Volume Visualization

Leonid I. Dimitrov and Miloš Šrámek Commission for Scientific Visualization Austrian Academy of Sciences

Overview

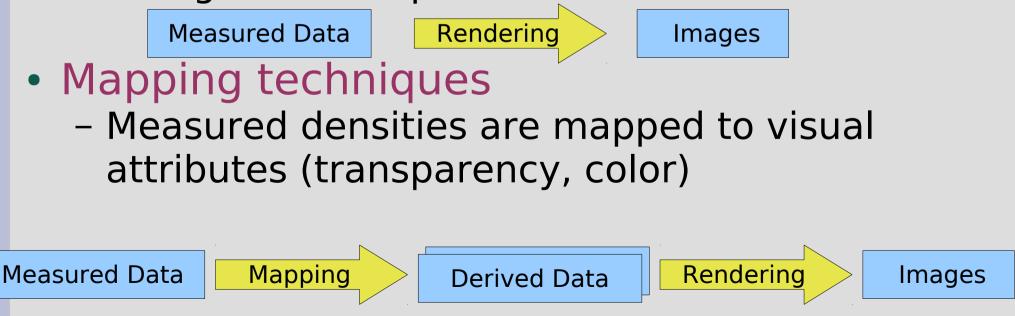
- Volume visualization
 - Volume viewing
 - Mapping
 - Volume rendering
 - Direct volume rendering
 - Isosurfacing

Volume Data

- A spatial sequence of 2D images slices
- Produced by
 - 3D scanners (tomographs)
 - Different physical background
 - Different and complementary properties
 - Simulation

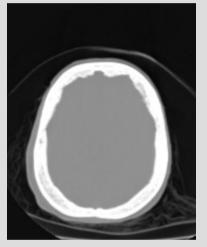
Volume Visualization

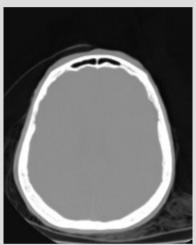
- Visually perceivable data presentation
- Understanding, not photorealism
- Simple volume viewing
 - Straightforward presentation of measured data



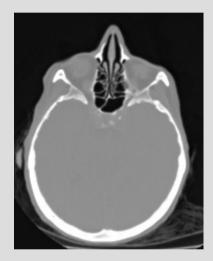
Volume Viewing (1)

