# Volume Rendering

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# Overview

- Volume visualization
- Volume viewing
- Volume visualization by mapping
  - Transfer functions & segmentation
- Direct volume rendering
  - DVR techniques,  compositing
- DVR algorithms
  - Splatting, ray casting, isosurfacing

# Volume Data

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

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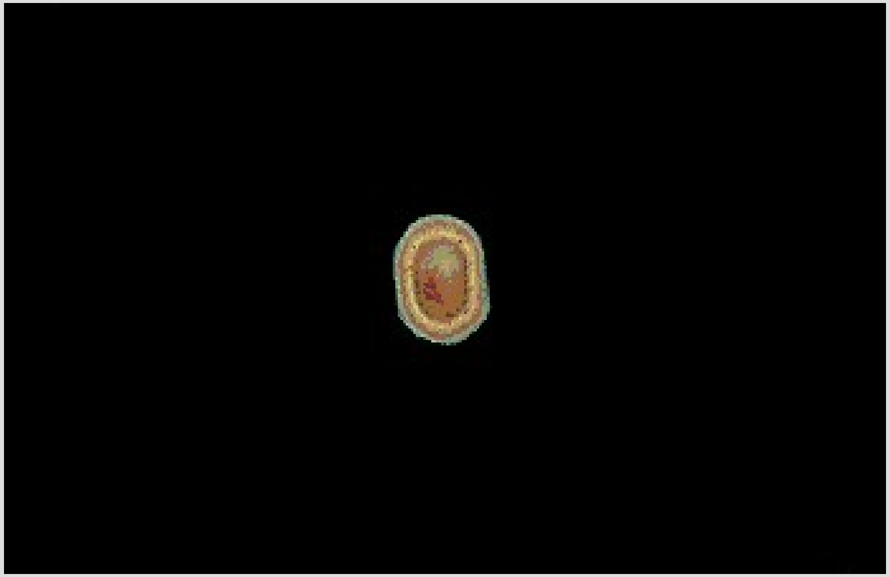


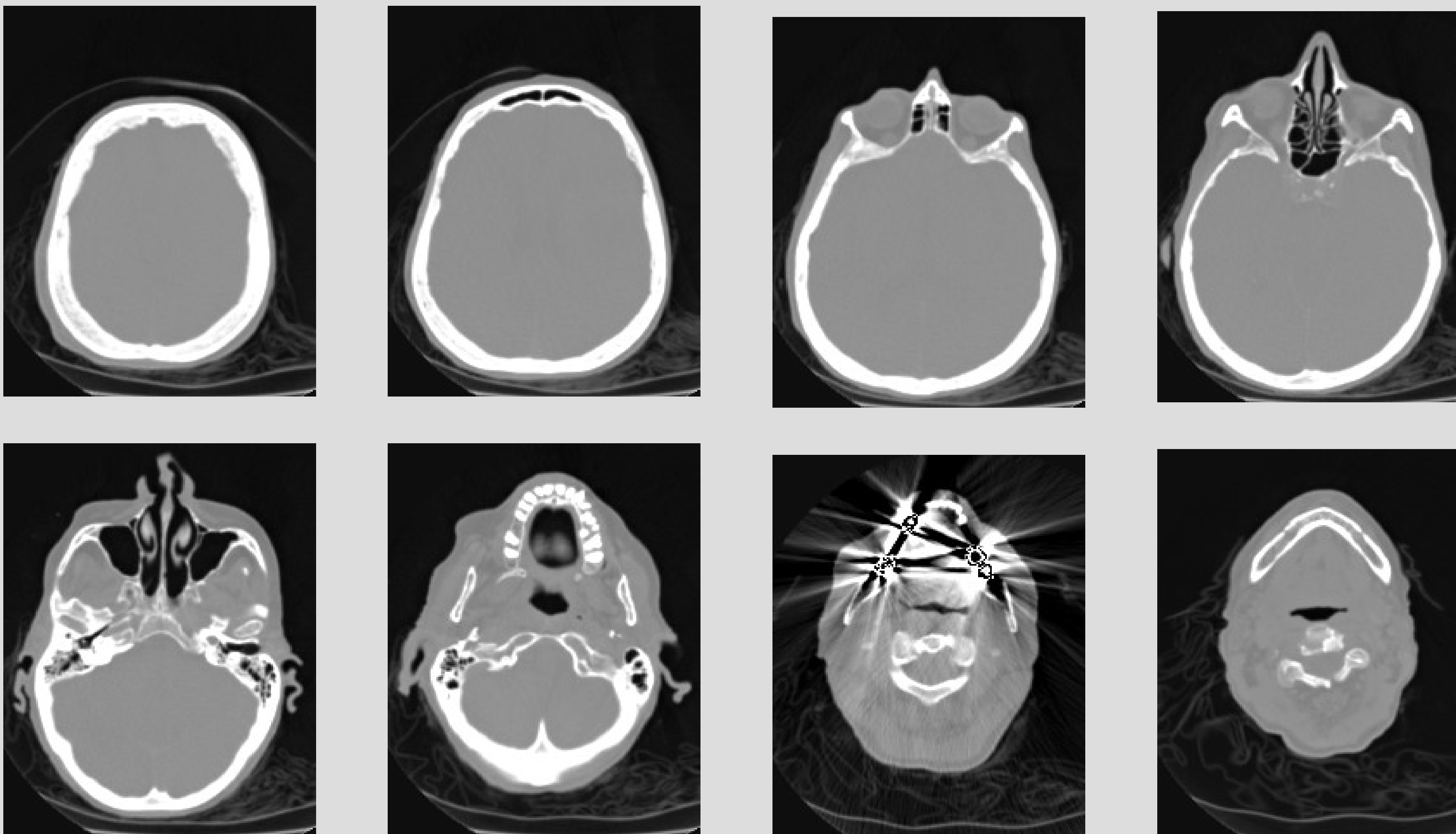
# Volume Visualization

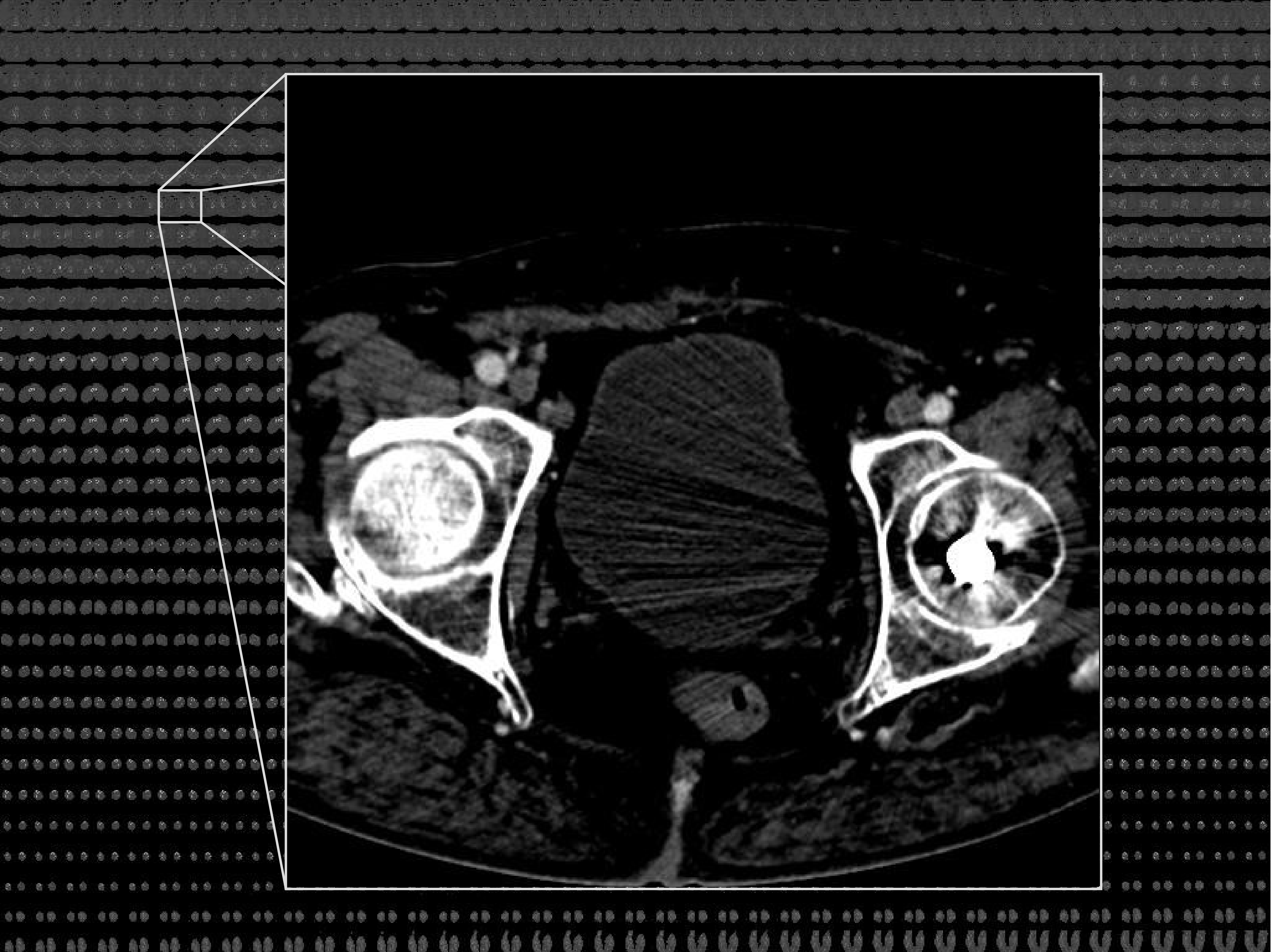
- Visually perceivable data presentation
- Understanding, not photorealism
- Simple volume viewing
  - Straightforward presentation of measured data


- Mapping techniques
  - Measured densities are mapped to visual attributes (transparency, color)

# Volume Viewing (1)

- Slice-by-slice viewing

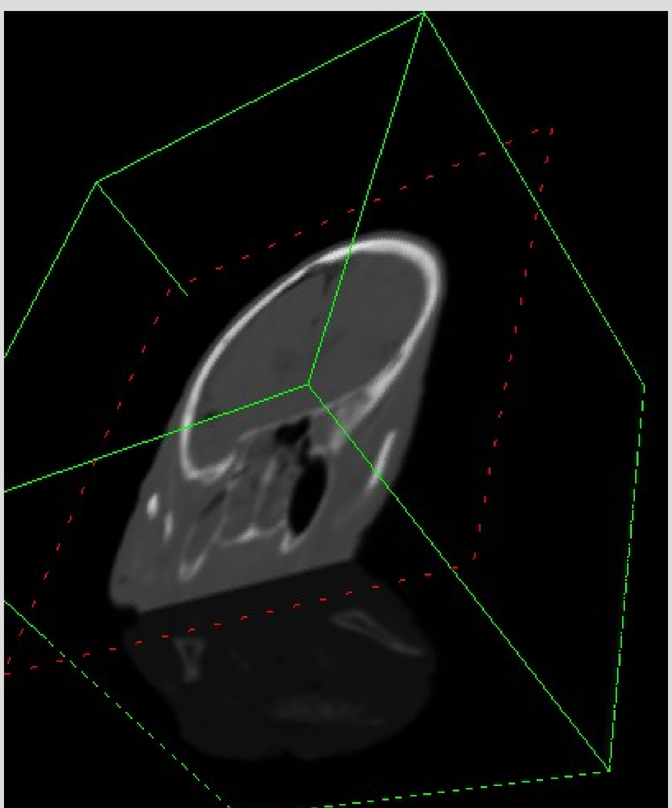




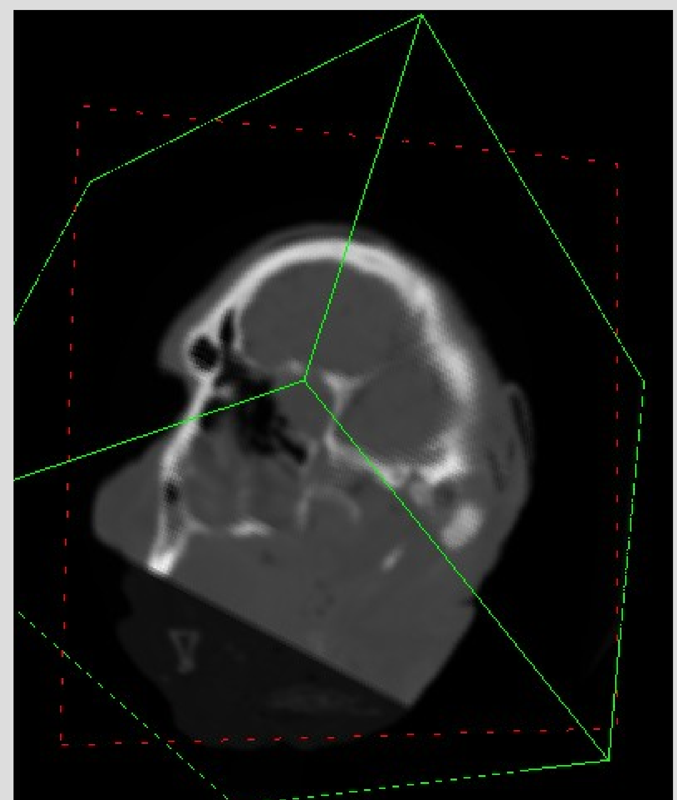
# Volume Viewing (2)

