contour in the neighbor slice Q_j .
- Criteria (selection):
 - the resulting volume shall be maximal.
 - the resulting plane shall be minimal.
- How can this be solved? Depiction on graph search (Keppel [1972], Fuchs [1977])



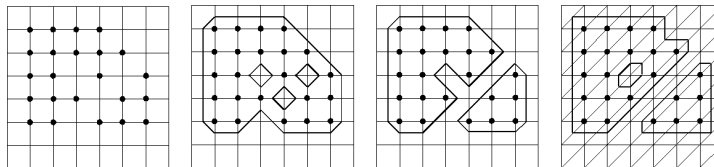


Surface Visualization: Marching Cubes

- Consideration of the 2D case (Marching Squares). Isoline for $\text{iso}=0.5$.



- Ambiguity:



© Dirk Bartz

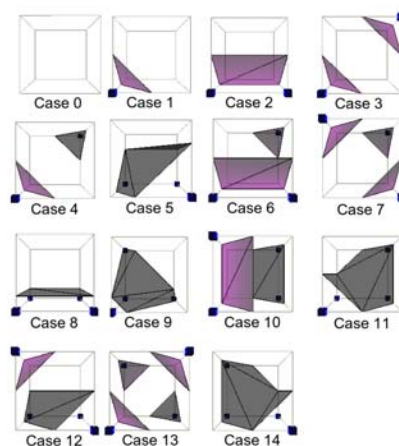


Surface Visualization: Marching Cubes

- 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.



© Dirk Bartz



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. Consideration of cubes 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

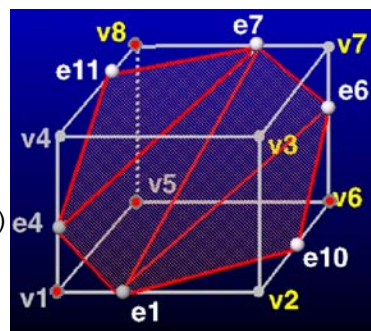
Step 4: Linear interpolation

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
- 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



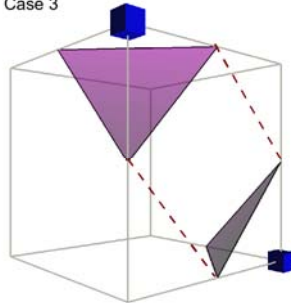
Virtual bronchoscopy

© Dirk Bartz

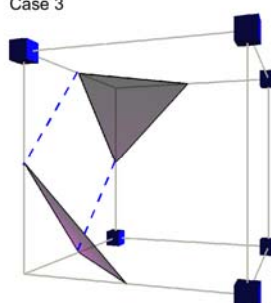


Surface Visualization: Marching Cubes

Case 3



Case 3



© 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.



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Surface Visualization: Marching Cubes

- How can this inconsistency be corrected?
 - Rule: e.g., always separate between positive endpoints and connect negative ones
 - Interpolation of points at the interface. The state of this point (above/below) is decisive (Nielsen, Hamann [1991])
 - Decomposition of the cells into tetrahedrons (Shirley, Tuchman [1990])



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Surface Visualization: Marching Cubes

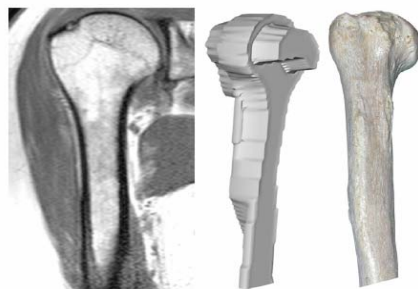
- How can Marching Cubes be accelerated?
 - Fast recognition of areas that are not affected by the surface.
Representation of the scene through hierarchic data structures, e.g., min-max-octrees (Wilhelms, van Gelder [1992])



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



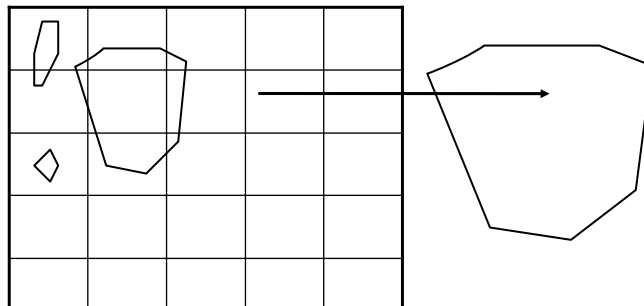
Surface Visualization: Smoothing and Noise Reduction

- **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

Connected Component Analysis



Term: Neighborhood: Cells which have common planes, edges or vertices, are neighbored 2, 1 or 0



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 (2,1,0) and not visited yet.

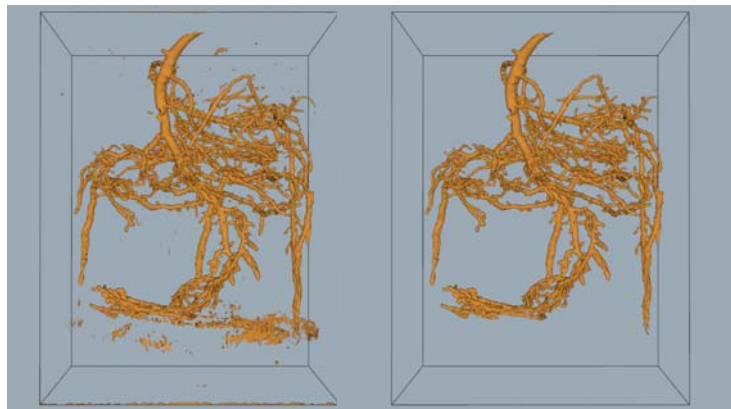
Result: all connected components

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

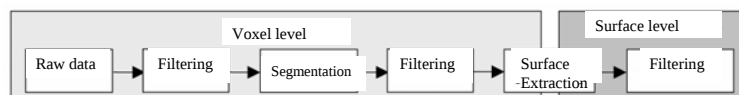
Disadvantages

- 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

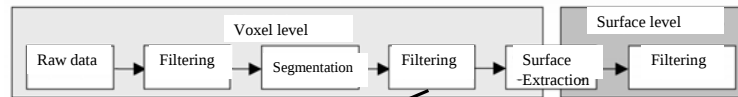
Adaptation of the respective procedures to

- 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	6	26	33	33	26	6
0	0	0	100	100	100	0	0	20	33	54	66	66	54	26
0	100	100	100	100	100	0	0	33	66	66	100	100	66	33
0	100	100	100	100	100	0	0	33	66	66	100	100	66	33
0	0	0	100	100	100	0	0	20	33	54	66	66	54	26
0	0	0	0	0	0	0	0	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, $v_{ref} = 50$



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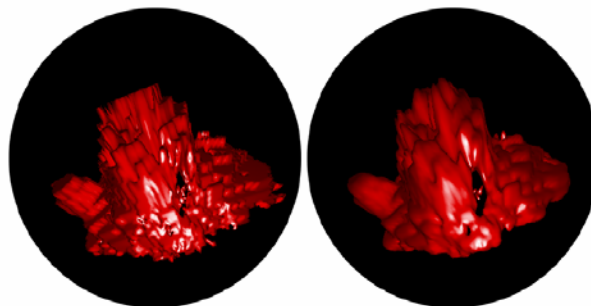
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Surface Visualization: Smoothing and Noise Reduction

- Smoothing of the segmentation result through morphological methods



Source: Neubauer et al., IEEE Visualization 2004



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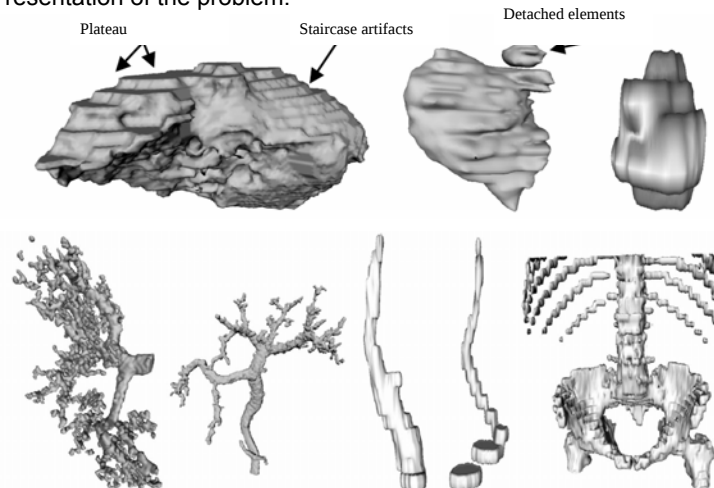
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Smoothing of Polygonal Surfaces

Presentation of the problem:



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

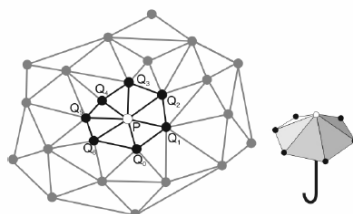
Measures:

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



Smoothing of Polygonal Surfaces

- Iterate over all vertices and replace each vertex 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 vertex (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

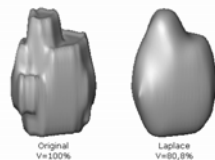


Smoothing of Polygonal Surfaces: Laplace Smoothing

- 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

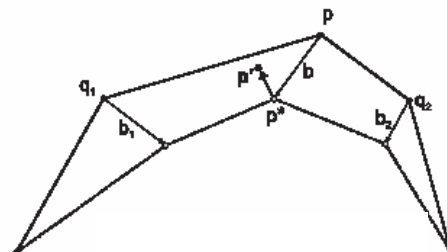


smoothing with $\alpha = 0.5$ and 20 iterations



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?

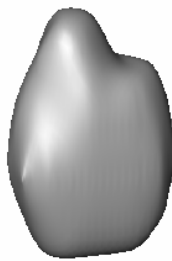




Smoothing of Polygonal Surfaces: Laplace Smoothing with Correction



Original
V=100%



Laplace
V=80,8%



Laplace+HC
V=99,8%

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



Smoothing of Polygonal Surfaces: Low-pass Filtering

- Alternating implementation of two filterings similar to Laplace with different factors α and μ
- Filtering: usually $1/n$ (all neighbors have the same influence; like Laplace)
- Selection of μ : a bit smaller than α
- Default: - $\mu = -1.02 \alpha$ (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



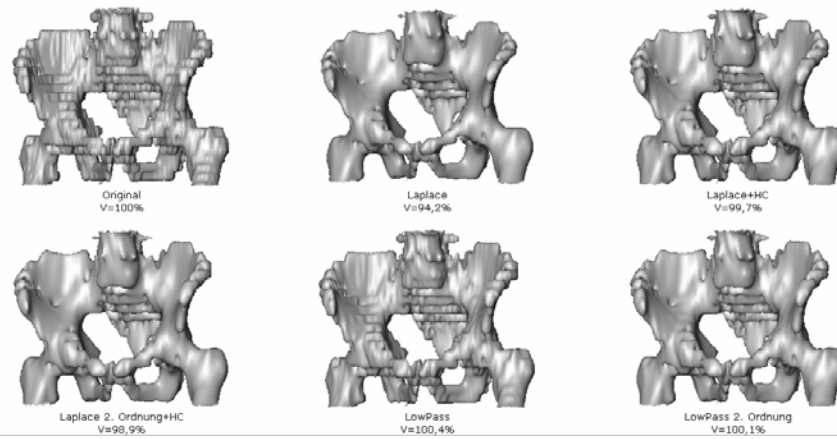
Smoothing of Polygonal Surfaces: Comparison of Methods

