GPU-based Volume Rendering

Michal Červeňanský

Outline

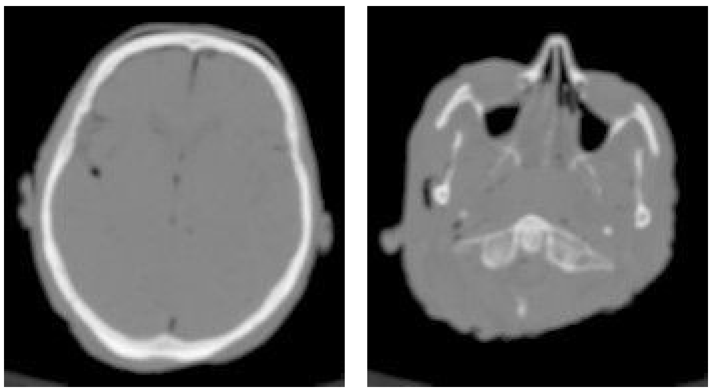
- Volume Data
- Volume Rendering
- GPU rendering
- Classification
- Speed-up techniques
- Other techniques

Volume Data

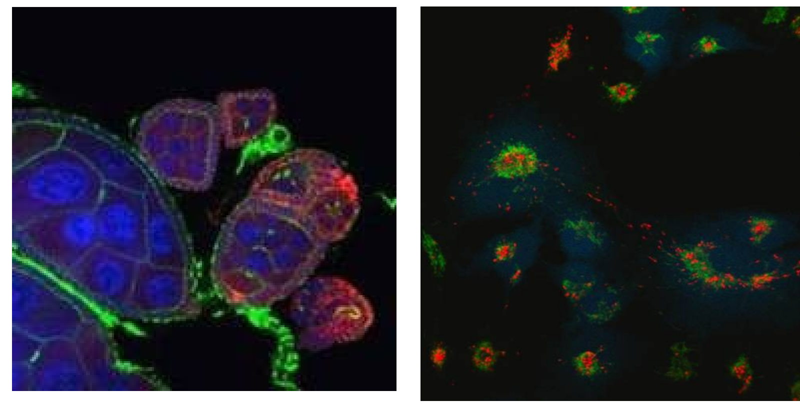
- Describe interior structures
- Liquids, gases, fire, natural phenomena
- Voxel – intensity, colour, …
- Measurement, simulations
- Medicine, geology, physics, …
- CT, MR, confocal microscopy
- 512x512x2000

Volume Data (2)