- Multiplanar reconstruction
  - Definition of new cutplanes

Axis aligned

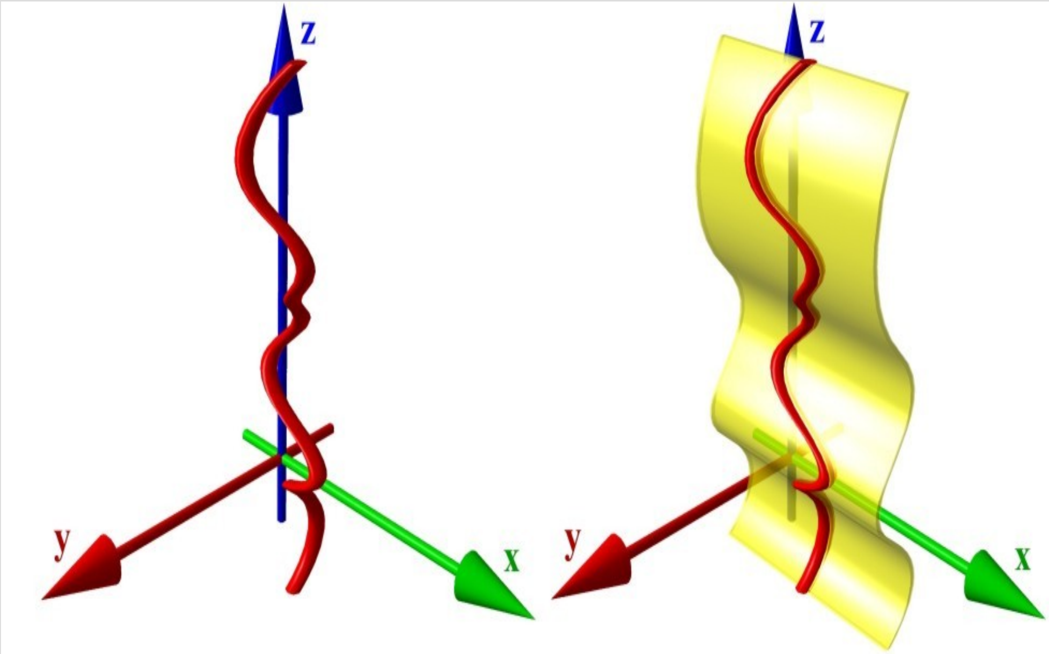


Oblique



# Volume Viewing (3)

- Curved planar reconstruction
  - Volume cutting along a line




Kanitsar 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

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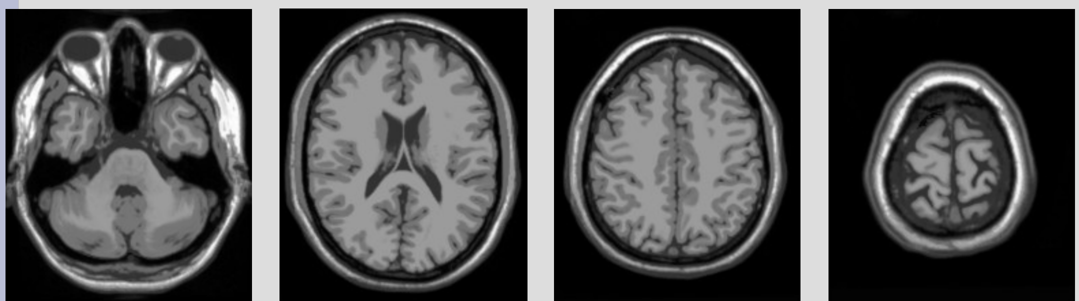
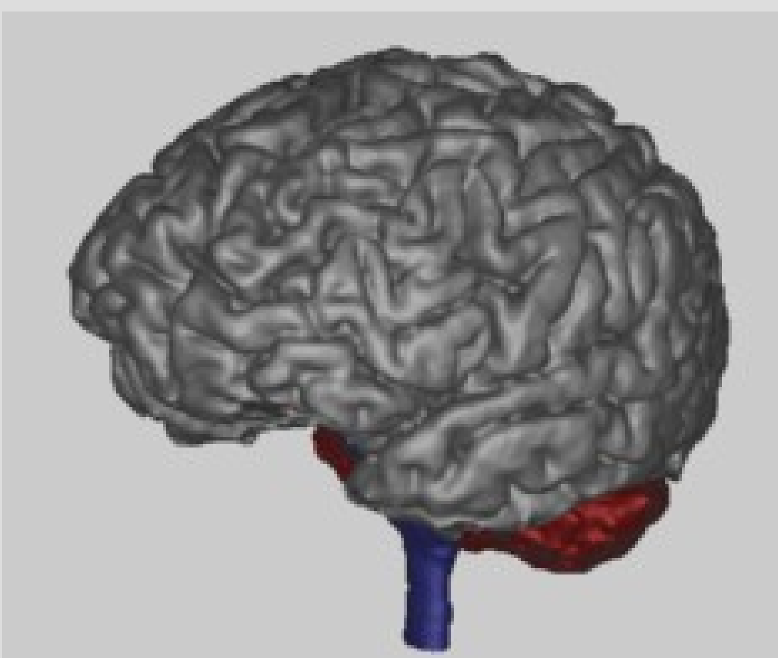
  - Transfer functions & segmentation
- Direct volume rendering
  - DVR techniques,  compositing
- DVR algorithms
  - Splatting, ray casting, isosurfacing

# Volume Visualization by Mapping





**Data Acquisition**

**CT, MRI, USG, PET, SPECT**

**Mapping**

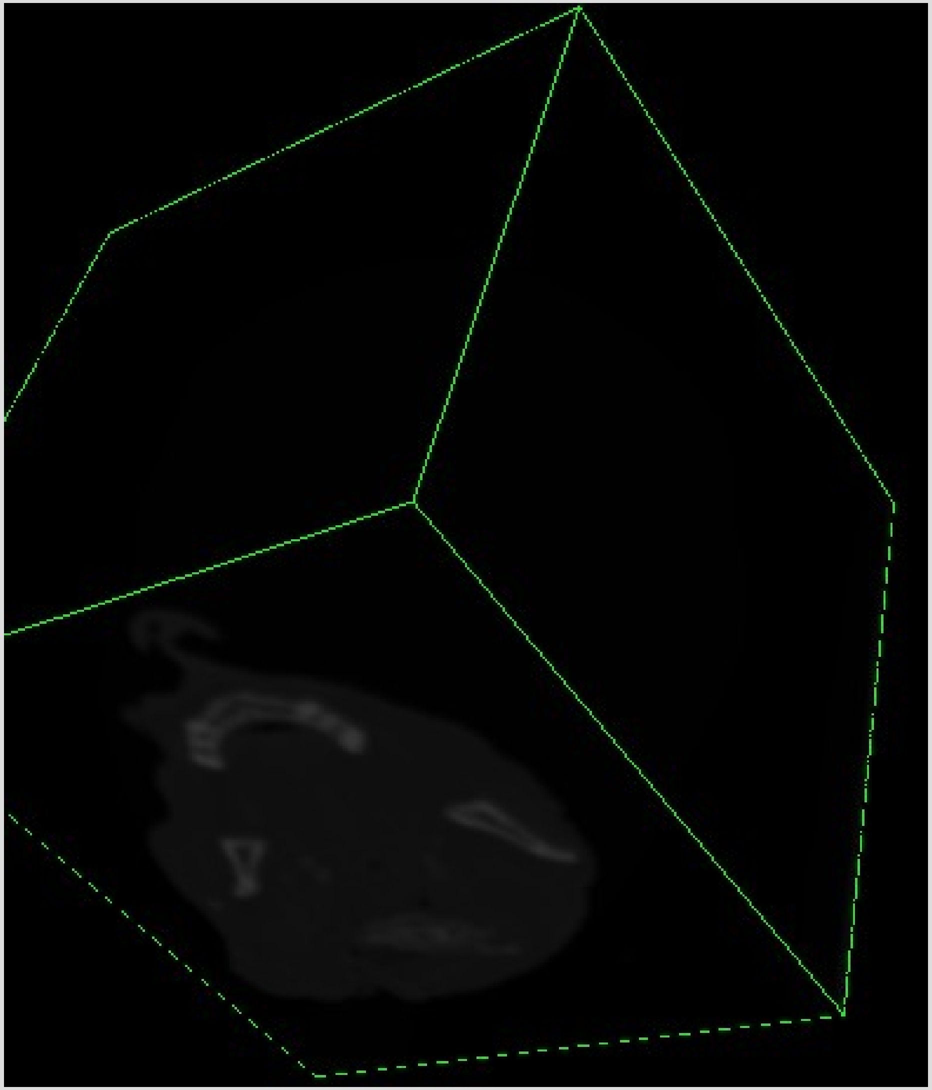
**Visual attributes**

**Rendering**

**Surface & Volume Techniques**

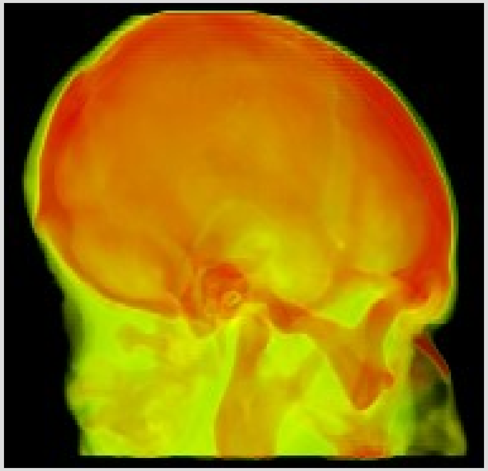
# Why Do We Need Mapping?

- 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

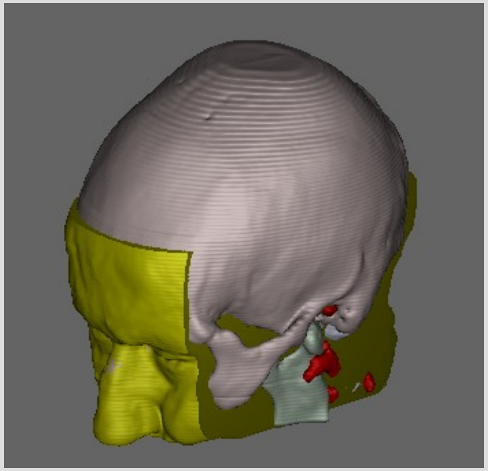


# Mapping

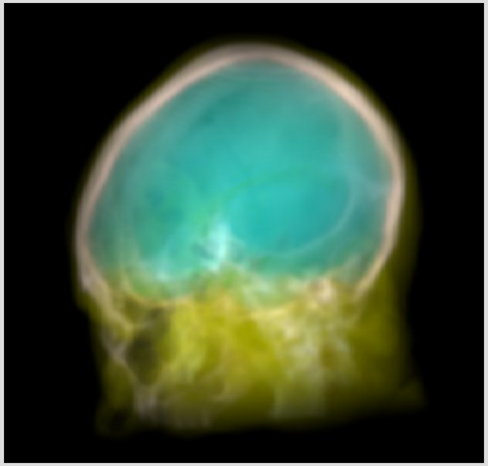
- Mapping: Assignment of visual attributes to data:
  - transparency, color, reflectance, surface strength...
- “Area of interest” specification achieved:



Density-based **classification**



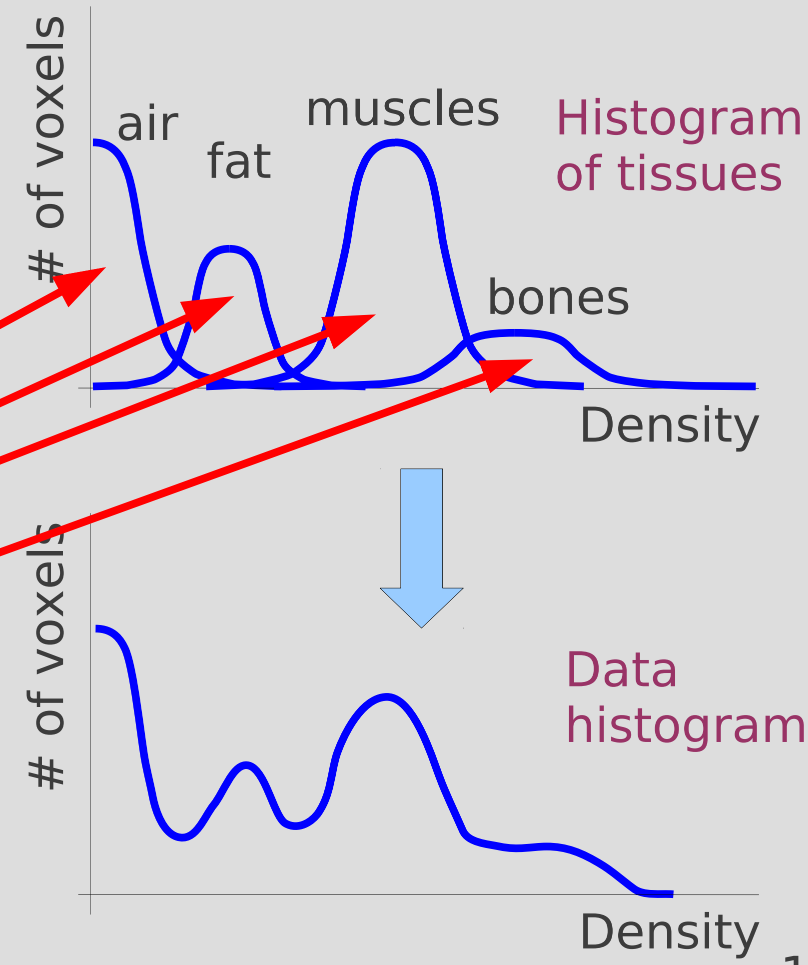
Space-based **segmentation**

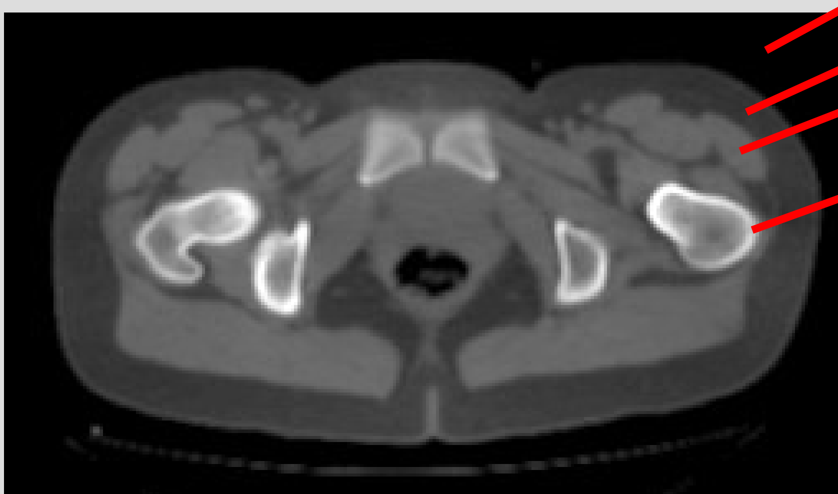


Combined

# Mapping by Density Classification

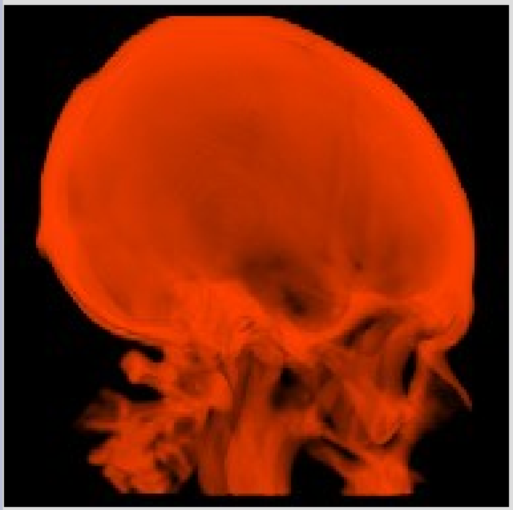
- Assumptions:
  - Areas of interest can be identified solely by density value
  - Neighbors in histogram are neighbors in space



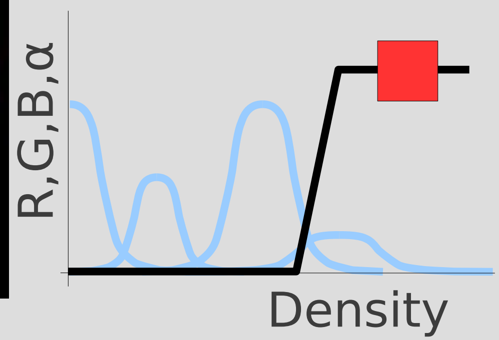



CT scan of a human pelvis

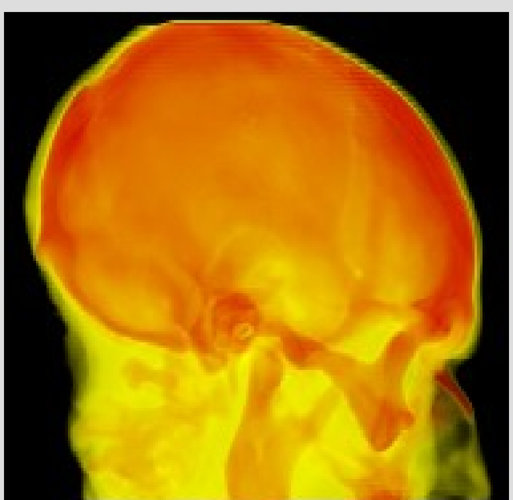
# Density Classification by Transfer Functions



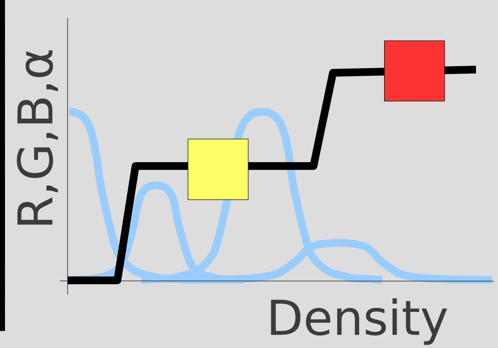
Bone only

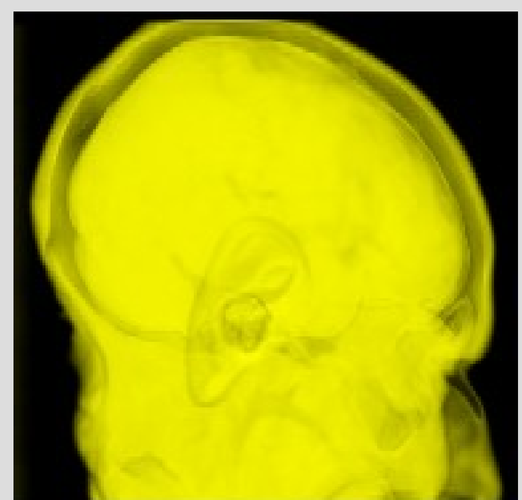



$$R, G, B, \alpha = f(density)$$

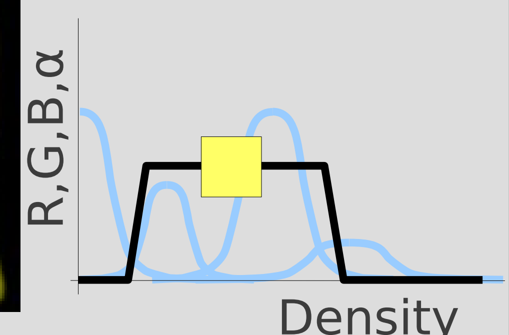


Bone & soft

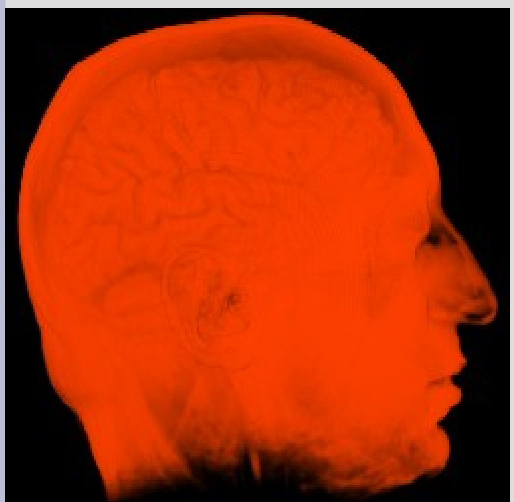


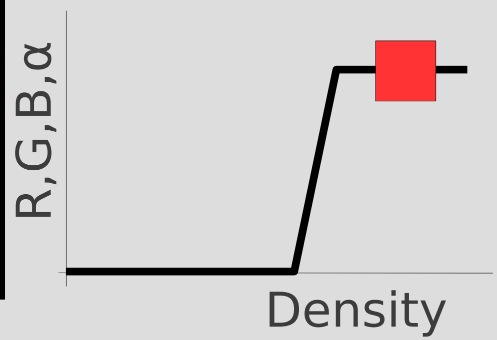



Soft only

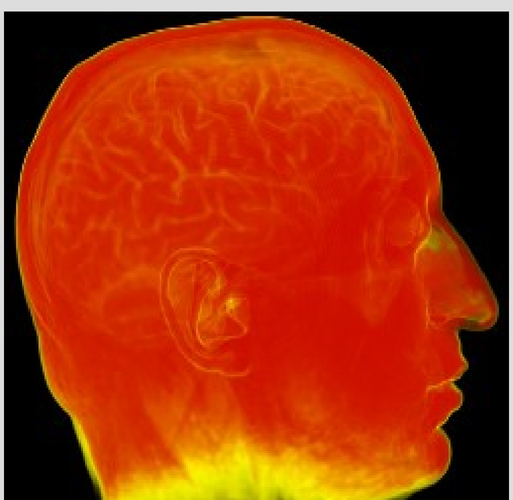


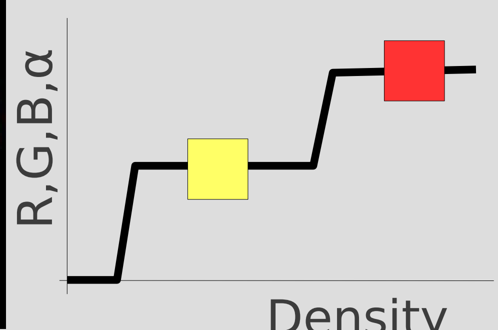
# Transfer Functions with General Data

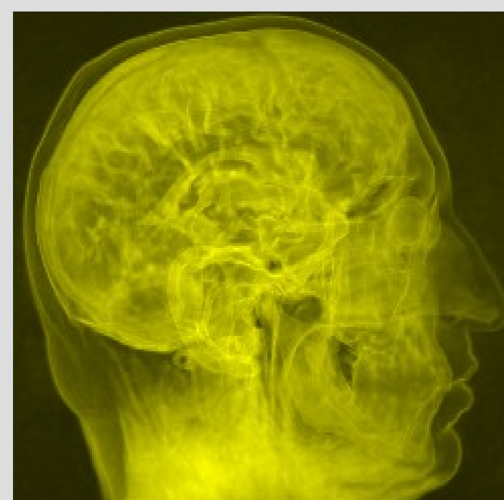


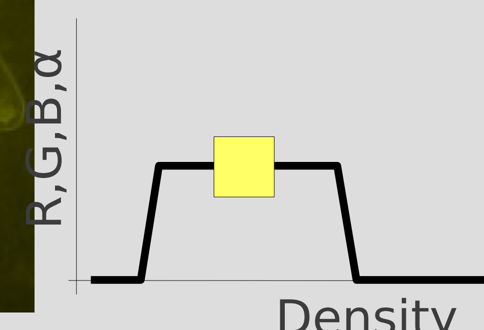



- MRI Data:
- The histogram/position model not fulfilled
- No TF can separate the tissues
- Additional info required