Slice-by-slice viewing



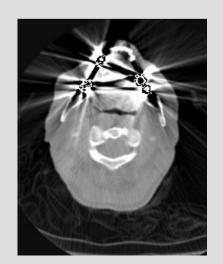


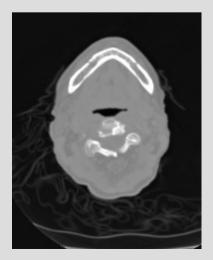


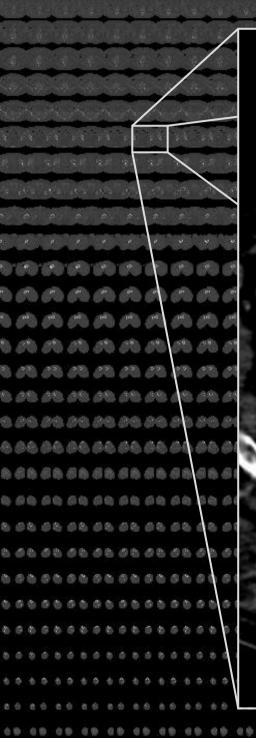




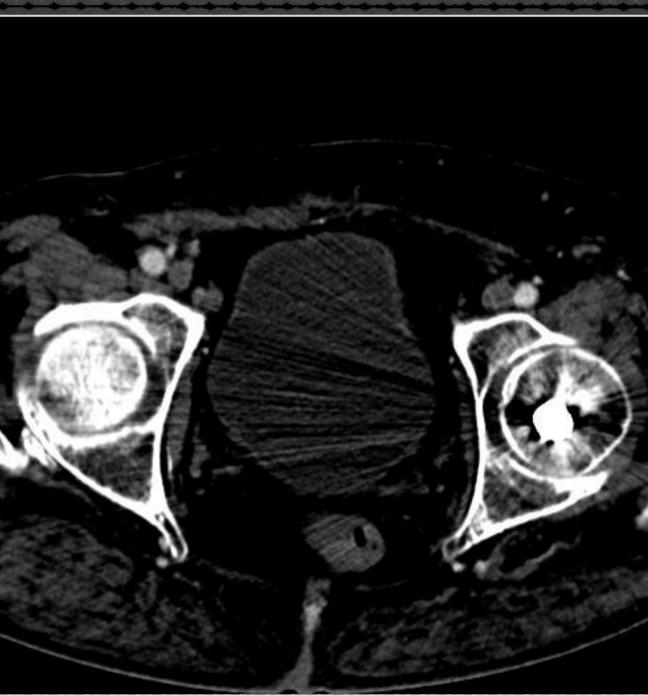








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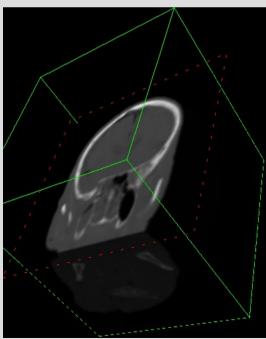


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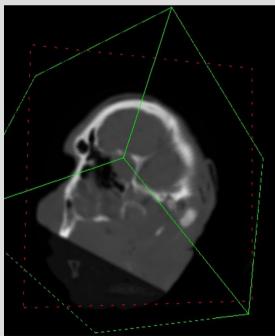
Volume Viewing (2)

Multiplanar reconstruction Definition of new cutplanes

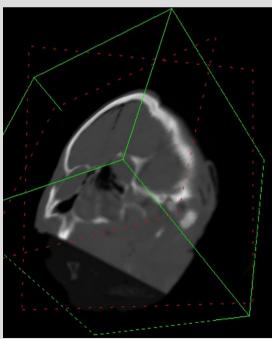
Axis aligned



Oblique

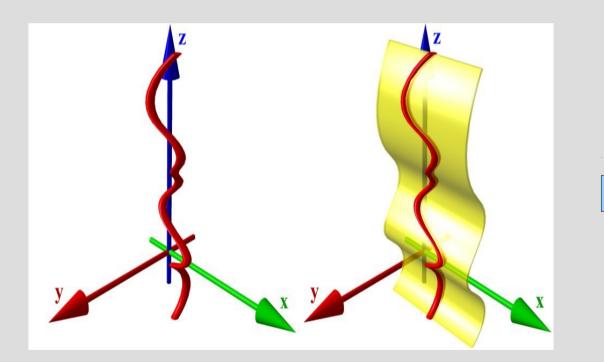


Combined



Volume Viewing (3)

 Curved planar reconstruction - Volume cutting along a line





2002

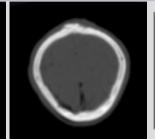
Volume Viewing (4&5)

- Reprojection
 - Add all values along a viewing ray
 - Simulation of X-ray projection

- Maximum intensity projection
 - Register the brightest value along a viewing ray
 - Suitable for thin structures



Volume Visualization by Mapping



Data Acquisition CT, MRI, USG, PET, SPECT

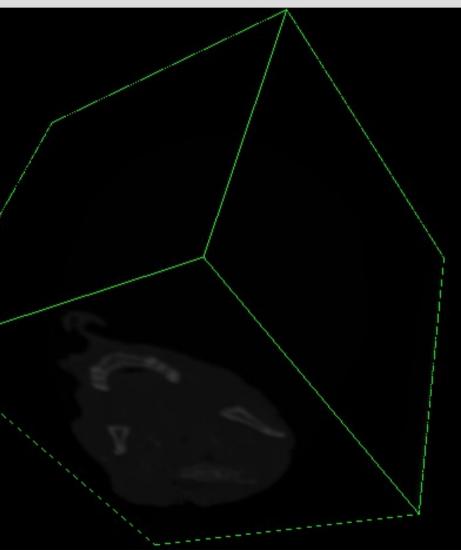
Mapping Visual attributes

Rendering

Surface & Volume Techniques

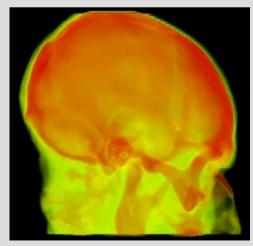
Why Do We Need Mapping?