Original	Laplace	Laplace+HC	LowPass	Laplace+HC 2. Ordnung	LowPass 2. Ordnung
V=100%	V=91,0% 2,03s	V=99,9% 3,91s	V=100,1% 4,36s	V=99,6% 224,14s	V=100,2% 220,95s
Original V=100%	Laplace V=80,0%	Laplace+HC V=99,0%	Laplace 2. Ordnung+HC V=96,2%	LowPass V=100,0%	LowPass 2. Ordnung V=99,2%

Smoothing factor: 0.5, 20 iterations



Smoothing of Polygonal Surfaces: Comparison of Methods



All images with smoothing factor 0.5 and 10 iterations



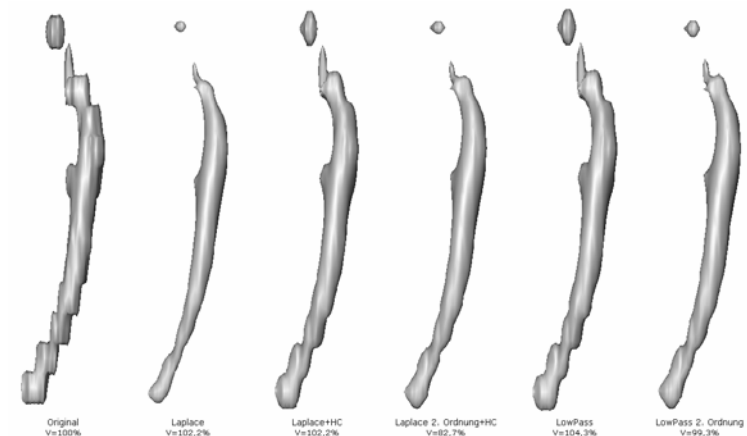
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Smoothing of Surfaces: Comparison of Methods



Carotid artery: Smoothing factor: 0.7 and 10 iterations



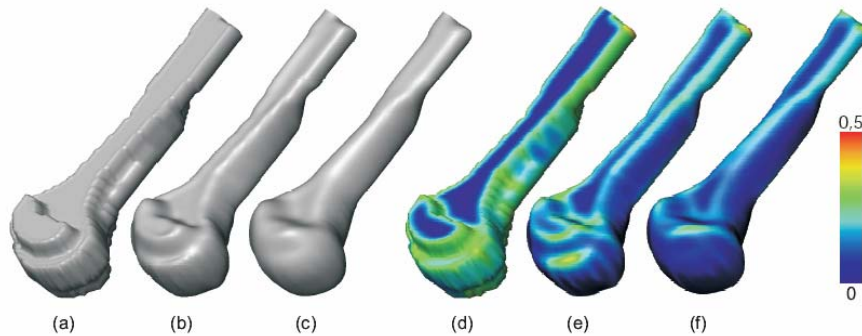
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Smoothing of Surfaces: Comparison of Methods



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



Smoothing of Surfaces: Further Methods

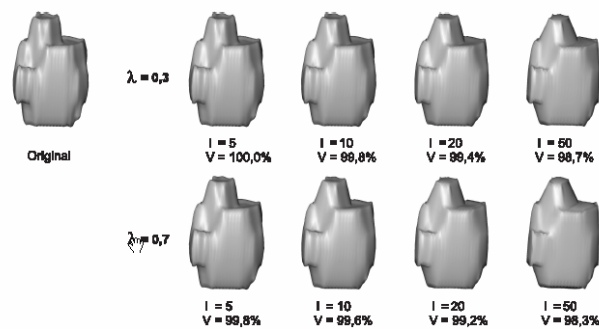
- **Average Value Filtering**
 - replaces the surface normal for the current point by the average normal of the considered surrounding and adapts the coordinates.
- **Median Filtering**
 - Sorts the normals in the neighborhood according to the angle of the current normal and - during the sorting - replaces the current normal by the normal which lies in the middle.
- **Mean Curvature Flow**
 - Uses curvature measures for the modification of vertices.



Smoothing of Surfaces

Average value filtering

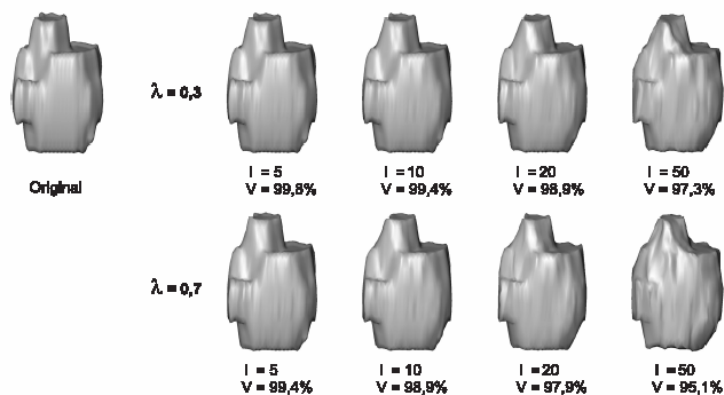
- Good volume maintenance, good smoothing for large and compact objects.
- New artifacts arise in case of smaller objects, especially for a high factor and a large amount of iterations



Smoothing of Surfaces

Median Filtering:

- Main application: maintenance of sharp edges in noise data
- problems similar to the average value filter, partly more distinctive

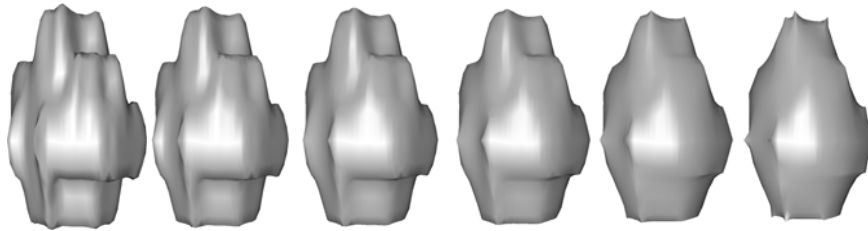




Smoothing of Surfaces

Mean Curvature Flow

- Problematic especially for compact objects in case of stronger smoothing factors



Original, smoothing after 5, 10, 20, 50 and 100 iterations.
No correction for volume maintenance.



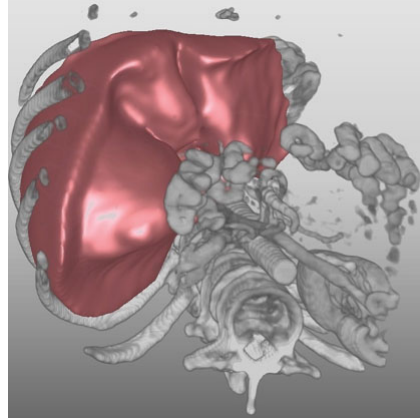
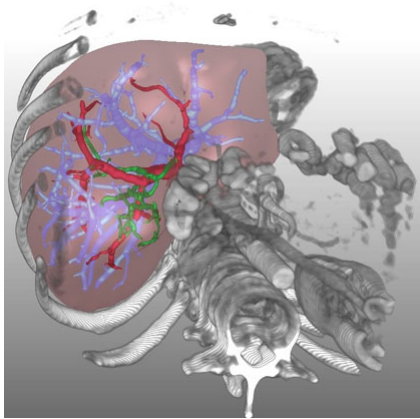
Smoothing of Polygonal Surfaces: Recommendations

- 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 even objects, especially with problem 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

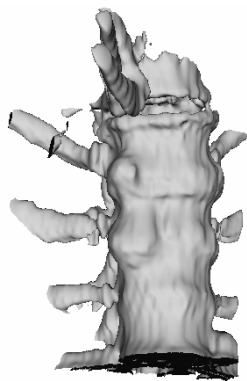


Surface Visualization: Examples

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



Surface Visualization: Examples



© Wolf Spindler, MeVis Bremen



© Thomas Gerstner, University of Bonn

- Good illustration of bony structures in CT data. Combination of several isosurfaces through an appropriate transparency adjustment.



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://www.wisg.cs.uni-magdeburg.de/cv/projects/LST/smoothing/>
- J. Vollmer, R. Mencil, 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>



Software for Medical Visualization

- MeVisLab, www.mevislab.de
- Amira, www.amiravis.com
- VTK, www.vtk.org
- METK www.metk.net

(based on MeVisLab) Softwaredemo:S1 C. Tietjen und K. Mühler, Di. 8.4.)



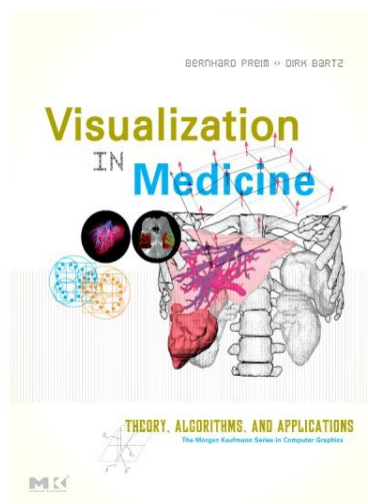
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More detail on all this



- 1 Introduction
- 2 Medical Image Data and Visual Perception
- 3 Acquisition of Medical Image Data
- 4 Medical Volume Data in Clinical Practice
- 5 Image Analysis for Medical Visualization
- 6 Fundamentals of Volume Visualization
- 7 Indirect Volume Visualization
- 8 Direct Volume Visualization
- 9 Algorithms for Direct Volume Visualization
- 10 Exploration of Dynamic Medical Volume Data
- 11 Transfer Function Specification
- 12 Clipping, Cutting, Virtual Resection
- 13 Measurements in Medical Visualization
- 14 Visualization of Vascular Structures
- 15 Virtual Endoscopy

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Links for Further Exploration

- GI-Fachgruppe „Visual Computing in der Medizin“ (www.fg-medvis.de). Next meeting: Berlin, 9. April
- Eurographics Workshop „Visual Computing in Biomedicine“ (www.vcbm.org, Delft, October)
- Related (and longer) tutorials:
 - <http://www.wisq.cs.uni-magdeburg.de/cvcms/de/tutorials>
- MedVis-Book (www.medvis-book.de)
- Software:
 - AmiraVis, www.amiravis.com
 - METK, www.metk.net
 - MeVisLab, www.mevislab.de
 - VTK, www.vtk.org

Visualisierung und virtuelle Realität in der Medizin

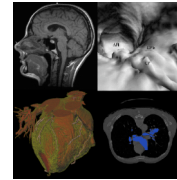
Volumenvisualisierung

Dirk Bartz

Visual Computing (ICCAS), University of Leipzig

dirk.bartz@iccas.de

(teilweise basierend auf Material von Klaus Mueller,
Stony Brook Univ.)