# 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

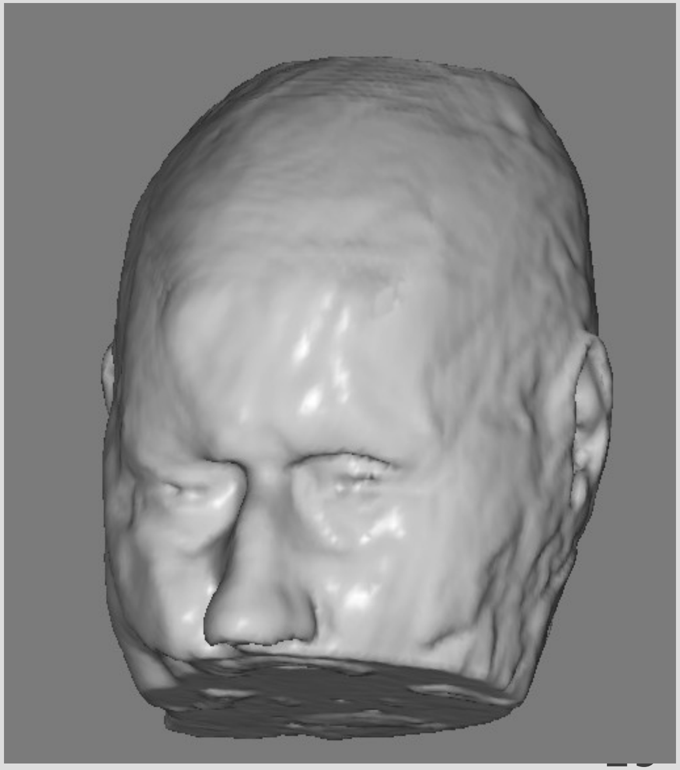
(not used for classification of rendering techniques)

# 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)

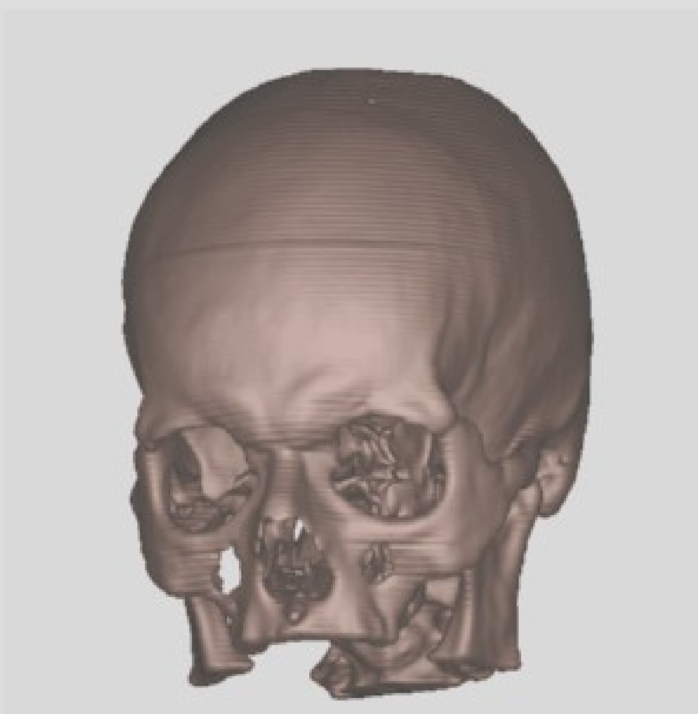
## Volume rendering

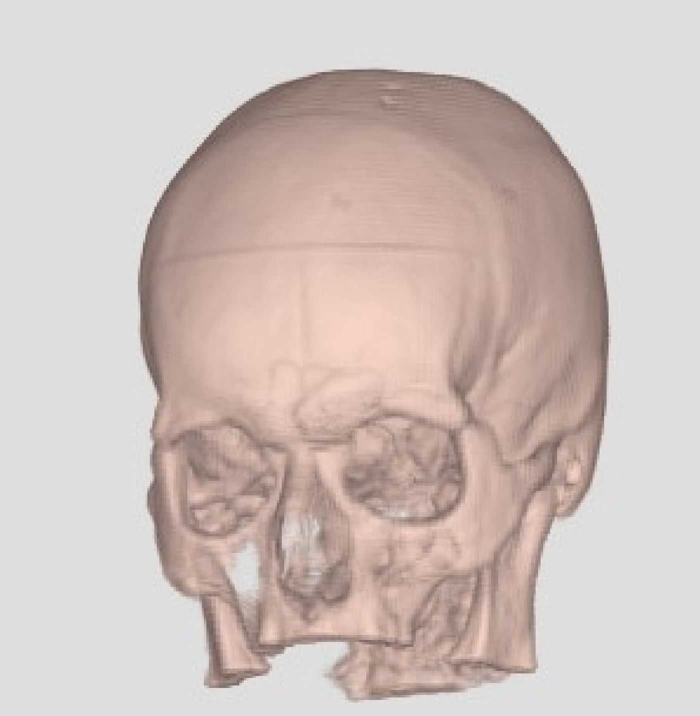
- Basic primitive: the voxel itself
- Rendering directly from volume data:
- Two flavors:
  - TF based: Direct volume rendering (DVR)
    - Semitransparent data, all volume samples potentially contribute to the image
  - Segmentation (object) based: Isosurfacing
    - Hard surfaces, only visible surfaces are displayed

# DVR vs. Isosurfacing

- Isosurfacing is a limit case of DVRs with special TF and parameter setting

Isosurfacing

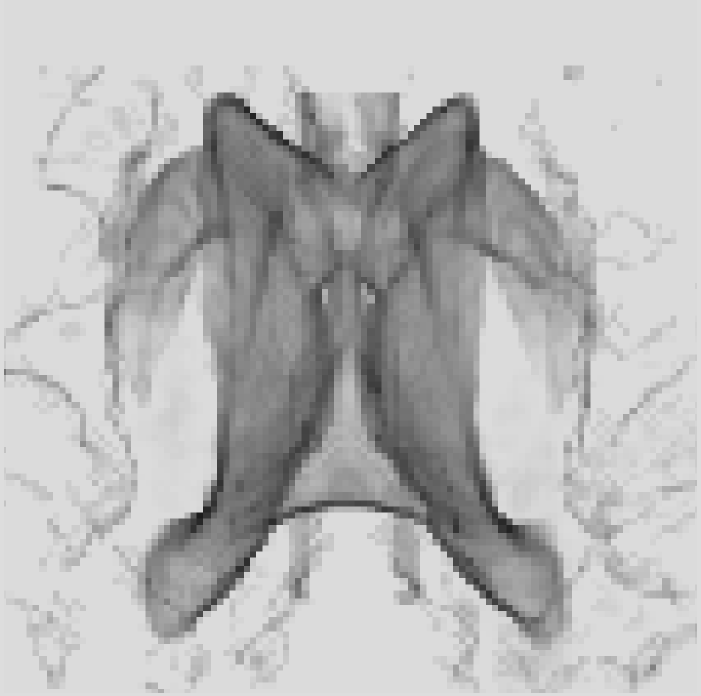


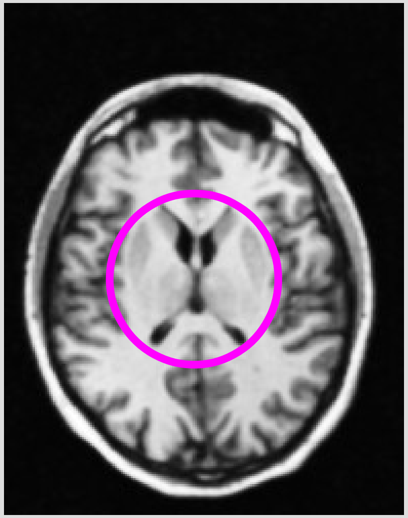


DVR

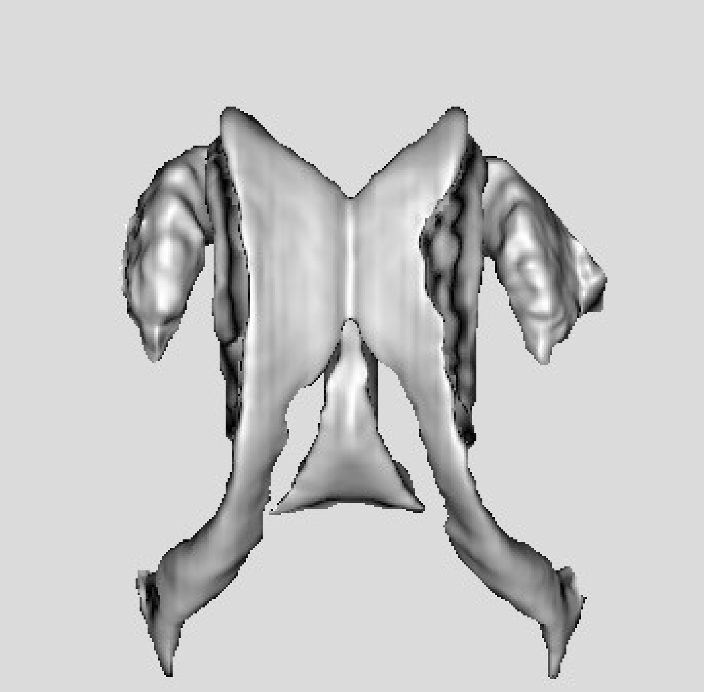
# When to Prefer DVR?

- Low data contrast, weak edges, thin objects





MRI head data: Ventricles & deep brain structures



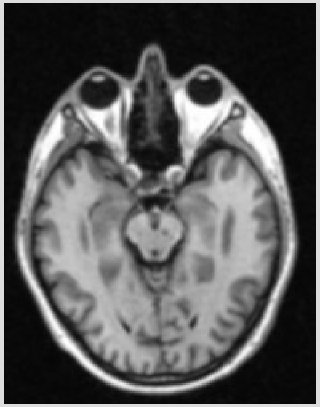
DVR

Isosurfacing

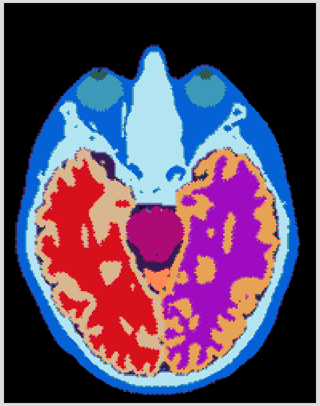
# When to Prefer Isosurfacing?

- Numerous & complex objects, TFs make no sense

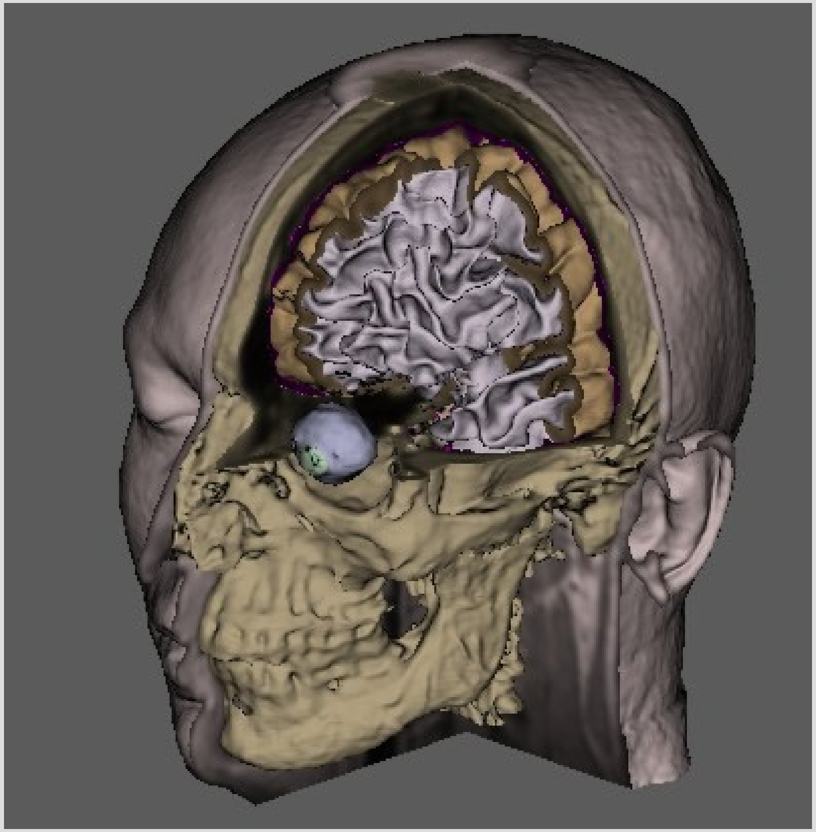
DVR



MRI data



Object labels



Isosurfacing with cutplanes

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# DVR Basics

- Simplified light interaction with semi-transparent 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
$\rho(t)$: Optical density (attenuation)
$\rho(t)I(t)$: Light attenuation at t
$k(t)$: Chromacity
$k(t)\rho(t)$: 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