- No visual representation readily exists for 3D data
- Area of interest is occluded by the black background
- We need something to make the background transparent



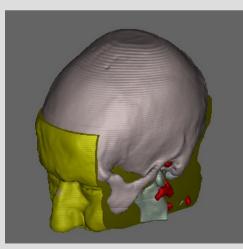
Assignment of Visual Attributes

- Mapping: Assignment of visual attributes to data:
 - transparency, color, reflectance, surface strength...
- "Area of interest" specification achieved:



Density-based classification

>>> …… >>>



Space-based segmentation

Mapping: Summary

Transfer function based:

- Color & transparency assigned to voxels
- Semitransparent volumes
- Display of volumes

Segmentation-based

- Unambiguous object definition
- Color & transparency assigned to objects
- Display of surfaces

not used for classification of rendering techniques

Classification of Rendering Techniques (1)

- Based on the basic rendering primitive
- Surface rendering
 - Basic primitive: 2D patches (polygons)
 - Extra data structure: a surface model
 - Decoupling of the model and the data
 - Rendered by standard CG approaches

Triangulation by the Marching Cubes technique, approx. 200000 polygons

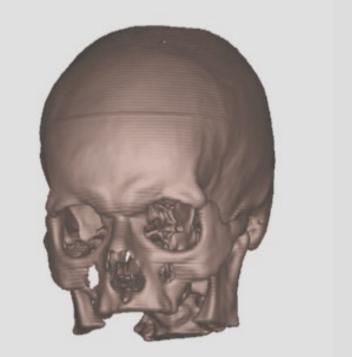


Classification of Rendering Techniques (2)

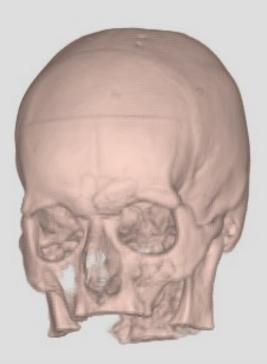
- Volume rendering
- Basic primitive: the voxel itself
- Rendering directly from volume data:
- Two flavors:
 - TF based: *Direct volume rendering* (DVR)
 - All (semitransparent) volume samples potentially contribute to the image
 - Segmentation (object) based: Isosurfacing
 - Only visible surfaces are displayed

DVR vs. Isosurfacing

- Rendering algorithms are similar
- Isosurfacing is a limit case of DVRs with special TF and parameter setting

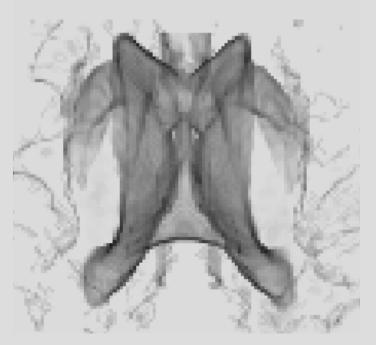


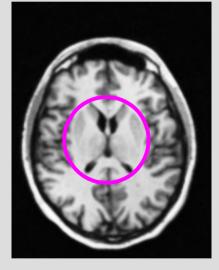
sosurfacing



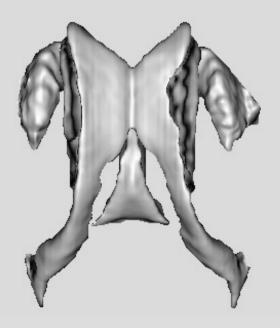
When to Prefer DVR?