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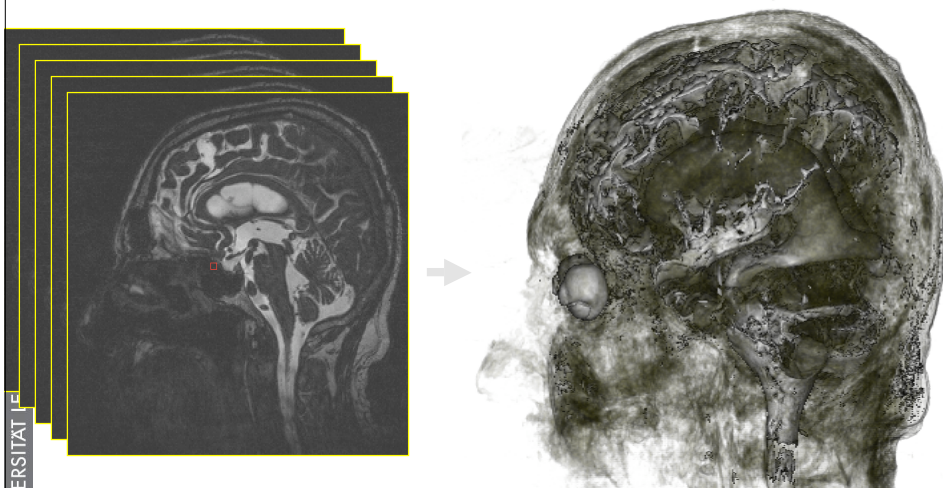
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innovation center
computer assisted surgery

Visual
Computing (VCM)



Einführung (1)

Visual
Computing (VCM)



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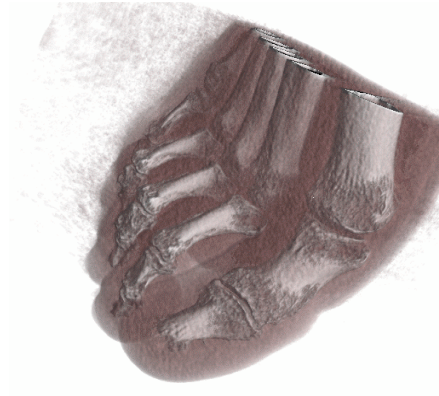
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Einführung (2)

Visual
Computing (VCM)



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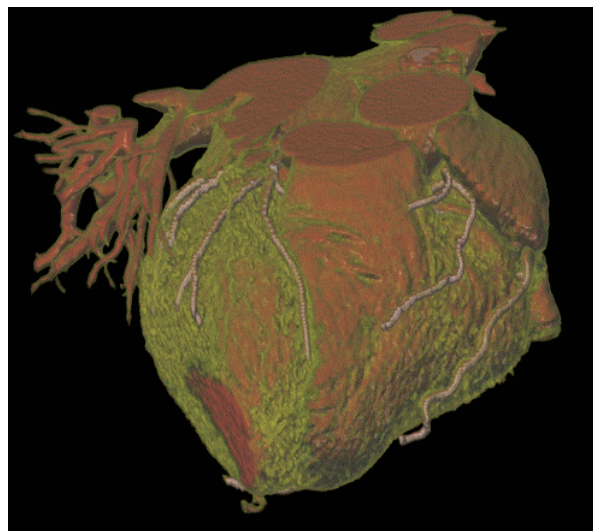
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Einführung (3)

Visual
Computing (VCM)



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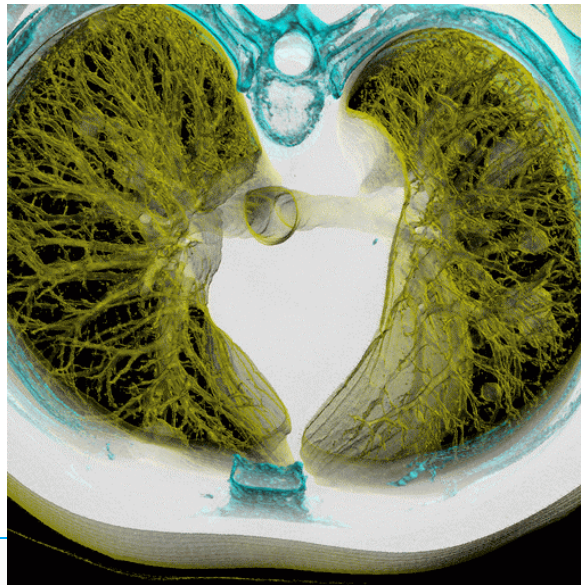
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Einführung (4)

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Computing (VCM)



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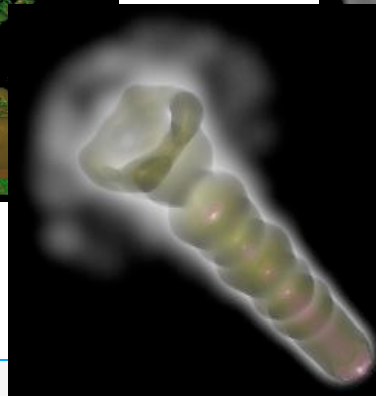
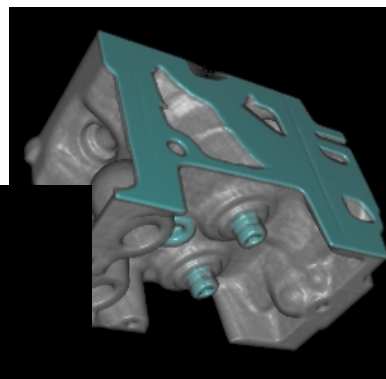
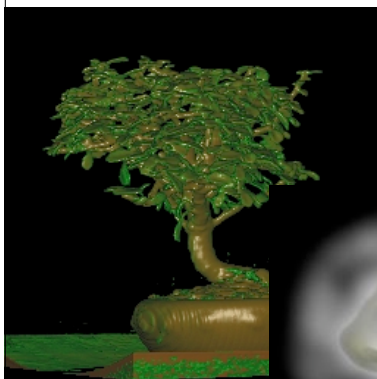
8

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Einführung (5)

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Einführung (6)

Visual Computing (VCM)

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Einführung (7)

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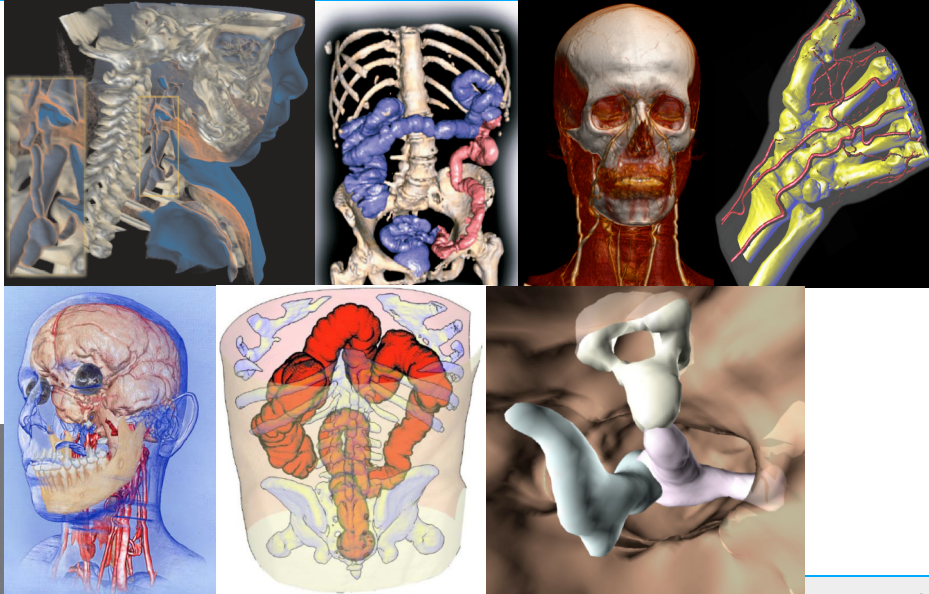
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Einführung (8)

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Computing (VCM)



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Bilder: U Linköping, Biotronics3D, VRVis, TU Vienna, U Tübingen, U Leipzig

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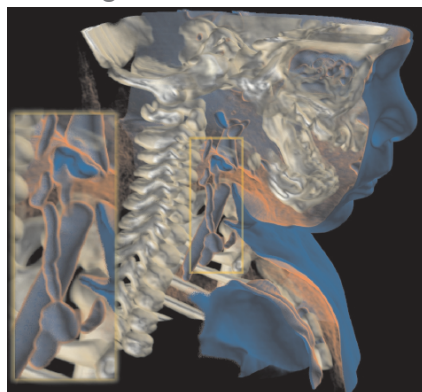
Einführung (9)

Visual
Computing (VCM)

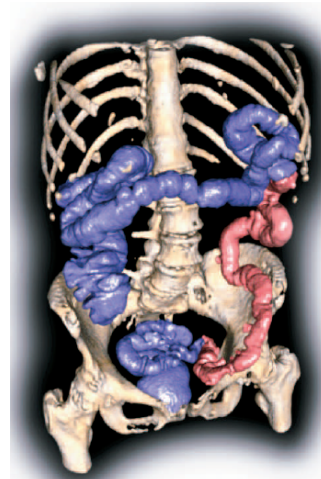


Direkte Volumendarstellung

- Diagnostische Untersuchung



Forensische Pathologie,
[Abb.: Linköping Univ.]



Polypdiagnose
[Abb.: Biotronics3D]

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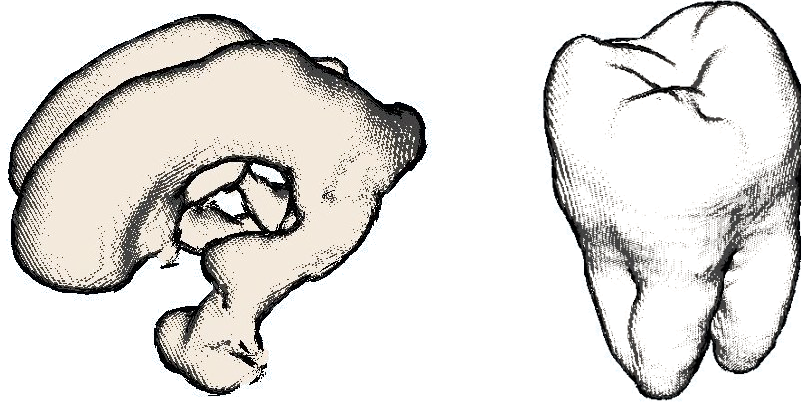


Einführung (10)

Visual
Computing (VCM)

Illustrative Darstellung

- Diagnose



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Visualisierung und VR in der [Salah et al., SimVis2005]

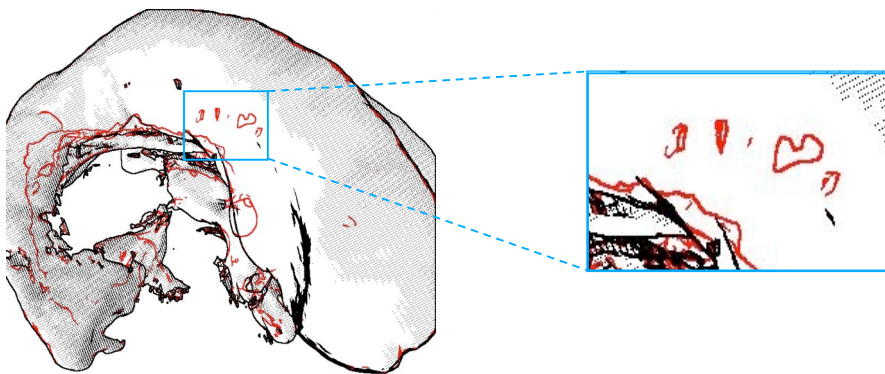


Einführung (11)

Visual
Computing (VCM)