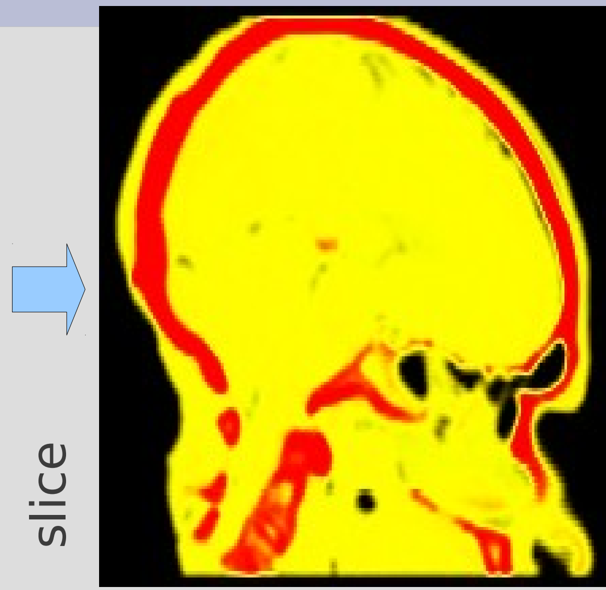
# DVR Techniques (1)

Free/adjustable parameters:

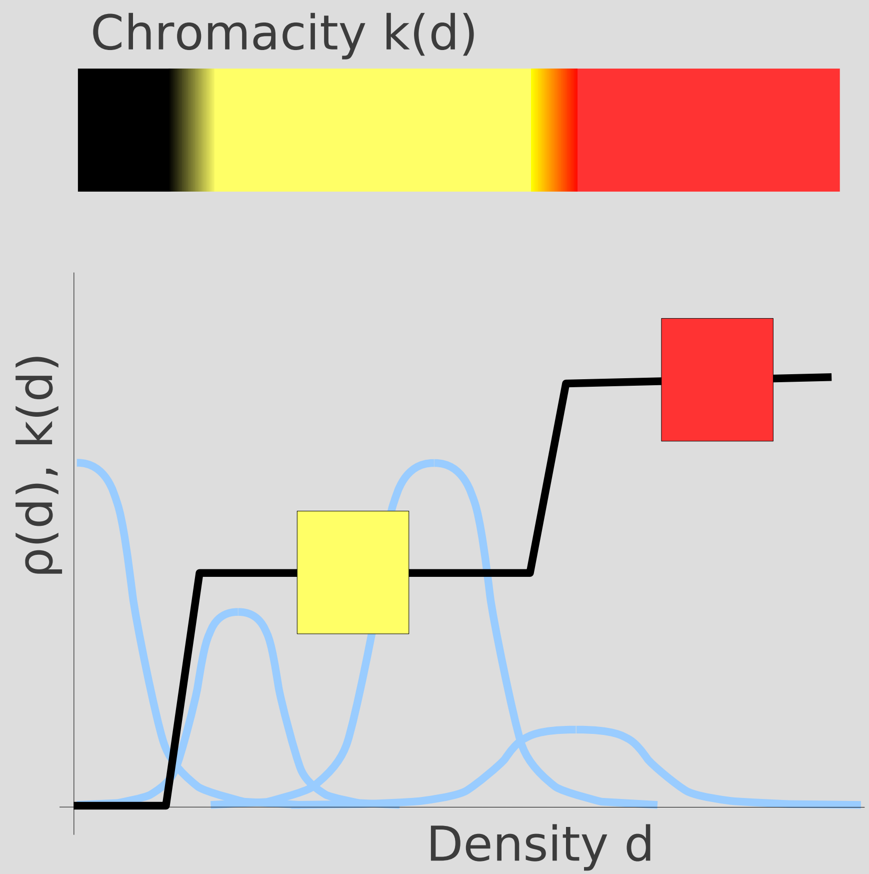
- Transfer functions: $\rho(t) = f_{\rho}(d(t))$

  $k(t) = f_k(d(t))$
- Edge accentuation: $\rho(t) \sim |\nabla d(t)|$
- Shading: $k(t) \sim \nabla d(t) . \vec{p} \;\; f_k(d(t))$
- ...

# ρ(d), k(d): Transfer Functions

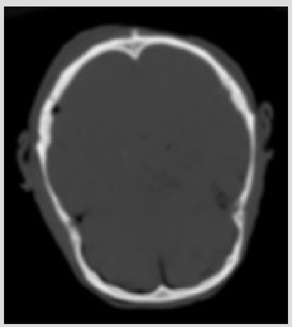




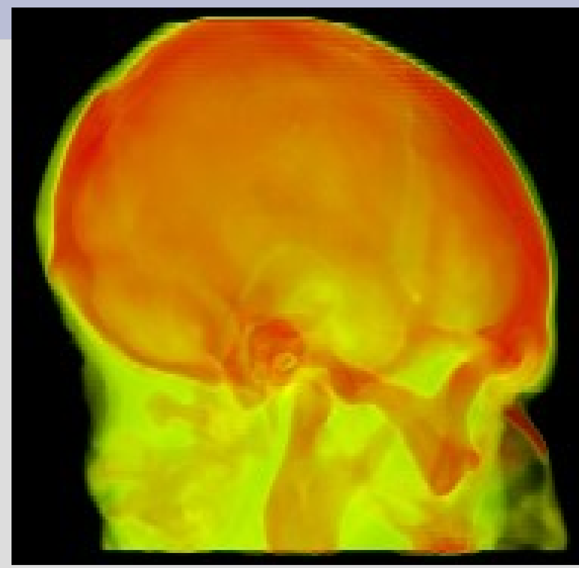


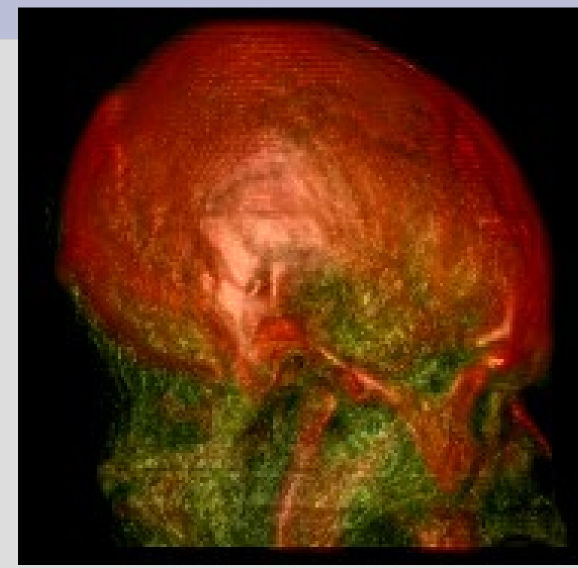
# DVR Techniques (2)

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



No edge enhancement

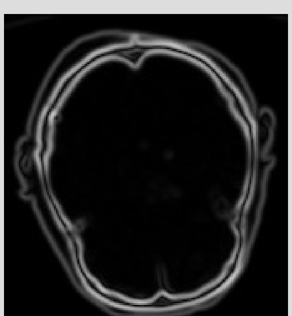




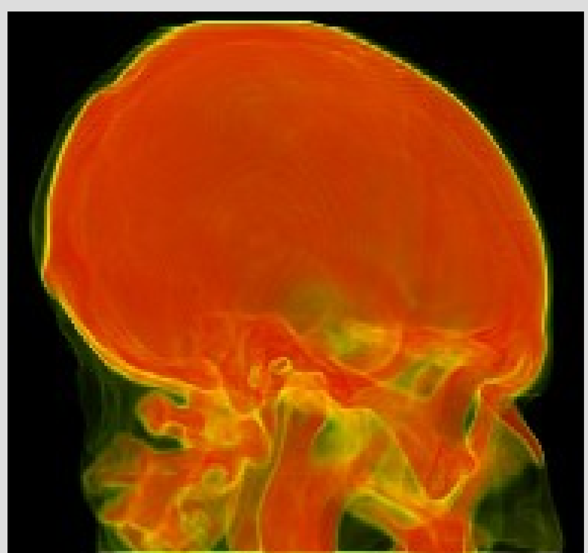
Unshaded

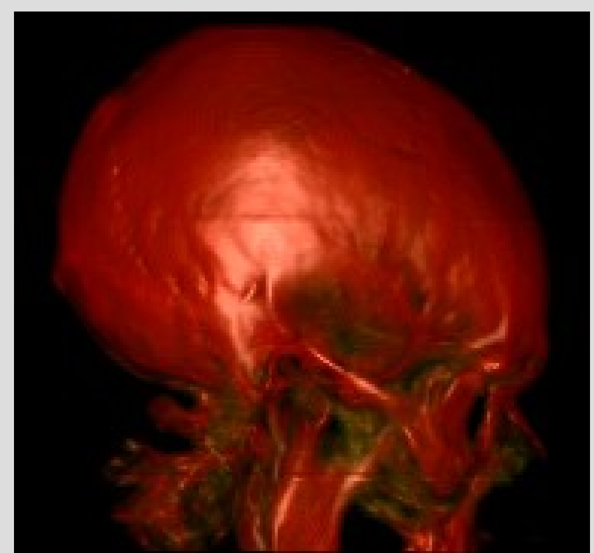
Shaded

$$\rho(t) \sim |\nabla d(t)|$$



Edge enhancement





# Rendering by Compositing

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

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

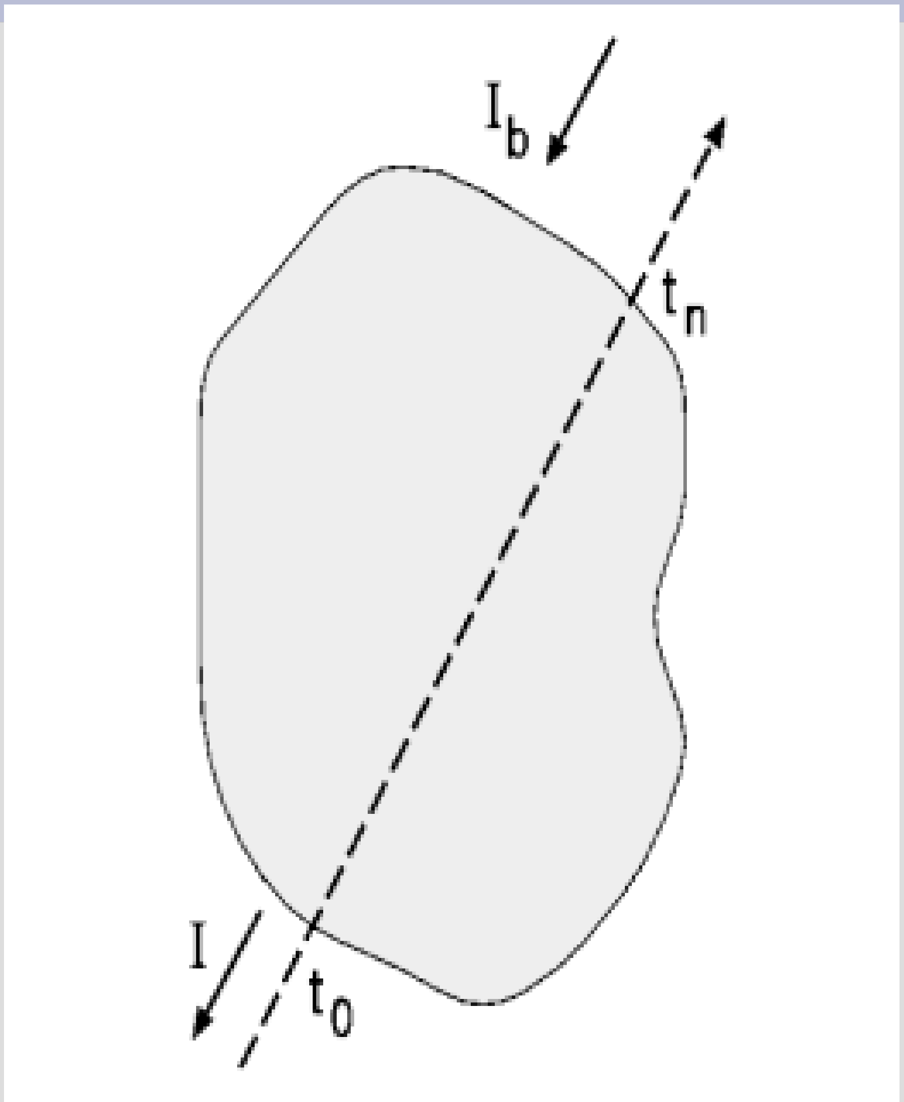
- Evaluation along a projection ray

# Volume Rendering Integral

- Integral form of the Beer's law

$$I = \int_{t_0}^{t_n} k(t)\rho(t)e^{-\int_{t_0}^{t} \rho(u)\,du}\,dt + I_b e^{-\int_{t_0}^{t_n} \rho(t)\,dt}$$