Low data contrast, weak edges, thin objects





MRI head data: Ventricles & deep brain structures

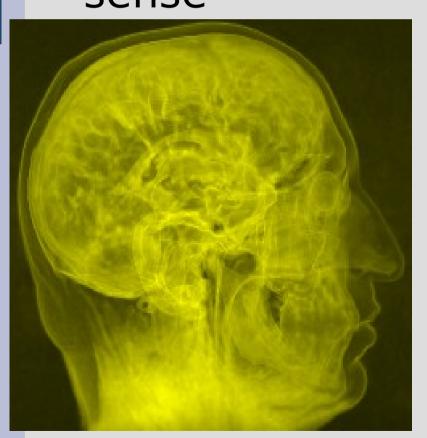


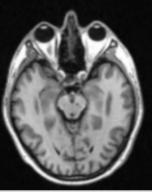
Isosurfacing

DVR

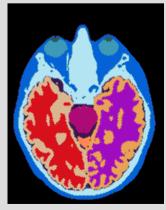
When to Prefer Isosurfacing?

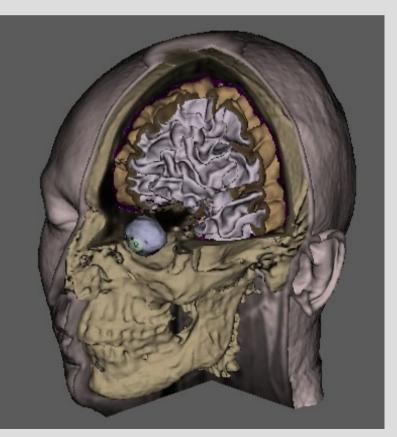
Numerous & complex objects, TFs make no sense





MRI data





Isosurfacing with cutplanes

DVR

Object labels

DVR Basics

- Simplified light interaction with semitransparent material
- Light attenuation and emission along a ray

$$\frac{dI(t)}{dt} = \rho(t)I(t) - k(t)\rho(t),$$

I(t): Light intensity at the point t
 ρ(t): Optical density (attenuation)
 ρ(t)I(t): Light attenuation at t
 k(t): Chromacity

k(t)p(t):Light emission rate at t

- No shadows, no reflections
- Numerical evaluation:
 - Per-segment compositing by Porter&Duff's operators
 - Front-to-back order
 - Back-to-front order

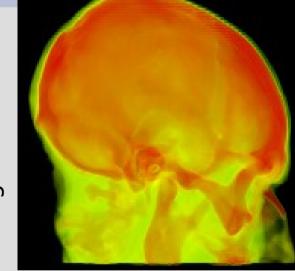
DVR Techniques (1)

Free/adjustable parameters (mapping):

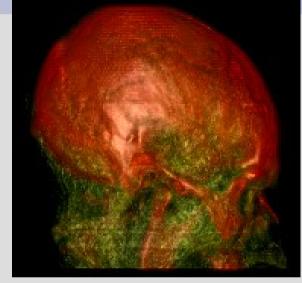
- Transfer functions: $\rho(t) = f_{\rho}(d(t))$ $k(t) = f_k(d(t))$
- Edge accentuation: $\rho(t) \sim |\nabla d(t)|$
- Shading: $k(t) \sim \nabla d(t) \cdot \vec{p} f_k(d(t))$
- Depth cueing
- Others: shape, size, ...

DVR Techniques (2)