Illustrative Darstellung

- Diagnose



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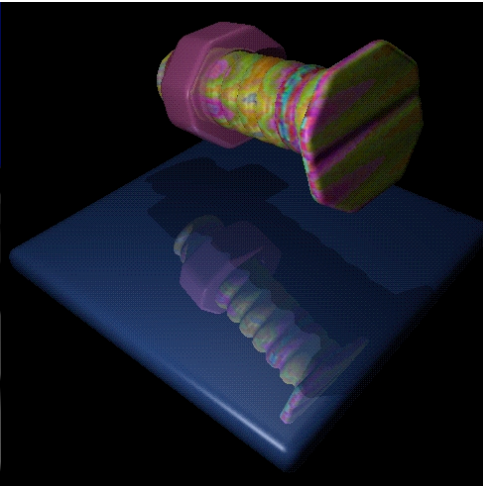
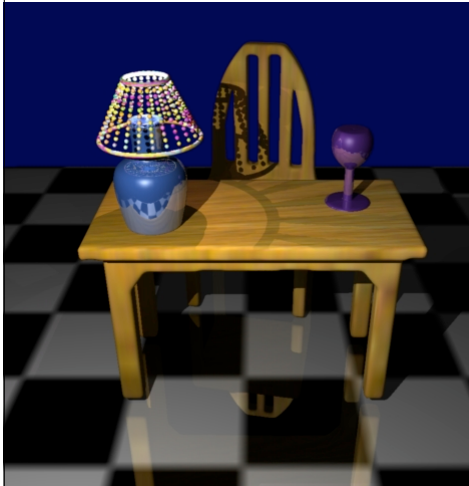
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Visualisierung und VR in [Fischer et al., IEEE Vis2005]



Einführung (12)

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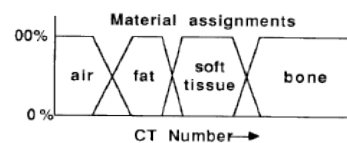
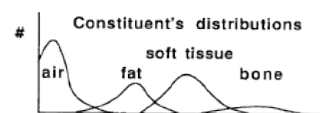
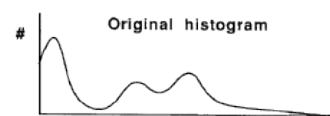


Datenanalyse

Visual
Computing (VCM)



- Die **Häufigkeitsverteilung** der Voxel eines Datensatzes nennt man **Histogramm**:
 - Bei 8bit: Häufigkeitsverteilung der 256 möglichen Datenwerte
 - Bei 12bit: 4096 mögliche Datenwerte



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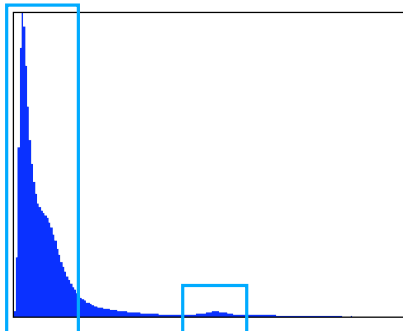
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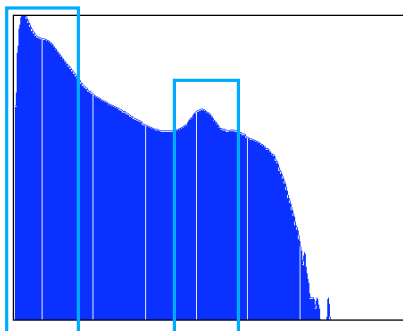
- MRT Datensatz, T2 gewichtet (Flüssigkeit)



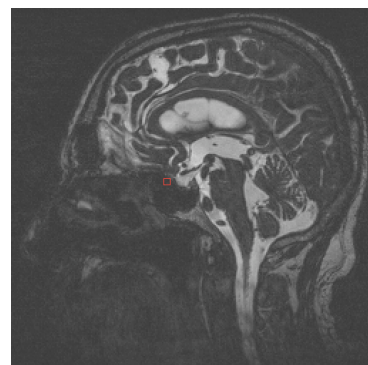
Lineares Histogramm



- MRT Datensatz, T2 gewichtet (Flüssigkeit)



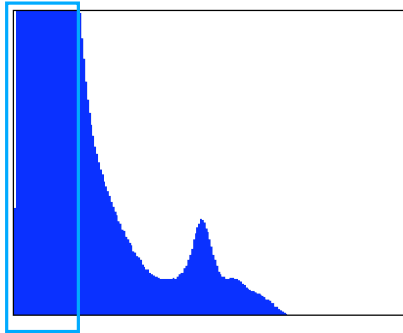
Logarithmisches Histogramm



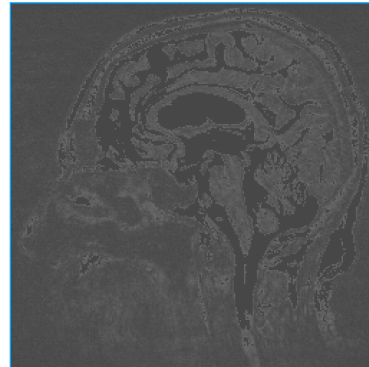
(heller gefiltert)



- MRT Datensatz, T2 gewichtet (Flüssigkeit)



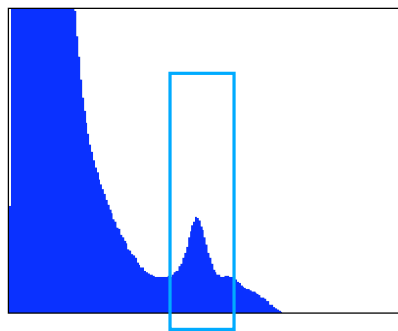
Skaliertes lineares Histogramm



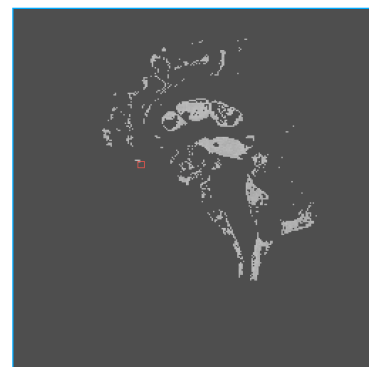
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- MRT Datensatz, T2 gewichtet (Flüssigkeit)



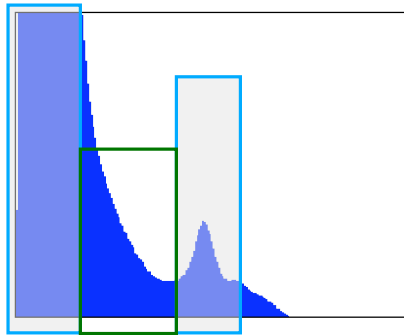
Skaliertes lineares Histogramm



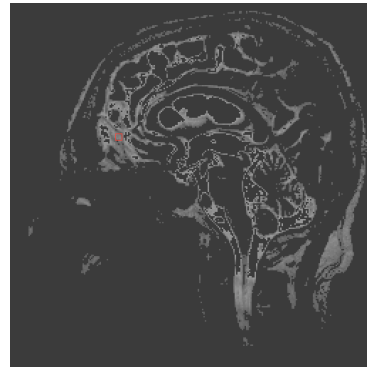
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- MRT Datensatz, T2 gewichtet (Flüssigkeit)



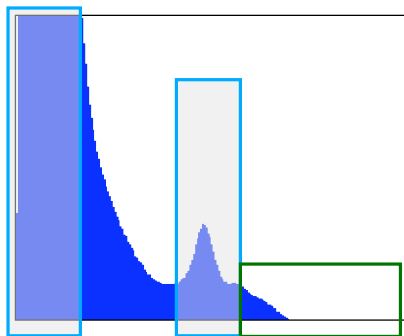
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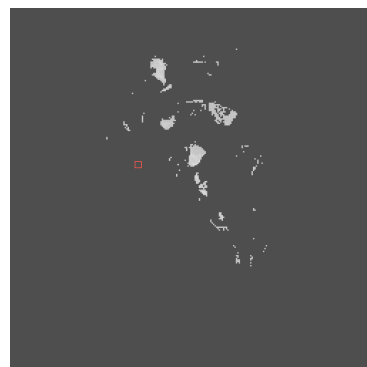
(heller gefiltert)



- MRT Datensatz, T2 gewichtet (Flüssigkeit)



Skaliertes lineares Histogramm



(heller gefiltert)



Transferfunktionen

Visual
Computing (VCM)

- Histogrammwerten (Voxelwerte) werden Tupel aus **Farbe (r,g,b) und Opazität (α)** zugewiesen

$$t_f: v \rightarrow (r, g, b, \alpha)$$

- Fokus liegt auf **Materialgrenzen**
- Erhöht **Frequenzspektrum** im Datensatz:

$$f_{\text{ges}} = f_{\text{ds}} \times f_{\text{tf}}$$

(und damit die Artefaktgefahr)

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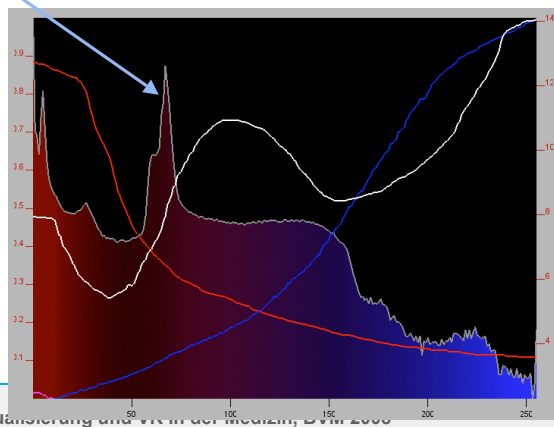


Transferfunktionen

Visual
Computing (VCM)

Beispiel einer Transferfunktion

- Histogramm
- Steigende oder fallende Flanken deuten auf **Materialgrenze**
- **Plateau** auf Material
- **Gradientenbetrag** ist auch nützlich