Object transparency



# Per Segment Evaluation of the VRI (1)

- **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)

- Break ray in segments, compute β and C
- 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

- Approximation of *ρ* and *k* by a constant:

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

$$C_i = k_i \alpha_i$$

- Chromacity premultiplied by opacity
- Scaling required with real data

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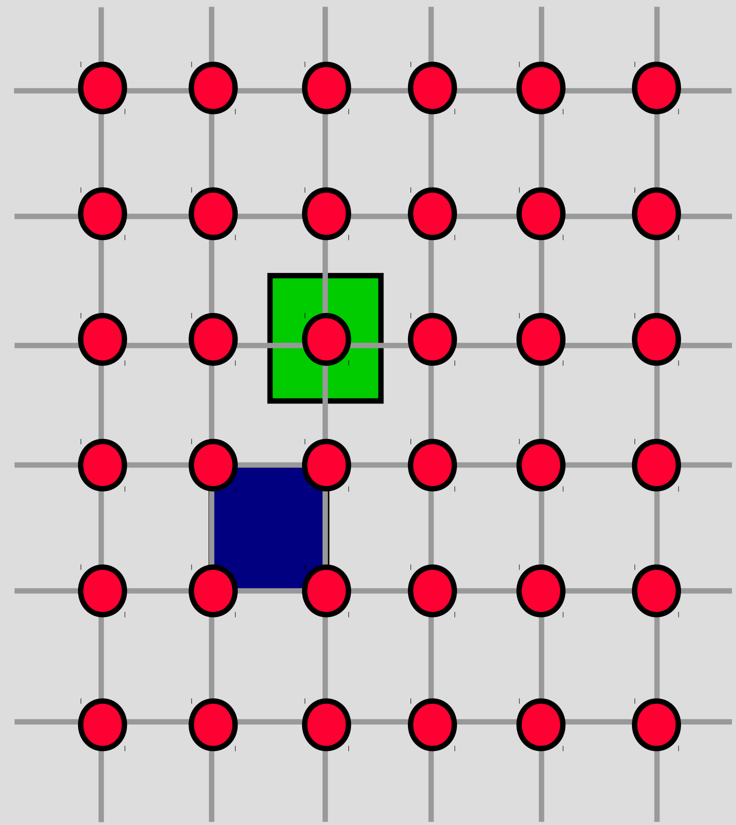
# DVR Algorithms

- 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

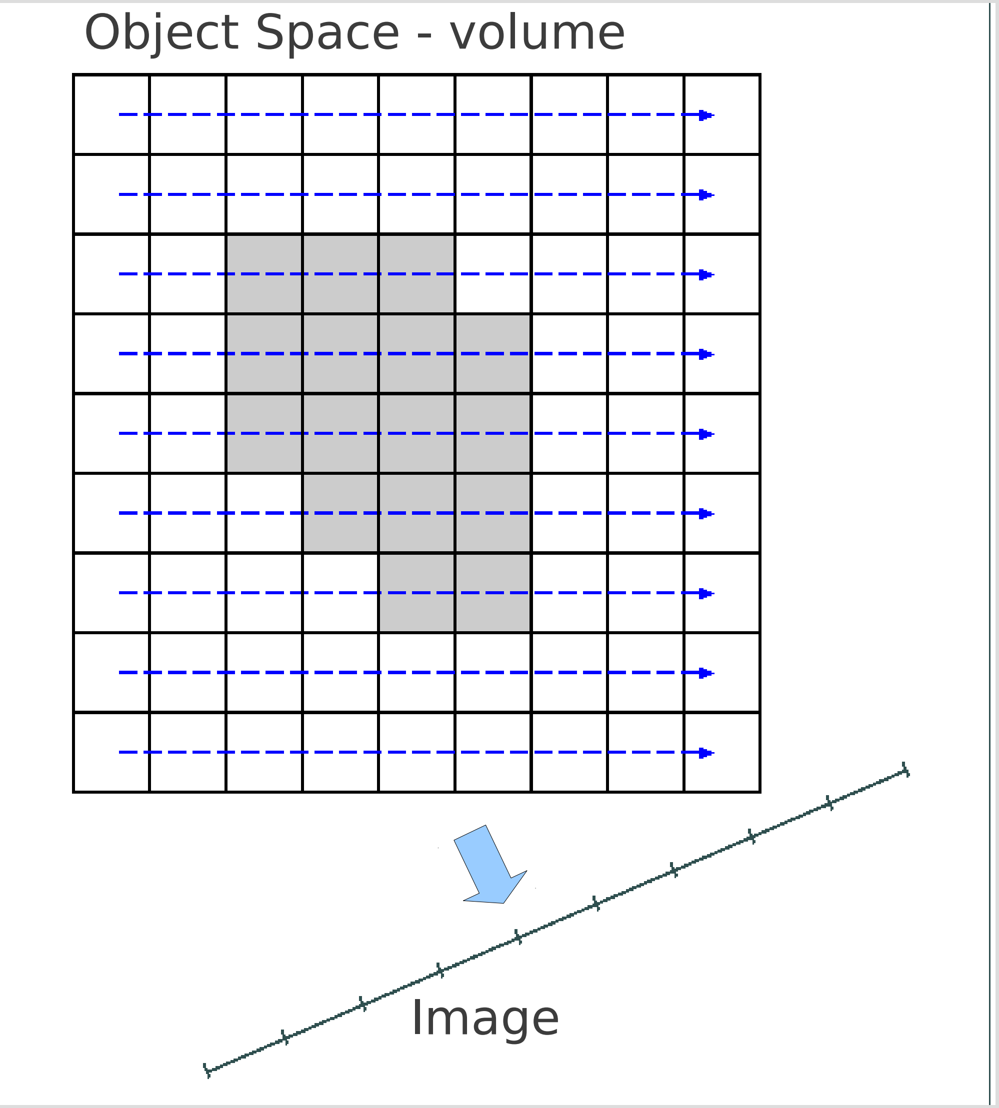
# 3D Discrete Space

- 3D grid point (sample):
- $P = [x, y, z], \quad x, y, z \in Z$
- 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



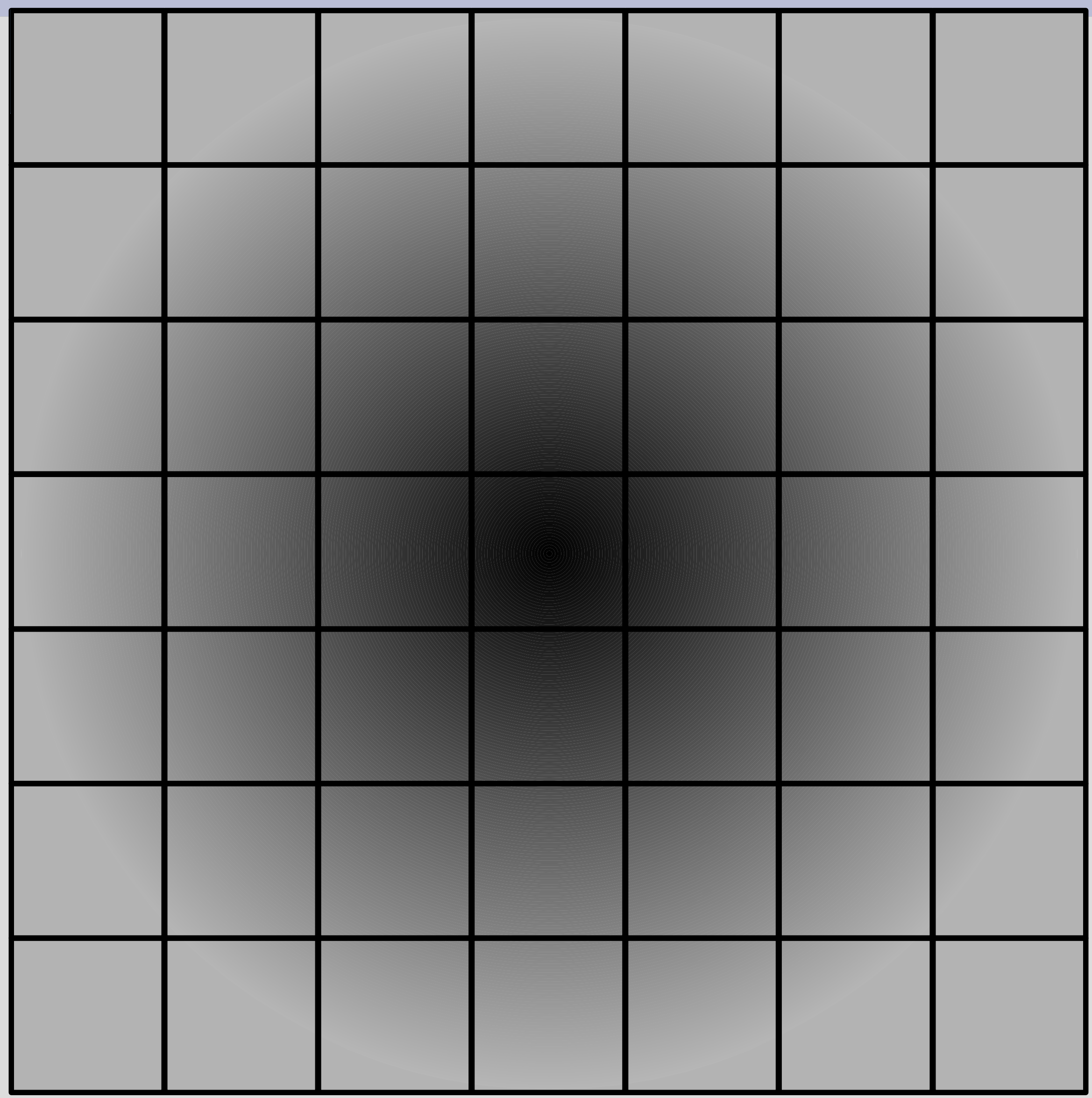
# Splatting Footprint (Westover)

- Sample represented as a cloud of particles
- High resolution footprint table: computed only once

$$\rho(s)\, h_v(x-x_s, y-y_s, z-z_s) \;\rightarrow \rho(s)\; footprint(x-x_s, y-y_s)$$