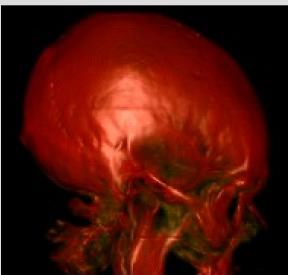


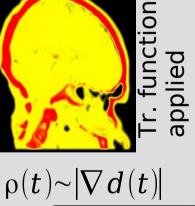


Unshaded

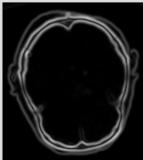


Shaded

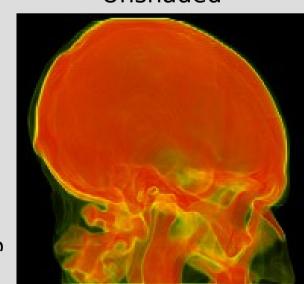




 $\rho(t) = f_{\rho}(d(t))$



Edge enhancement



Rendering by Compositing

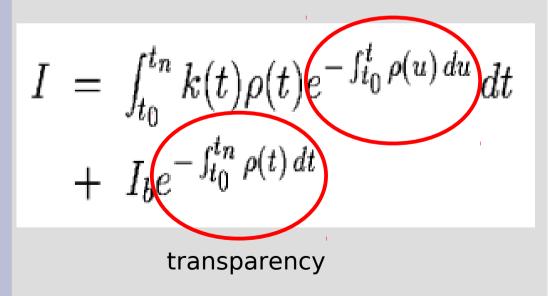
- Interaction with matter results in absorption
 - Beer-Lambert law:

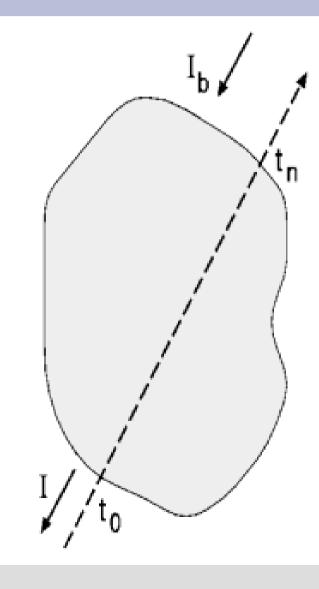
$$\frac{dI(t)}{dt} = \rho(t)I(t) - k(t)\rho(t),$$

Evaluation along a projection ray

Volume Rendering Integral

 Integral form of the Beer's law





Per Segment Evaluation of the VRI (1)

Transparency:

$$e^{-\int_{t_i}^{t_{i+1}}\rho(u)\,du}$$

- 1: fully transparent
- 0: fully opaque
- Opacity:
 - amount of stopped light
 - opacity = 1 transparency
- Segment opacity: $\alpha_i = 1 e^{-\int_{t_i}^{t_{i+1}} \rho(u) \, du}$
 - The amount of light stopped along a segment

Per Segment Evaluation of the VRI (2)

Front-to-back compositing

$$I_{m} = I_{m-1} + (1 - \beta_{m-1})C_{m}$$

$$\beta_{m} = \beta_{m-1} + (1 - \beta_{m-1})\alpha_{m}$$

'under' operator

Back-to-front compositing

$$I_m = C_m + (1 - \alpha_m)I_{m-1}$$

'over' operator

- I accumulated color
- C- sample color
- β accumulated opacity
- α sample opacity

Approximations

$$\alpha_i = 1 - e^{-\rho_i \Delta t_i}$$
$$C_i = k_i \alpha_i$$

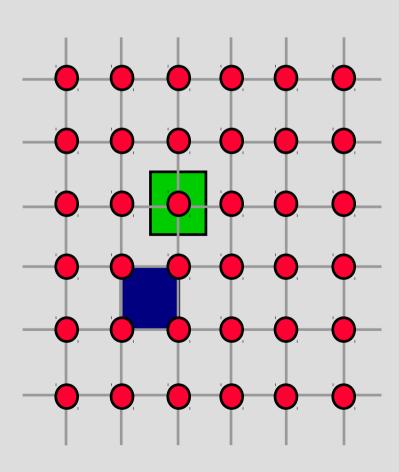
- Chromacity premultiplied by opacity
- Scaling required with real data

DVR Algorithms

- Object-order algorithms (splatting)
 - Projection of samples from volume to image
 - Compositing in image plane
- Image-order algorithms
 - Ray casting based
 - Sequence of samples along the ray
 - Compositing along the ray