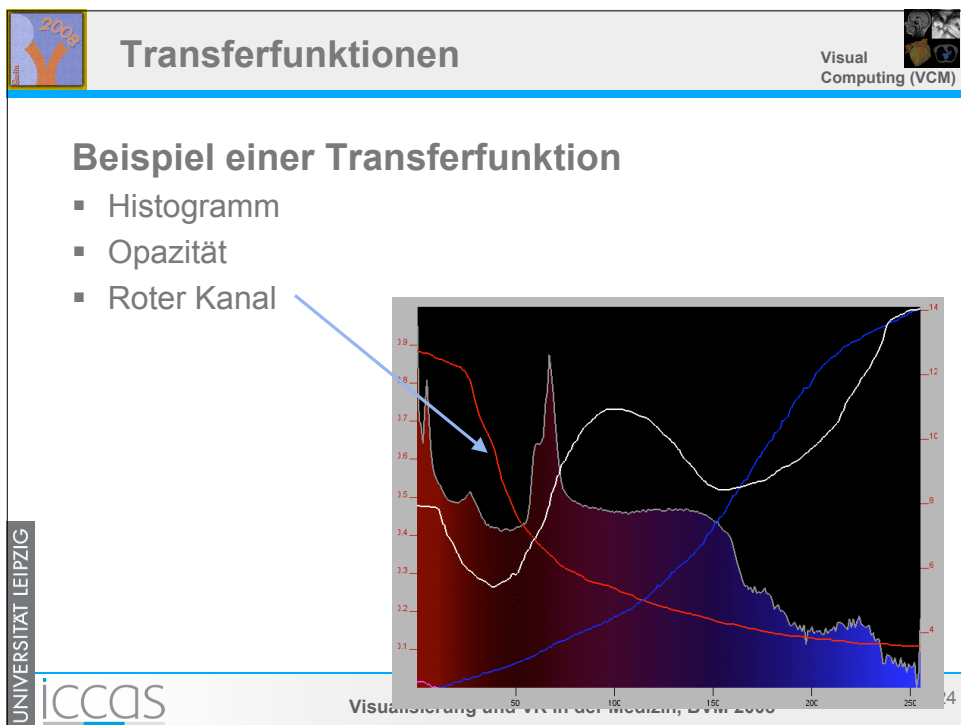
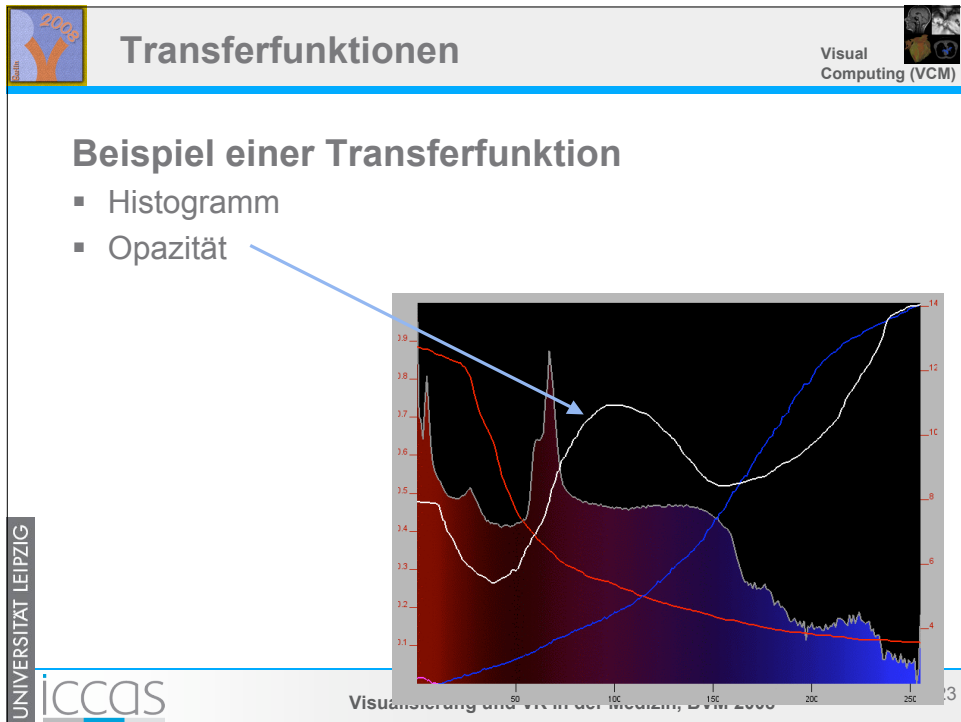


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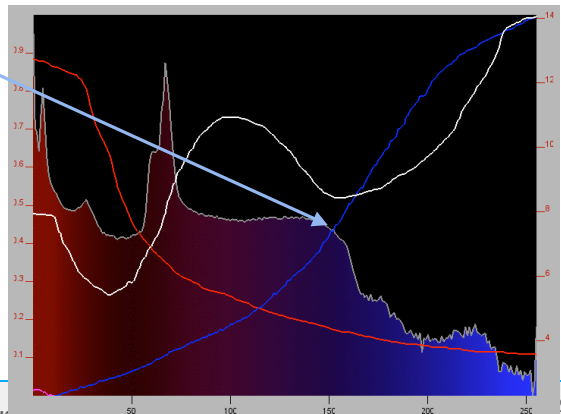


Transferfunktionen

Visual
Computing (VCM)

Beispiel einer Transferfunktion

- Histogramm
- Opazität
- Roter Kanal
- Blauer Kanal



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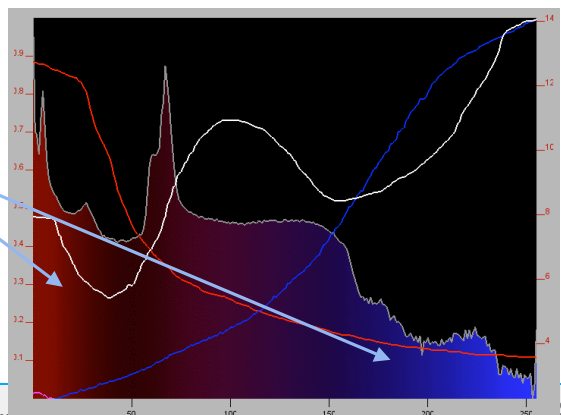


Transferfunktionen

Visual
Computing (VCM)

Beispiel einer Transferfunktion

- Histogramm
- Opazität
- Roter Kanal
- Blauer Kanal
- Endfarbe

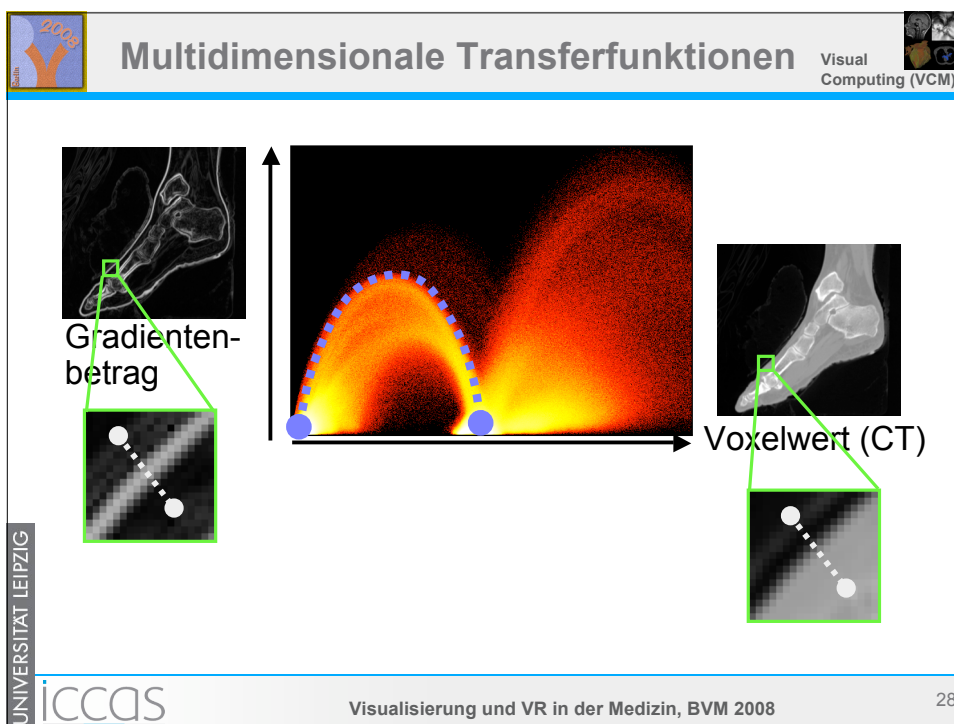
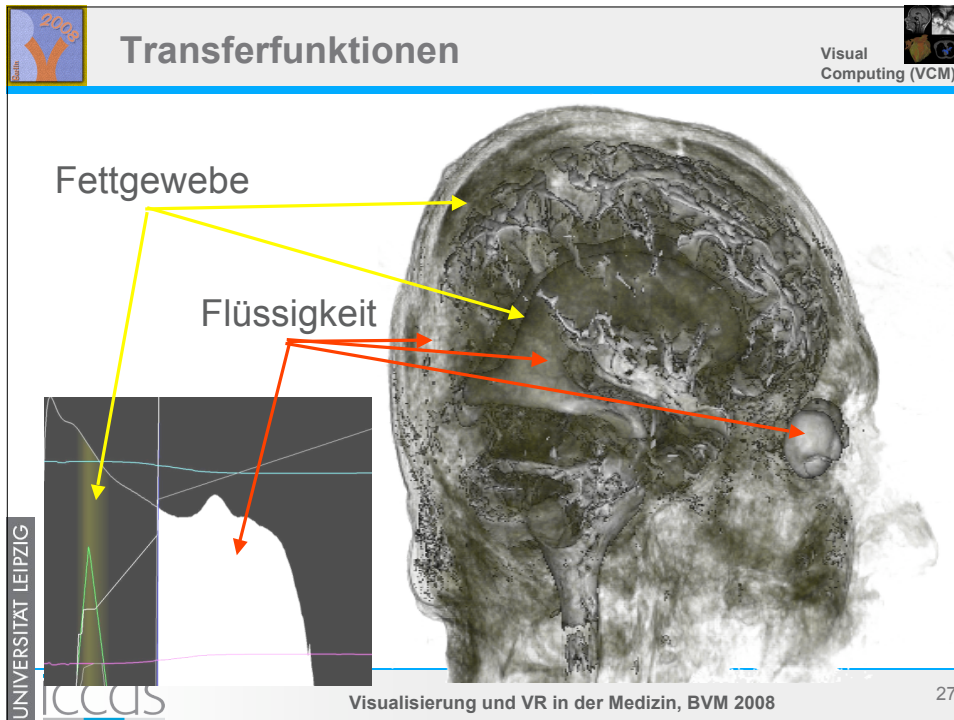


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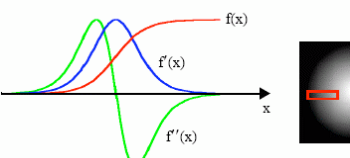
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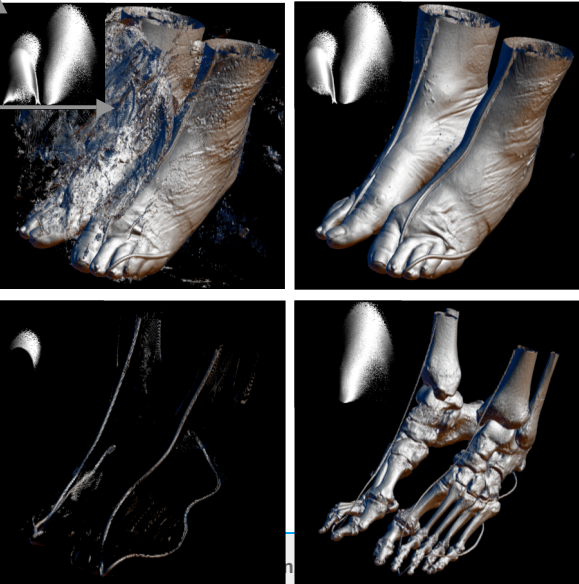


Multidimensionale Transferfunktionen





- Materialgrenzen können mit Hilfe des Gradientenbetrags beschrieben werden

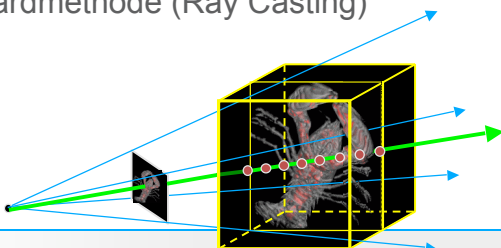




Volumendarstellung



- Strahlen werden in **diskreten Abständen** (Abtastpunkte) durch die Bildebene **ins Volumen geschossen** (casten)
- **Abtastpunkte** werden durch Interpolation in der Zelle bestimmt
- Abtastpunkte werden **klassifiziert** (Transferfunktionen), **beleuchtet** (Normale) und **akkumuliert** in Bildebene (Composting)
- Standardmethode (Ray Casting)





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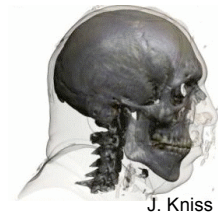
30



Volumendarstellung

Visual
Computing (VCM)

- Identifiziert Materialgrenzen (Oberflächen) und betont sie durch die Modellierung des Lichts
 - Erfordert Normalen (approximiert durch Gradienten)
 - Abbildung von Dichten/Intensitäten auf Farben
 - Aufgabe der **Transferfunktionen**
- Mehrere eingebettete Oberflächen möglich
 - Deshalb semi-transparente Darstellung vorderer Oberflächen
 - Und akkumulierte Farben
 - Auch durch **Transferfunktionen**