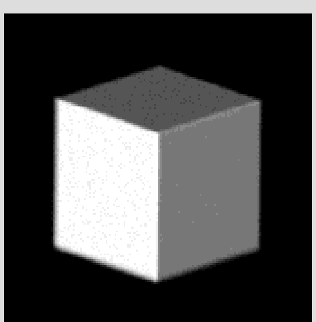
- BTF, FTB compositing

# Footprint table

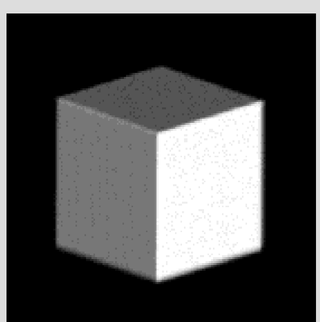


# Splatting artifacts (1)

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

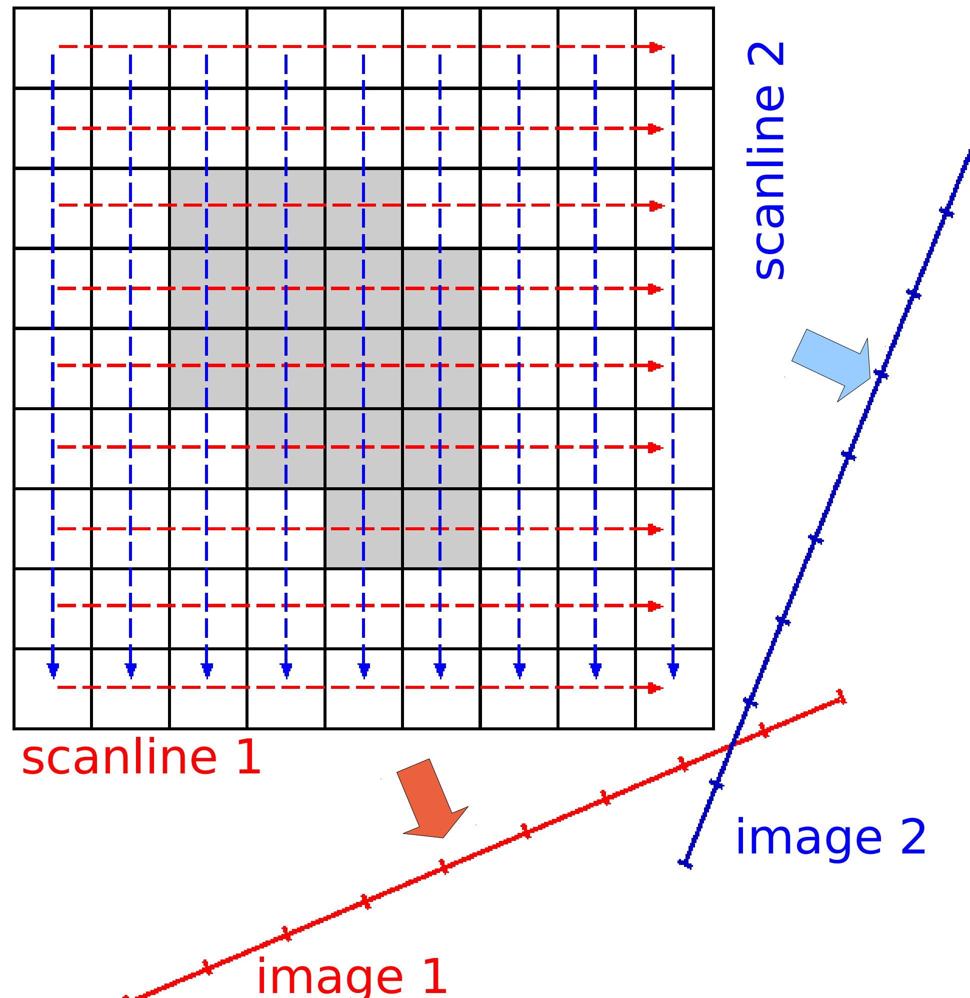


rot=45°



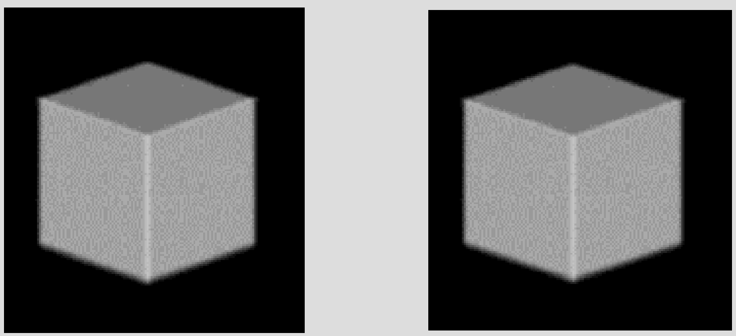
rot=45.1°

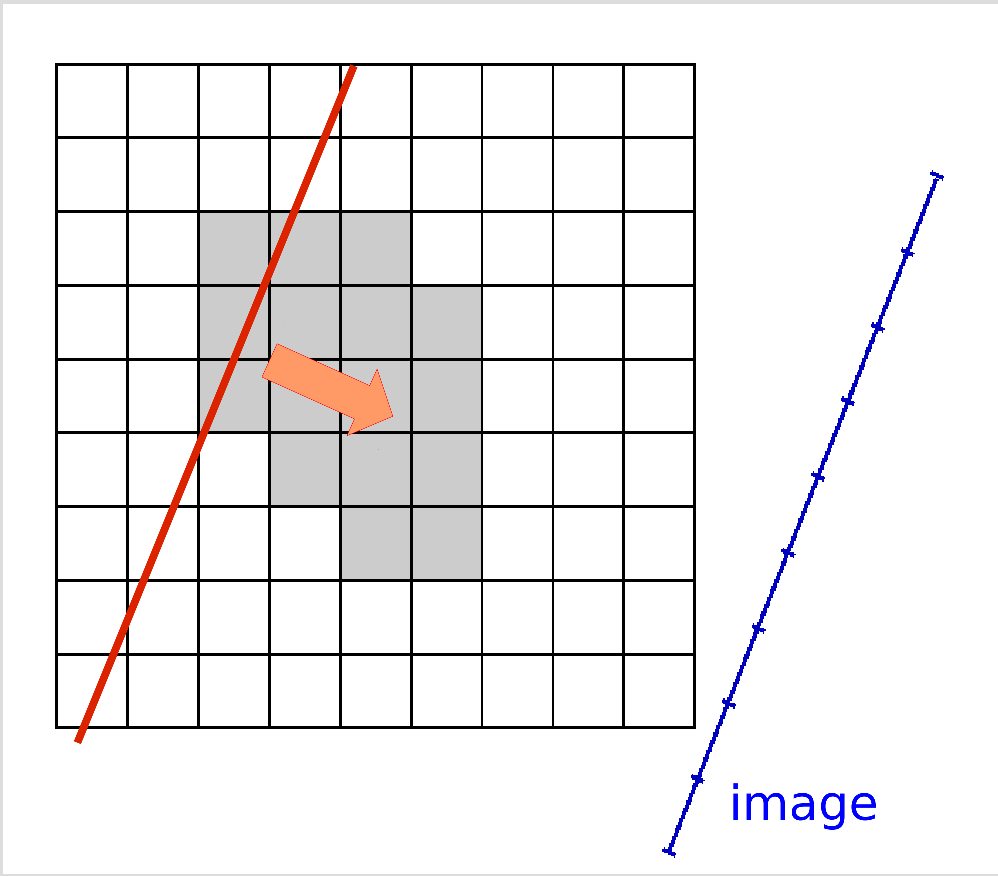
[Mueller 1998]



# Splatting artifacts (2)

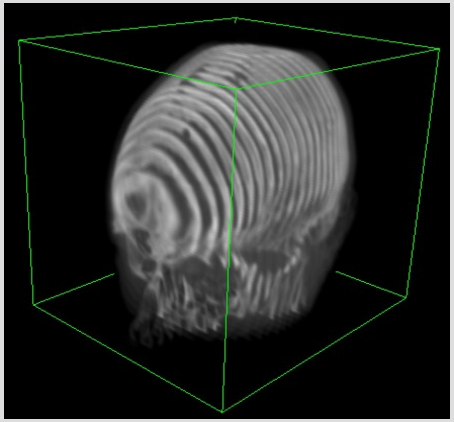
- Image aligned sheet-buffer
- No popping

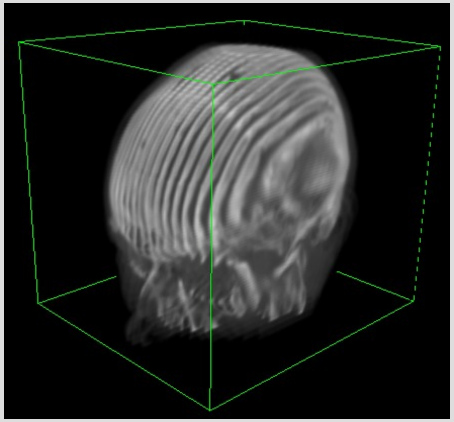


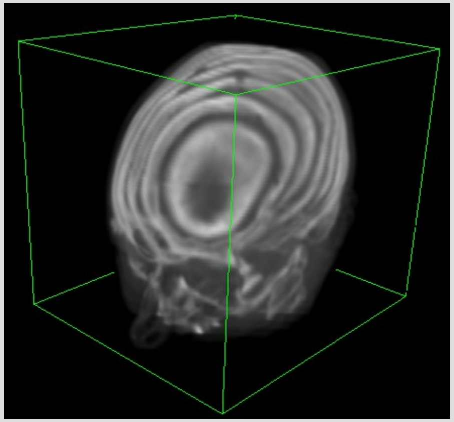
# HW Acceleration by Texture Mapping

- Do the costly part  by hardware
- 2D Textures
  - compositing only
  - volume aligned slices
  - three copies of the volume required



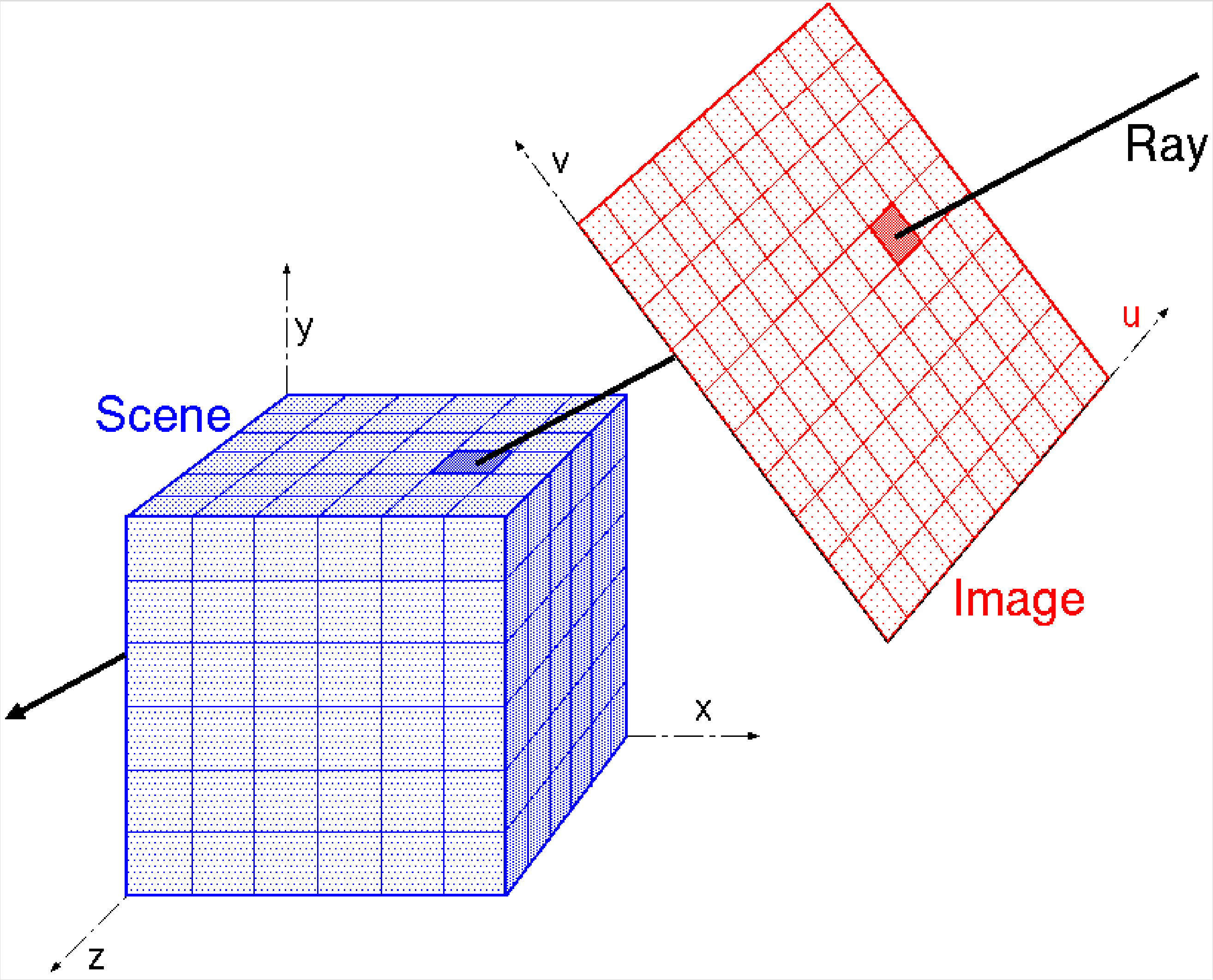


- 3D Textures
  - interpolation & compositing
  - image aligned slices



- Shading possible in fragment programs

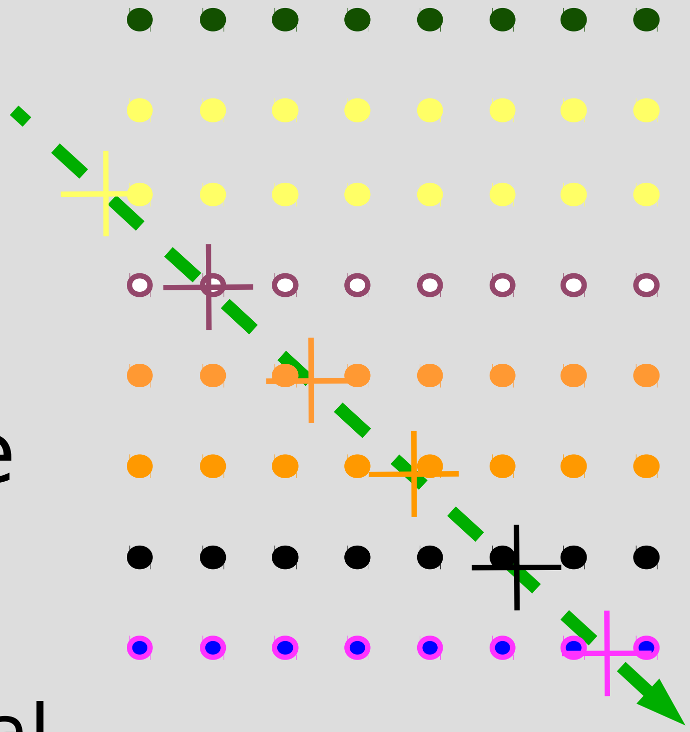
# Image Order VR by Ray-Casting (1)