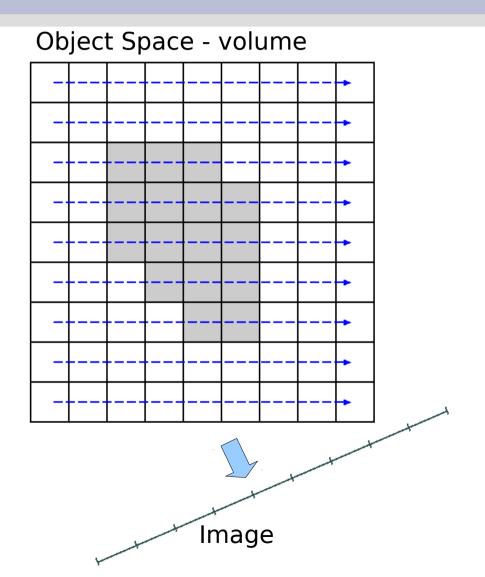
3D Discrete Space

- 3D grid point (sample):
- $P = [x, y, z], x, y, z \in Z$
- Value at sample P: density
- Voxel:
 - Voronoi neighborhood of P
 - NN interpolation
- Cell:
 - 8 samples
 - higher order interpolation



Object-Order VR: Splatting

- Samples/voxels are projected (splatted) onto the viewing plane
- Back-to-front of front-to-back order
- One sample projects onto several pixels



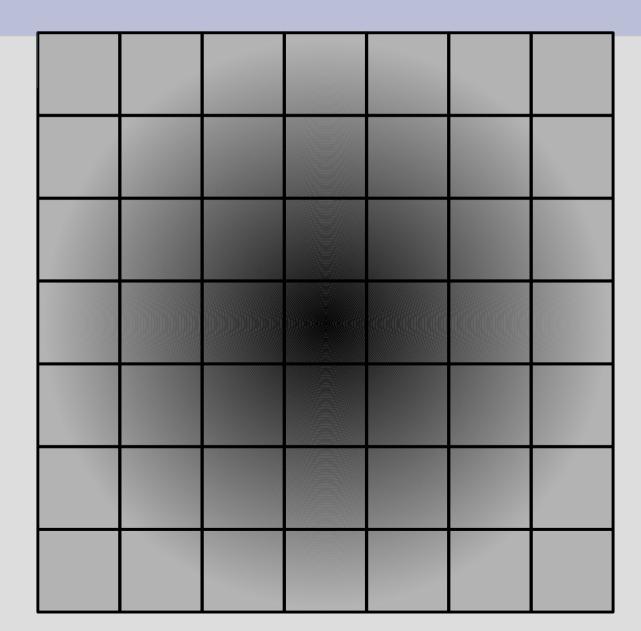
Splatting Footprint (Westover)

- A sample is represented as a cloud of particles
- High resolution footprint table: computed only once

 $\rho(s) \ h_{\nu}(x-x_s, y-y_s, z-z_s) \ \rightarrow \rho(s) \ footprint(x-x_s, y-y_s)$

• BTF, FTB compositing

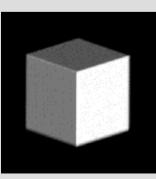
Footprint table



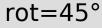
Splatting artifacts (1)

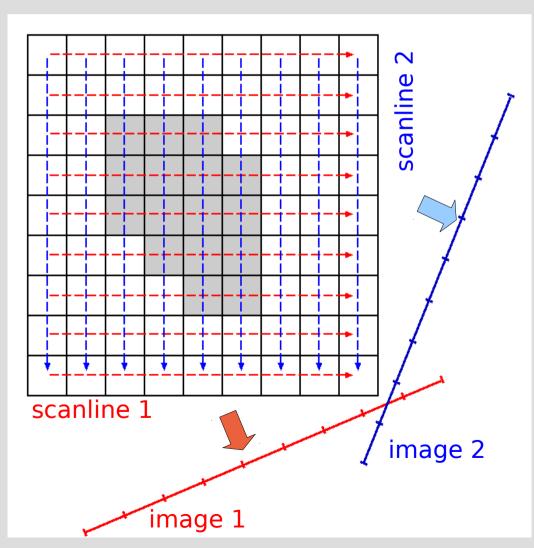
- Traversal order depends on viewing angles
- The most parallel scanline to image is chosen
- Popping artifacts:





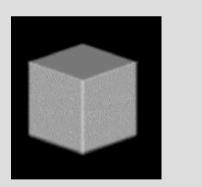
Mueller 1998



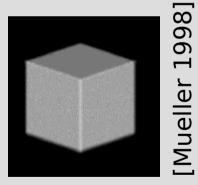


Splatting artifacts (2)

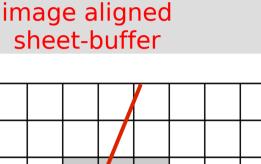
- Image aligned sheet-buffer
- No popping

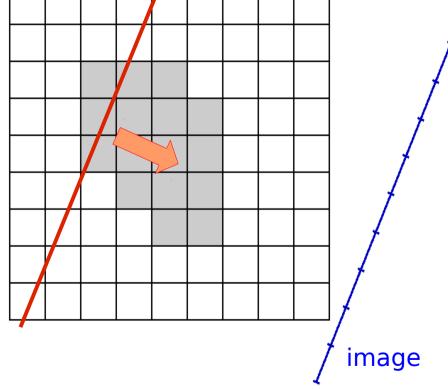


rot=45°



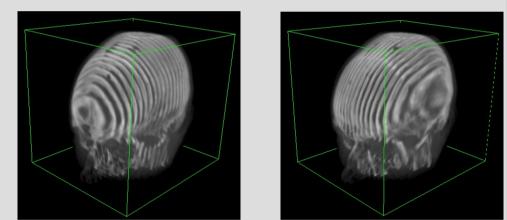
rot=45.1°





HW Acceleration by Texture Mapping

- Do the costly part by hardware
- 2D Textures
 - compositing only
 - volume aligned slices
 - three copies of the volume required
- 3D Textures
 - interpolation & compositing
 image aligned clices
 - image aligned slices
- Shading possible in fragment programs



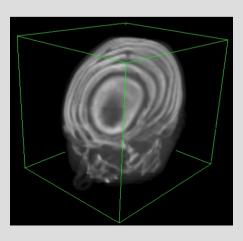


Image Order VR by Ray-Casting (1)

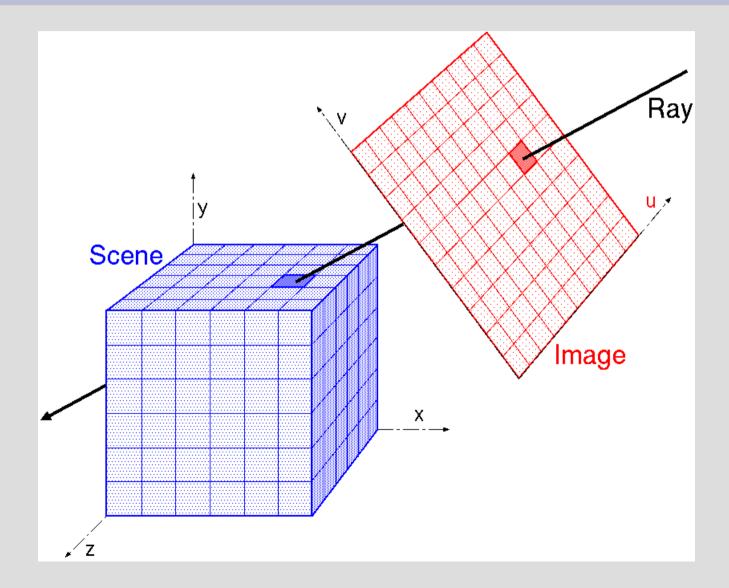
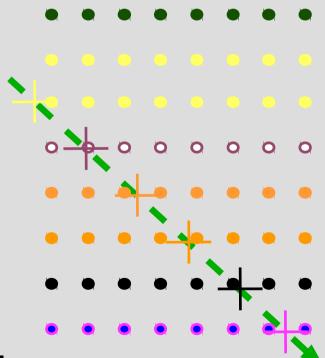