J. Kniss

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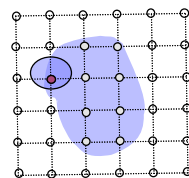
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Raycasting Fundamentals

Visual
Computing (VCM)

Akkumulation



Farbe

Opazität = (1 -
Transparenz)

1.0

Objekt (color, opacity)

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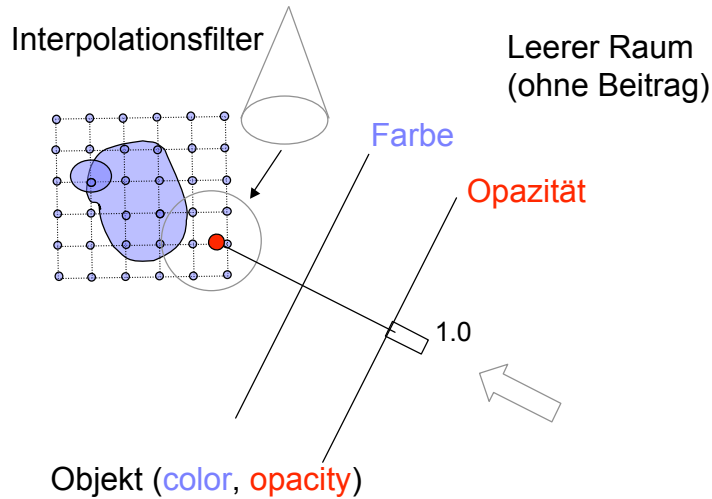
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Raycasting Fundamentals

Visual
Computing (VCM)



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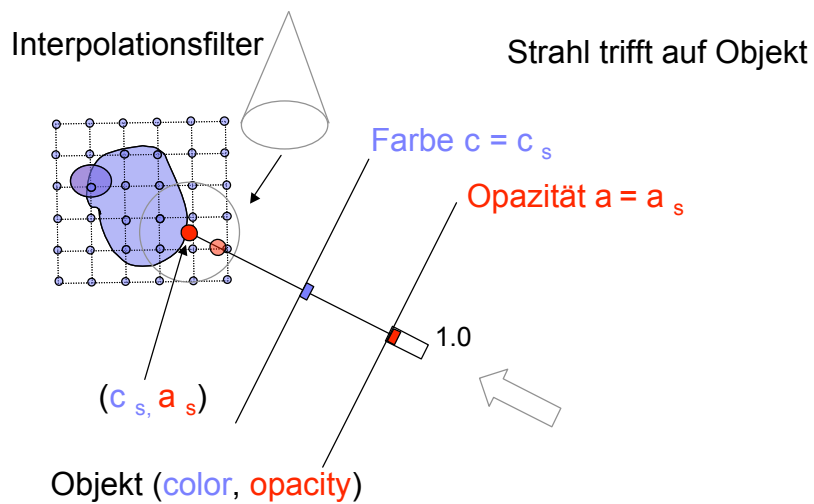
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Raycasting Fundamentals

Visual
Computing (VCM)



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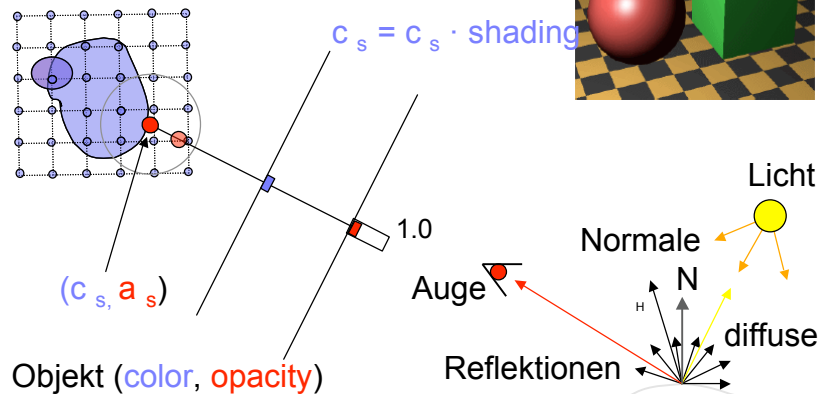
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Raycasting Fundamentals

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Computing (VCM)

Beleuchtung (Phong-Modell)



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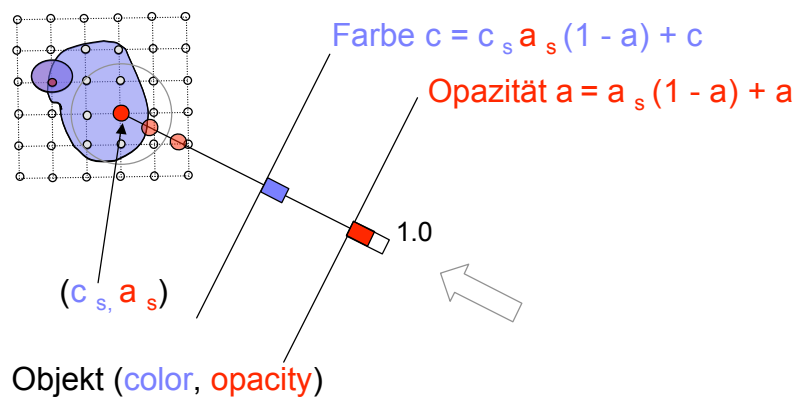
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Raycasting Fundamentals

Visual
Computing (VCM)

Akkumulation



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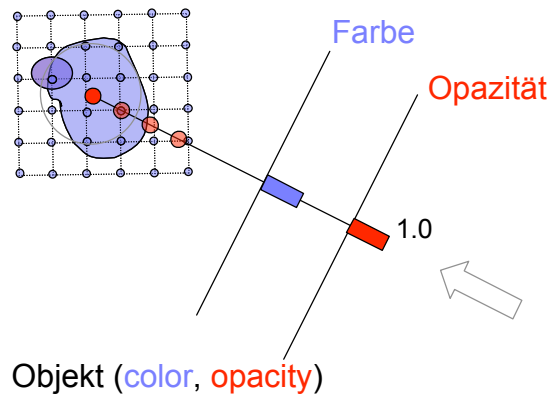


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Akkumulation



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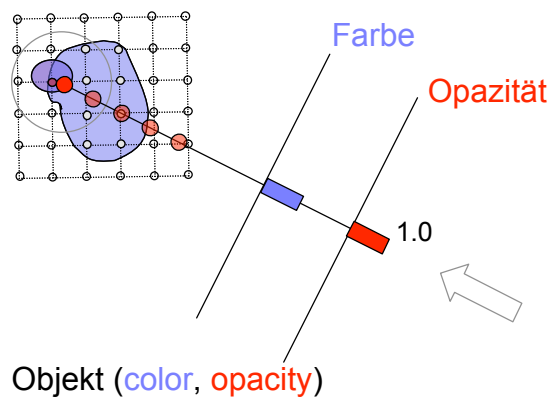


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Akkumulation



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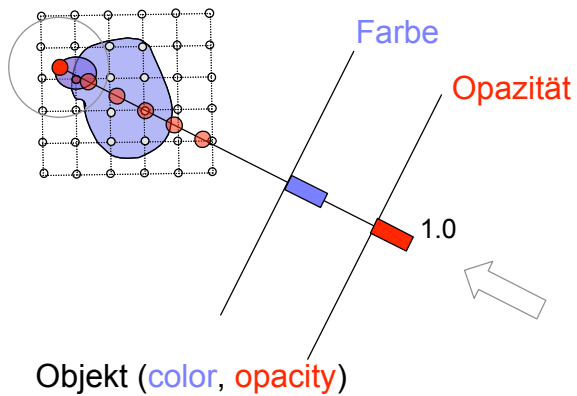


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Visual
Computing (VCM)



Akkumulation



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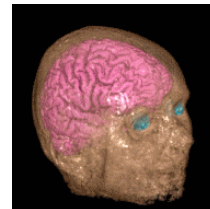
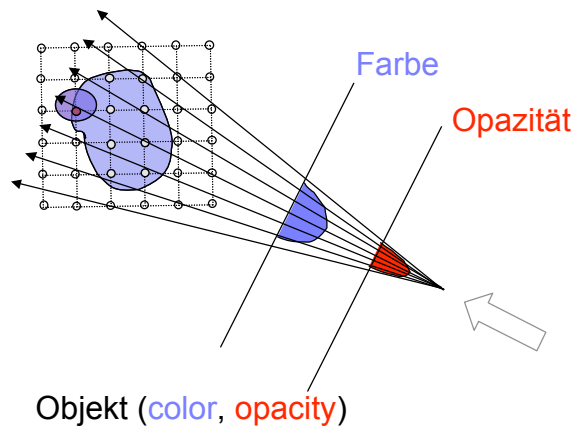


Raycasting Fundamentals

Visual
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Endbild



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Compositing (1)

Visual
Computing (VCM)

- **Verknüpft** die **einzelnen beleuchteten Abtastwerte** zum Gesamtbeitrag
- **Berechnet** das Volume-Rendering-Integral (bzw. seine Approximation)
- Sehr **empfindlich für Fehler** bei zu geringer Genauigkeit (oft das Problem bei Hardware-basierten Volume-Rendering-Verfahren)

$$I(s) = I_{s_0} e^{\left(-\int_{s_0}^s \tau(t) dt\right)} + \int_{s_0}^s q(p) e^{\left(-\int_{s_0}^p \tau(t) dt\right)} dp$$

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Compositing (2)

Visual
Computing (VCM)

- Wir brauchen eine diskrete Approximation des Volume-Rendering-Integrals:
 - Approximation des Integrals durch Summe über konstante Schrittweite Δs , und
 - $s_i = i \Delta s$ als aktueller Abtastwert von n Werten
 - Wir nehmen an: $s_0 = 0$ (Vereinfachung)

$$e^{-\int_0^s \tau(t) dt} = e^{-\sum_{i=0}^{n-1} \tau(i\Delta t) \Delta t} = \prod_{i=0}^{n-1} e^{\tau(i\Delta t) \Delta t} = \prod_{i=0}^{n-1} t_i$$

Transparenz

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Compositing (3)

Visual
Computing (VCM)

- Ähnlich wie s , wird $q(s)$ mit $q_i = q(i \Delta s)$ ersetzt:

$$\int_0^s q(p) e^{\left(-\int_p^s \tau(t) dt\right)} dp = \sum_{i=0}^{n-1} q_i \Delta p \prod_{j=i+1}^{n-1} t_j$$

- und damit insgesamt:

$$I(s) = I_o \prod_{i=0}^{n-1} t_i + \sum_{i=0}^{n-1} q_i \Delta s \prod_{j=i+1}^{n-1} t_j$$

Transparenz

Hintergrundlicht

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Compositing (4)

Visual
Computing (VCM)

- Analog zur vereinfachten Darstellung

$$I(s) = \int_0^s g(p) \tau(p) e^{\left(-\int_0^p \tau(t) dt\right)} dp$$

- findet man auch häufig, mit $s = n \Delta s$:

$$I(s) = \sum_{i=0}^{n-1} g(i \Delta s) \tau(i \Delta s) \prod_{j=0}^{i-1} e^{-\tau(j \Delta s)}$$