# Image Order VR by Ray-Casting (2)

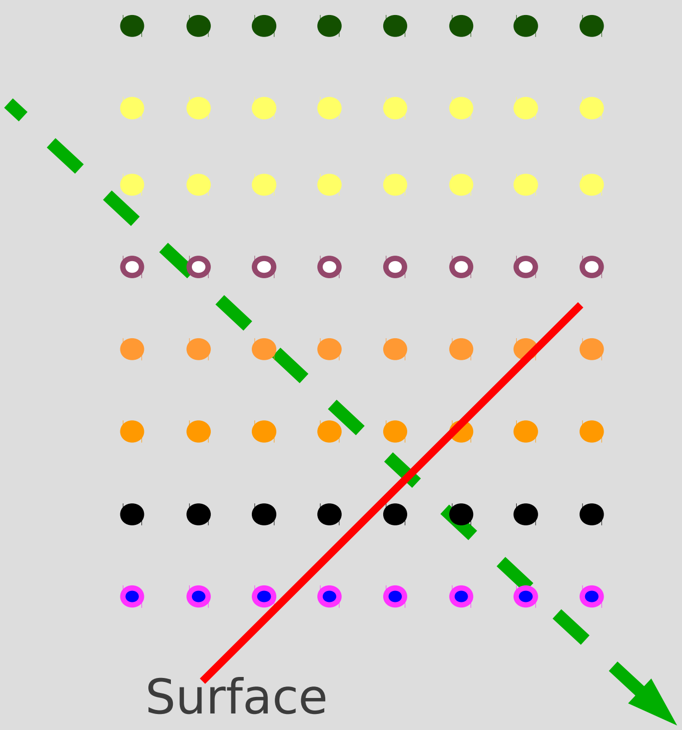
- Shoot rays from each pixel
- Define a sequence of samples
- Accumulate color and opacity along each ray

- CPU and GPU implementations possible
- Acceleration required:
  - Adaptive sampling, empty space skipping, hierarchical subdivision, early termination



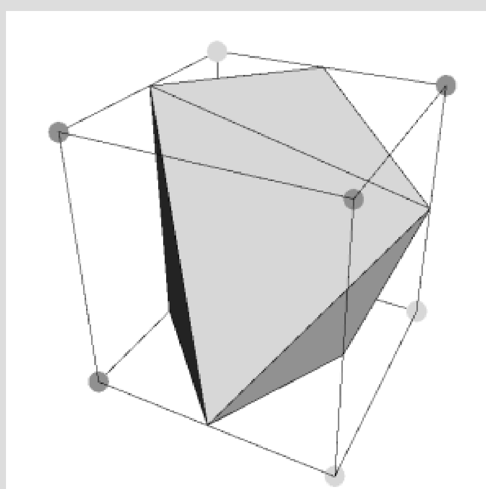
# Isosurfacing Basics

- 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

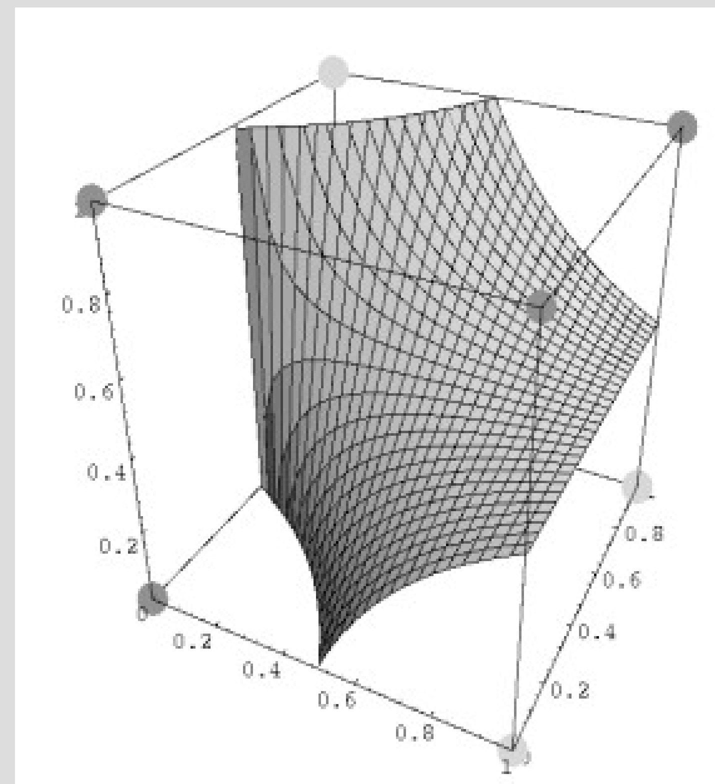


# Isosurfacing

- Isosurface definition by interpolation & thresholding
- Interpolation domain:
  - Original densities
  - Segmentation labels



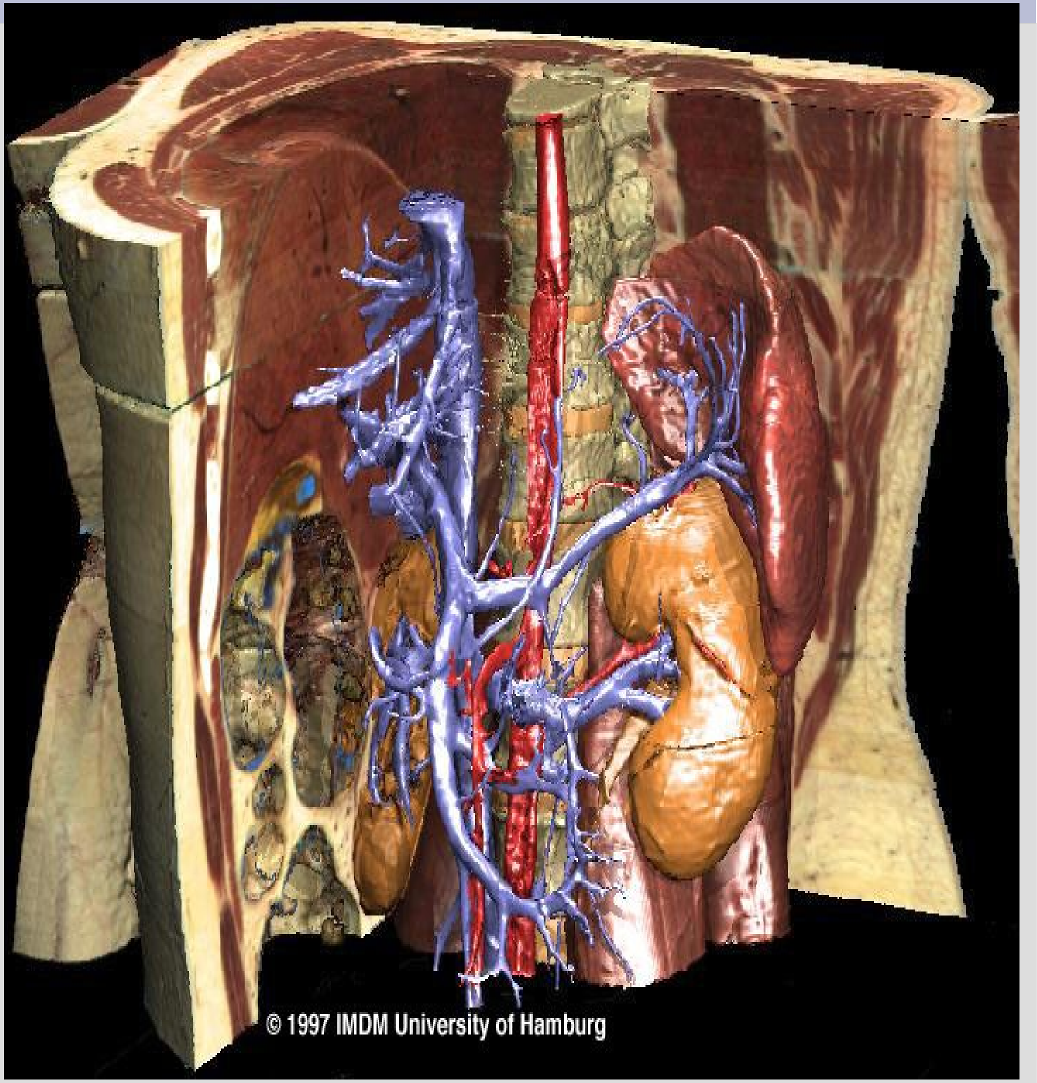
Triangulation by the MC algorithm




Interpolation surface within a single cell (trilinear interpolation)

# 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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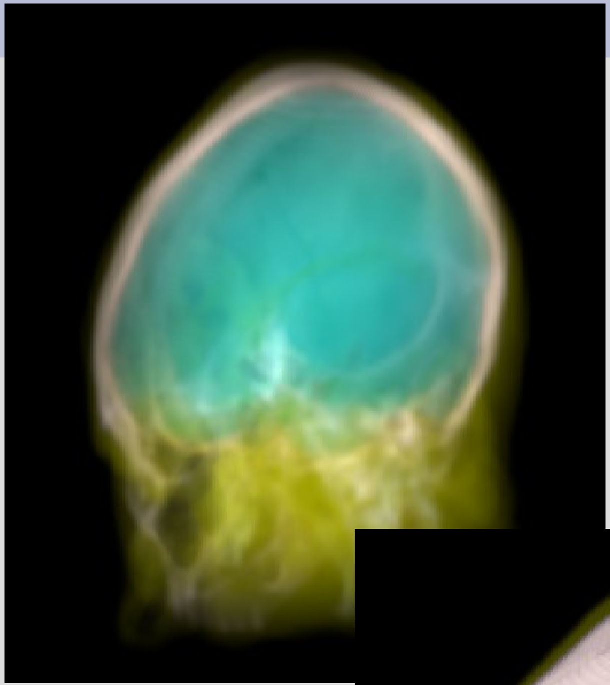

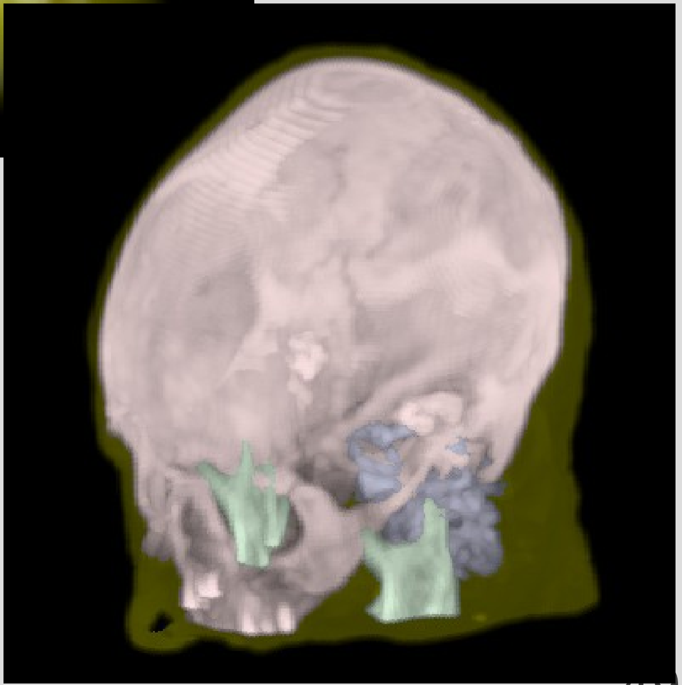

# Conclusion

- 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...)

# Thank you!

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