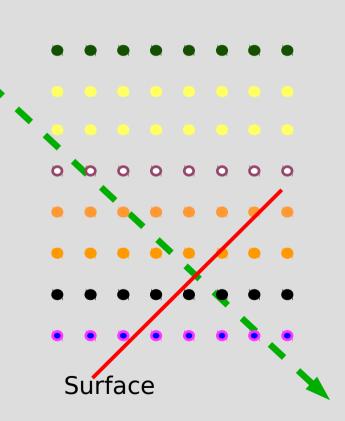
Image Order VR by Ray-Casting (2)

- Shoot rays from each pixel
- Define a sequence of samples
- Accumulate color and opacity along each ray
- CPU and GPU implementations possible
- Acceleration required:
 - Adaptive sampling, empty space skipping, hierarchical subdivision, early termination



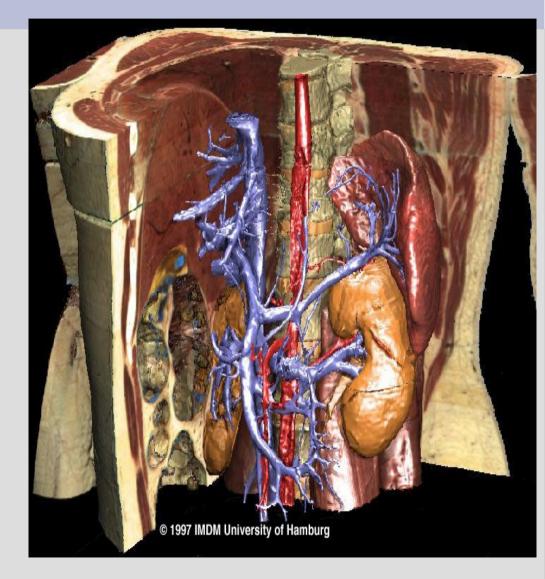
Isosurfacing Basics

- Interpolation domain:
 - Original densities
 - Segmentation labels
- Algorithms:
 - (First hit) ray tracing
 - Ray/surface intersections by numerical root finding
- CPU and GPU implementations possible
- Acceleration required



Ray Casting Advantages

- Simplicity and flexibility
- Combination of techniques possible:
 - DVR, isosurfacing,
 MIP, CPR, cutplanes
 - per object definition of techniques and parameters



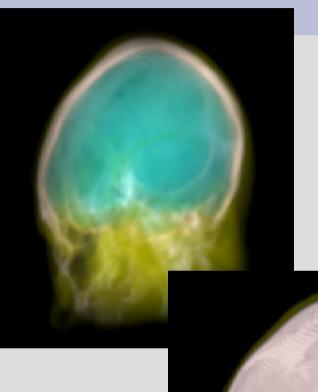
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Conclusion

- We have plentiful volume rendering techniques
- We do not have enough memory
- The computers are not fast enough
- The doctors still prefer slice-by-slice viewing (but getting better recently...)

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8.4	58	66	68	0	60	10	86	86	8.6	83	86		66	66	68	68	61	10	6.6	68	0.6	6.6	90.1	56	504	50	60	00	86	90	60.	90	66	66	60	00	66	86	66	60	96	000
÷.	00	66	6	80	6.01		6 6	66	0.0	4		0	•	•	00	10	0.0	6	0	00	0.0	0.1	101	101	9.6.0	66	0.0	00	0.0	66	961	6	6.6	66	6.6	0.0	6.6	00	00	0.0	561	000
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6.0	0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0 0	0	01	8.6	8 8	6.8	0.8	0.0	8 8	0.0	ê ()	0.0	0	0 1	0 0	0 0 0	0	0.0	6.0	0.6	1	0.6.0	0	6 ð	0-0	0 0	6 ð	0 0	0 0	0.0	0.6	0.01	0.0.0
6.0	- 0	0.0	0	A	0 0	0.0	6 Q	÷ •	N		V١	N	0 0	Ve	0.3	δK)[4 0	0.0		e	G	V	e 1	d	0	. C			3 8 6	0	0 0				a e	8	8 e :	6 e (6 e 1	0 0 0 0 0 0
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