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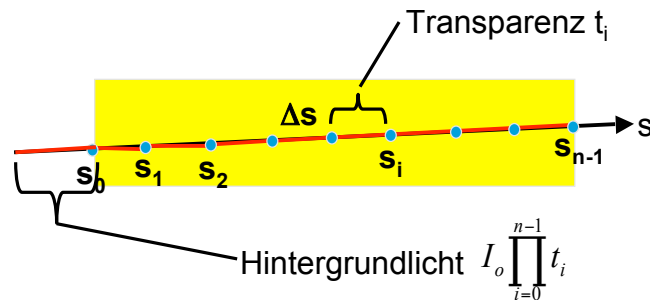
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Compositing (5)

Visual
Computing (VCM)

▪ Anschaulich:



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Compositing (6)

Visual
Computing (VCM)

▪ Over-Operator ist assoziativ (hier n=3):

$$\begin{aligned}
 I(s) &= I_o \prod_{i=0}^2 t_i + \sum_{i=0}^2 q_i \prod_{j=i+1}^2 t_j \\
 &= I_o(t_0 t_1 t_2) + (q_0 t_1 t_2 + q_1 t_2 + q_2) \\
 &= q_2 + t_2(q_1 + t_1(q_0 + t_0 I_o)) \\
 &= q_2 \text{ over } (q_1 \text{ over } (q_0 \text{ over } I_o))
 \end{aligned}$$

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Compositing (7)

Visual
Computing (VCM)

- Summe/Produktreihe aufzulösen
 - Back-to-Front Algorithmen

```
I = I0  
for (i=0; i<=n-1; i++)  
    I = I*ti + qi
```

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Compositing (8)

Visual
Computing (VCM)

Summe/Produktreihe aufzulösen

- **Front-to-Back Algorithmen** verwendet

```
I=0; T = 1; i=n-1;  
while (T > epsilon && i >= 0)  
    I = I*T + qi;  
    T = T*ti;  
    i--;  
I = I + T*I0;
```

- Vorteil: **Early Ray Termination**, wenn T/a sehr nahe an 0/1 (voll transparent/opak) liegt.

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Übersicht

Visual
Computing (VCM)

- **Darstellungsmodi:** Röntgen, MIP, Beleuchtete Darstellung
- **Elementares Volumenrendern:** Raycasting
- **Transferfunktionen:** bilden Rohdaten auf Visualisierung ab
- **Darstellungsqualität:** post- vs. Pre-beleuchtete Darstellung
- **Kontrolle Darstellungsaufwand:** Verdeckung, Bedeutung
- **Darstellungsbeschleunigung:** Nutze GPUs

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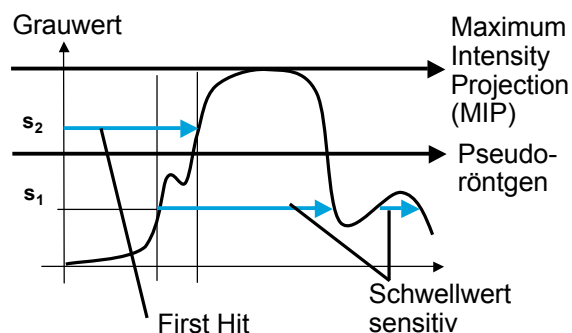
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Compositing (9)

Visual
Computing (VCM)

- **Spezielle Compositing-Verfahren:**



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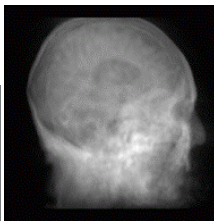


Volumendarstellung: Pseudo-Röntgen

Visual
Computing (VCM)



- Akkumulationsvariationen ergeben **unterschiedliche Ergebnisse**
- Gleichmäßige Integration - Pseudo-Röntgen
- Gut für ersten Überblick
- Aber Überzeichnung und Dichte erschweren Interpretation



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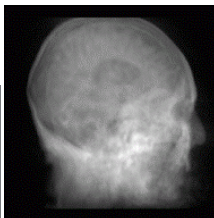


Volumendarstellung: Pseudo-Röntgen

Visual
Computing (VCM)



- Akkumulationsvariationen ergeben **unterschiedliche Ergebnisse**
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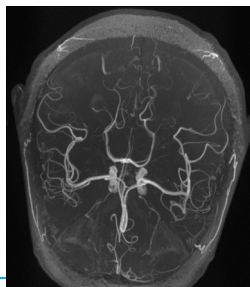


Volumendarstellung: MIP

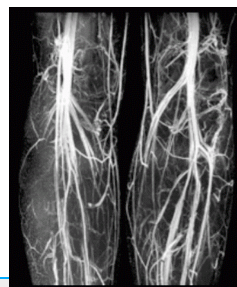
Visual
Computing (VCM)

- MIP = **M**aximum **I**ntensity **P**rojection
- Eingeschränkter als Pseudo-Röntgen
- Sucht nur Maximum entlang des Strahls
- Nimmt an, dass Maximum am wichtigsten ist
- Klinisch oft für ersten Blick verwendet
- Sehr gut bei Angiographien

Kopf



Beine



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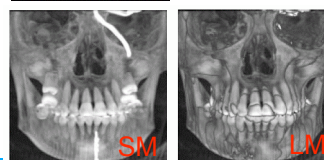
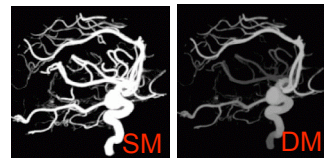


Volumendarstellung: MIP

Visual
Computing (VCM)

Variationen der MIP

- Standard MIP (SM)
- Dünnschicht-MIP (TM)
(thin-slab MIP)
- Tiefen-gewichtetes MIP (DM)
(Depth-shaded MIP)
- Lokales Maximum MIP (LM)



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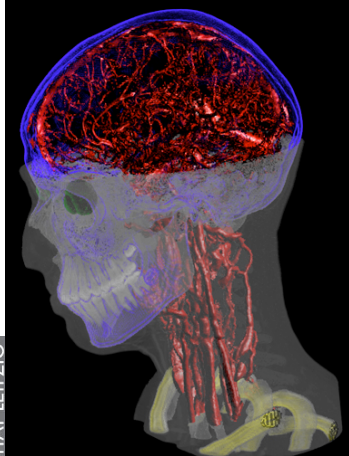
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Bsp: Two-Level Volume Rendering

Visual
Computing (VCM)



- Haut und Zähne: MIP mit unterschiedlichen Gewichtungen
- Blutgefäße und Augen: Volumendarstellung
- Schädel: Illustrative Konturen
- Wirbel: Gradientenbetrags-gewichtete Volumendarstellung
- Anwendung einer Schnittebene auf Haut

[Hauser et al. 2001]

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Compositing (10)

Visual
Computing (VCM)



Volume-Rendering-Pipeline revisited: Pre-Beleuchtung

- Erzeugt **Farbvolumen** ($RGB\alpha$) statt Skalarvolumen
- Abtastung ist **Interpolation im Farbraum**
- Dadurch können **Farbartefakte** entstehen (Farbbluten)
- Korrektur durch **opazitätsgewichtete** Interpolation [Wittenbrink et al. VolVis 1998]

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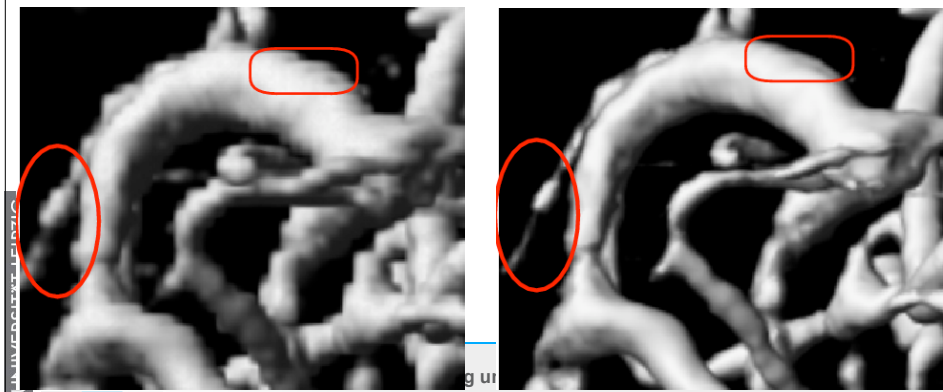


Compositing (11)

Visual
Computing (VCM)



Volume-Rendering-Pipeline revisited: Pre-Beleuchtung und Farbartefakte

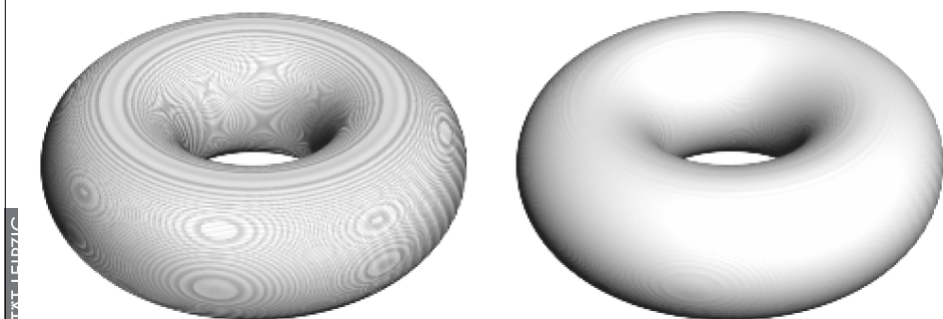


Compositing (12)

Visual
Computing (VCM)



Volume-Rendering-Pipeline revisited: Pre-Shading und Farbartefakte



[Wittenbrink et al. VolVis 1998]

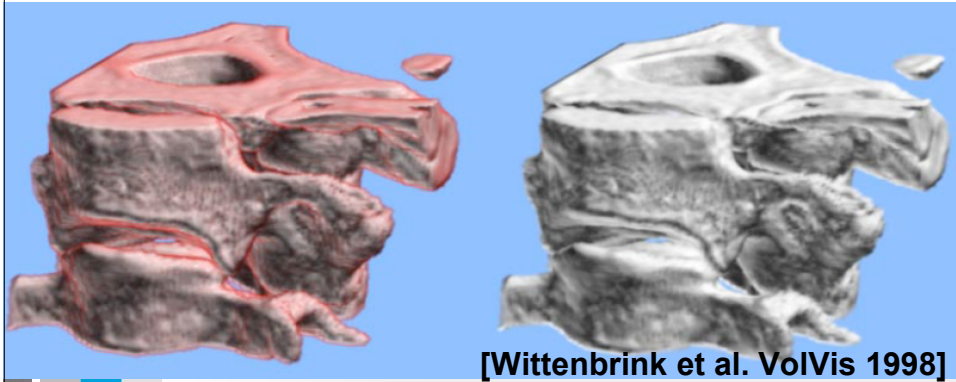
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Volume-Rendering-Pipeline revisited: Pre-Shading und Farbartefakte



[Wittenbrink et al. VolVis 1998]



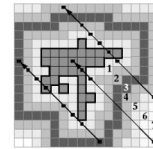
- Gedanken machen über
 - Cache-Management -- Cache-Faults sind teuer
 - Spezifiziere Darstellungsaufwand -- Verbrauche Ressourcen nicht auf Kleinigkeiten
 - Detailmanagement -- Konzentriere Aufwand auf wichtige und Fokusregionen
 - Letzteres durch Segmentierung und Klassifikation bestimmen



Kontrolle Darstellungsaufwand (2)

Visual
Computing (VCM)

- Nutze Early-Ray-Termination ($\alpha < 0.9$)
 - β -accleration [Danskin 92] beschleunigt Strahlen je opaker sie werden
- Space leaping
 - Überspring Leerraum zwischen Objekten
 - Statisches Schemata für feste Transferfunktionen clouds [Cohen 94], Distanzfelder [Hong 97] [Srámek 00]
 - Oder dynamische Schemata mit Raumaufteilungen wie Octrees



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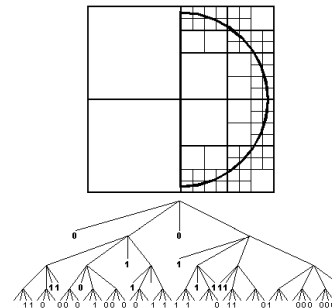
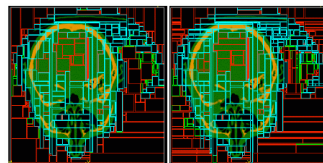


Kontrolle Darstellungsaufwand (3)

Visual
Computing (VCM)

- Hierarchische Raumaufteilung
 - Speichere min-max Voxelwerte in jedem Knoten
 - Überspringe Knoten mit Null-Transferfunktion im Intervall
 - sonst, rekursives absteigen im Baum [Wilhelms 1990]
- Unregelmäßige Raumaufteilungen
 - BSP-trees, kd-trees, etc.

[Li 03]



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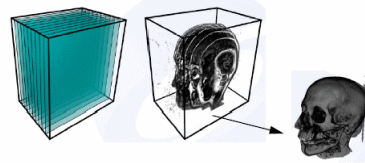


GPU Rendering: Konzept

Visual
Computing (VCM)

Basisansatz [Rezk-Salama 01]

- Repräsentiere Volumen als Stapel von ausgerichteten "Proxy-Polygonen"
- Volumenschichten werden mit Texturemapping auf Proxies abgebildet
- Polygone werden projiziert, von vorne nach hinten
- Schicht für Schicht beleuchtet und zusammengefügt

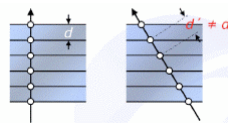


GPU Rendering: Probleme

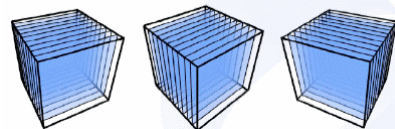
Visual
Computing (VCM)

Hauptnachteile:

- Abtastabstand d ist größer als 1.0 für nicht achsenparallele Blickrichtung



- Braucht drei Volumenstapel für jede Hauptrichtung



from: Engel, Kraus, Ertl, Graphics Hardware Workshop 2001

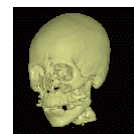
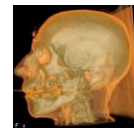


GPU Rendering: Zusammenfassung

Visual
Computing (VCM)



- Der Texturemapping-Ansatz ermöglicht hohe Darstellungsraten für moderat-große Datensätze
- Neuere GPU-basierte Ansätze verwenden:
 - Raycasting ("natürlichere" Variante)
 - Empty-space Skipping
 - Early-Ray-Termination, Verdeckungsrechnung
 - Fortgeschrittene Effekte (Schatten, Materialeigenschaften, weiterentwickelte Beleuchtung, etc.)
 - Mischen von Polygonen und Voxeln
- Insgesamt Vorteile bei Geschwindigkeit (Flexibilität, Qualität)



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Qualitätsfragen

Visual
Computing (VCM)



- Wann wird Beleuchtet
 - Vor Interpolation (Pre-shading)
 - Nach Interpolation (post-shading)
- Beide Reihenfolge haben Vorteile
 - **Pre-shading** erfordert keine aufwendige Beleuchtung während der Interpolation
 - Hat aber auch schlechtere Qualität (Farbbluten, Blurring)
 - **Post-shading** ist aufwendiger
 - hat aber bessere Qualität [Mueller 1999]
 - Erfolgt nur in relevanten Regionen
- Pre-Integrated Shading [Engel 2001]

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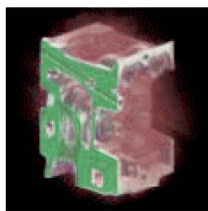


Qualitätsfragen

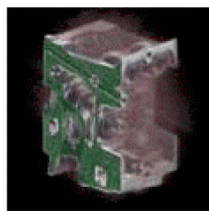
Visual
Computing (VCM)

Gradientenmodellierung

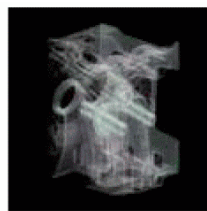
- Um Grenzflächen zu betonen, kann Farbe oder Opazität mit dem Gradientenbetrag multipliziert werden



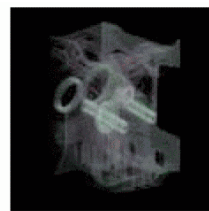
Keine



Opazität



Beleuchtung



Beide

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Qualitätsfragen

Visual
Computing (VCM)

- **Verfahren** bestimmt Darstellungsqualität
- **Abtastrate** wichtig für Qualität:
 - Je höher, desto besser, desto langsamer
- Abtastrate wird häufig **bei Bewegung gesenkt**
- **Interpolationsverfahren** (Abtastwerte) beeinflusst Qualität

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Volumen- vs. Oberflächendarstellung

Visual Computing (VCM)



- **Unterschiedliche** Stärken und Schwächen
- **Anwendung** bestimmt Wahl

Volumendarstellung

- Voxel als Basiselement
- Direkte Repräsentation
- Bessere visuelle Qualität (Interpolation)
- Teurer
- Schwieriger zu kontrollieren
- Meist benutzt wenn kein Vorwissen vorhanden ist

Oberflächendarstellung

- Dreieck als Basiselement
- Metarepräsentation
- Reduzierte visuelle Qualität (Interpolation)
- Günstiger
- Leichter zu kontrollieren
- Meist benutzt wenn Vorwissen vorhanden ist

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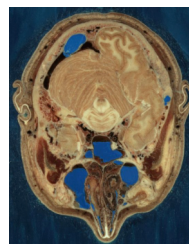
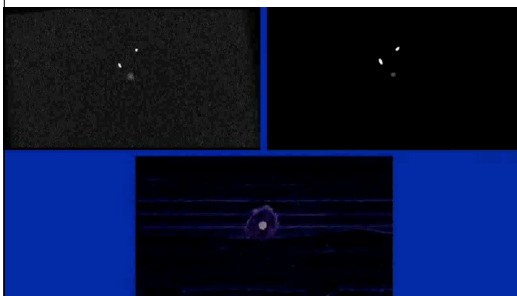
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Anatomie heute: Visible Human/Korean

Visual Computing (VCM)



Schnitt durch Visible Human,
Quelle: NLM



3D-Rekonstruktion,

<http://vkh3.kisti.re.kr/>

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Limitationen von Volumendaten - Aliasingprobleme

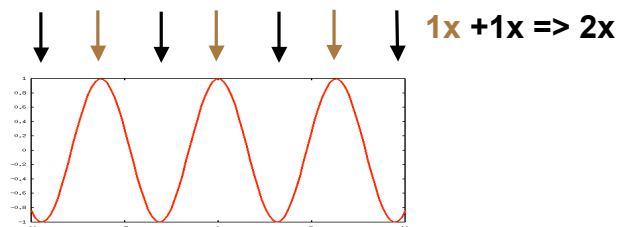
Die meisten Bild-/Volumenartefakte können zurückgeführt werden auf

- Verletzung des **Abtasttheorems**
- **Partialvolumeneffekte**
- **Interpolationsartefakte**



Abtasttheorem (Nyquist, Shannon):

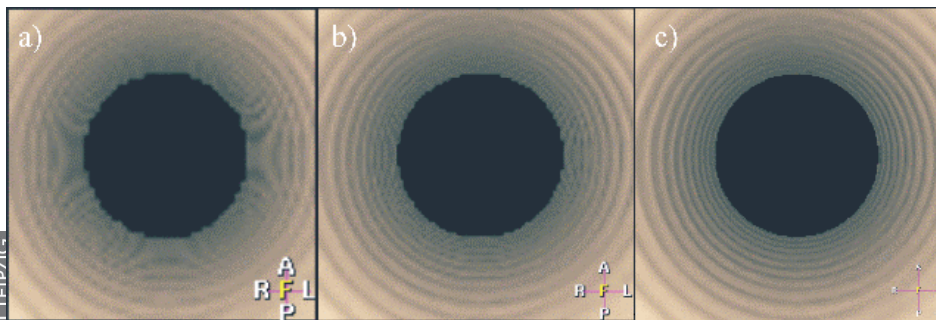
- Für eine geeignete Rekonstruktion eines Signals (zB. Bilddaten) braucht man mindestens eine **doppelt so schnelle** Abtastung (Frequenz) als das Ursprungssignal selbst (**Nyquist - Rate**)





Alias-Effekte bei Unterabtastung

- Moiré-Artefakte verschwinden bei ausreichender Abtastung

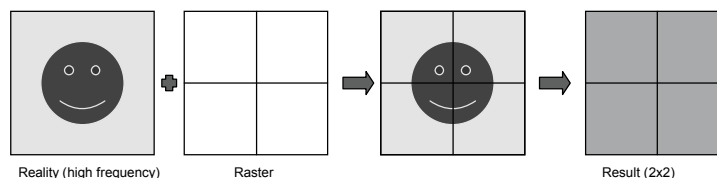


Abtastrate



Partialvolumeneffekte

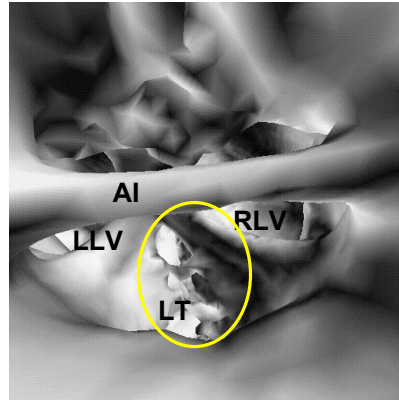
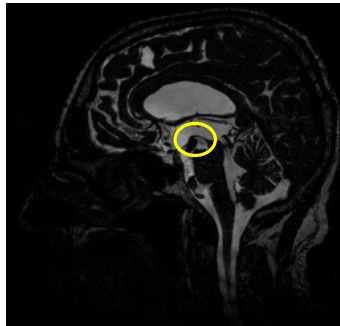
- I.W. auch durch Unterabtastung (Volumenrekonstruktion)
- Hohe **Intensitätsunterschiede** zwischen benachbarten Strukturen
- Abtastung reflektiert diese Unterschiede (hohe Frequenzen) nicht
- **Artefakte der Materialgrenzen** (zB., Löcher, Pseudoverbindungen) wegen inhärenter **Glättung**





Partialvolumeneffekte

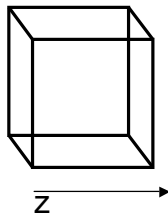
- Große **Intensitätsunterschiede** verursachen Defekte im Materialschnittstellen



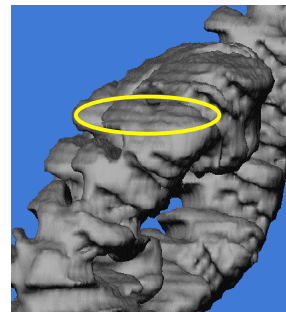
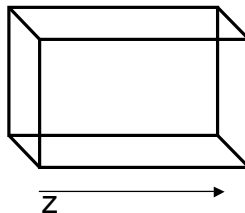
Treppenartefakte

- Problem der Normalen ($\vec{n}$) bei anisotropen Datensätzen

isotrop



anisotrop





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Visual
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