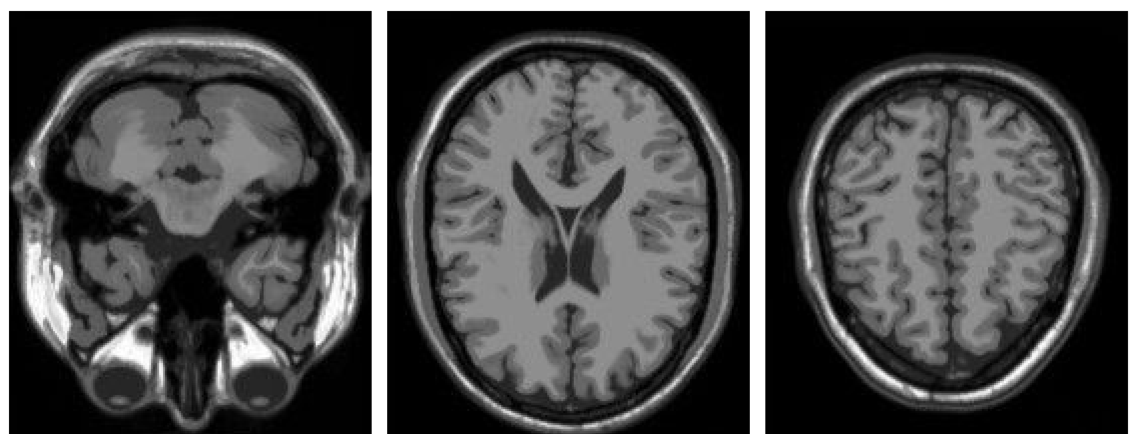
- CT dataset



Confocal microscopy

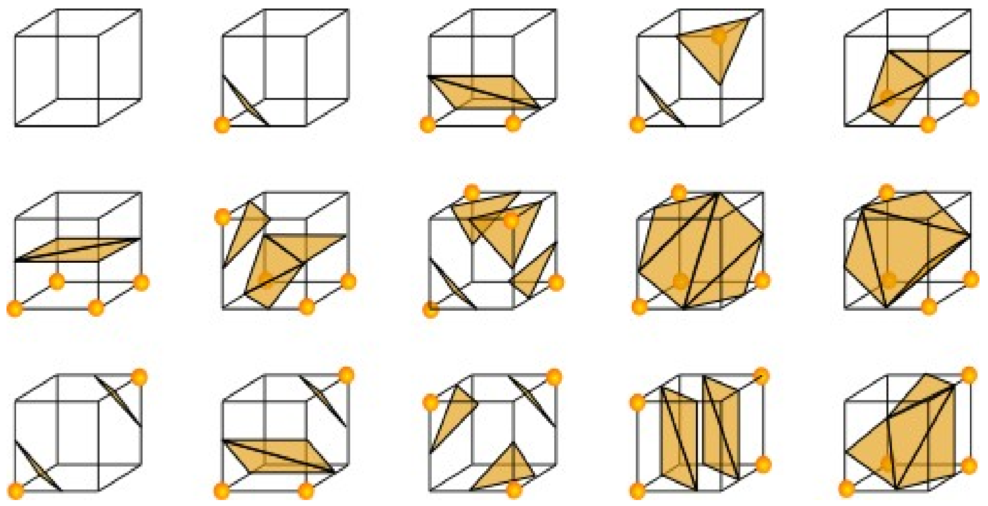


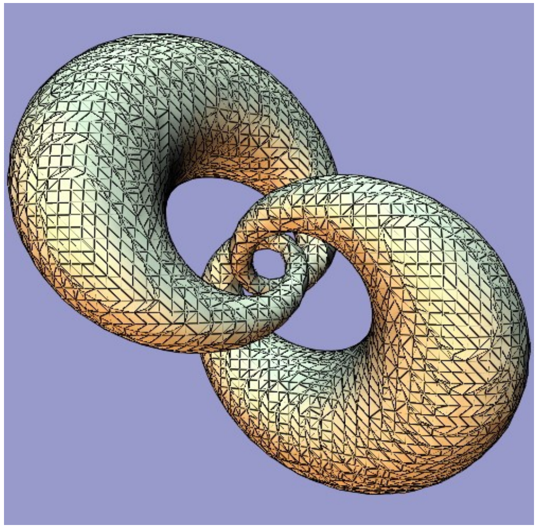
- MRI dataset



Volume Rendering

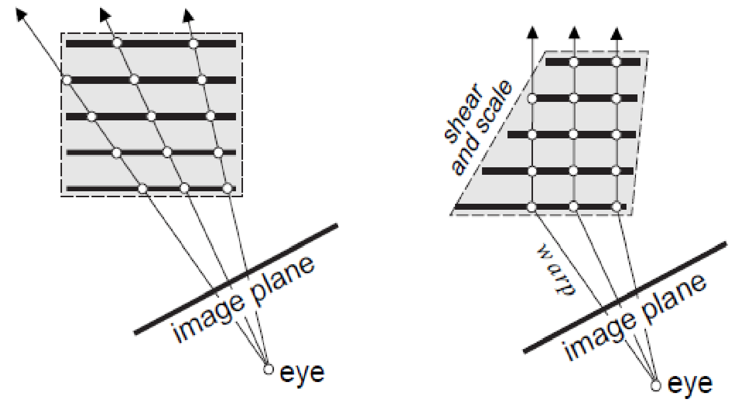
- Indirect methods – surface rendering
  - Contour detection
  - Isosurface extraction (marching cubes)

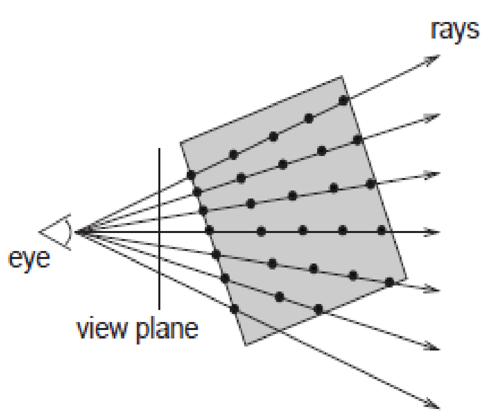


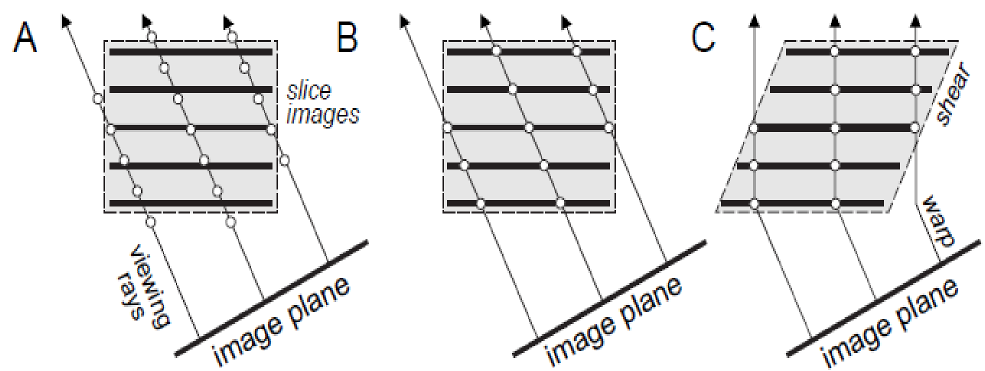


Volume Rendering (2)

- Direct methods
- Direct volume rendering
  - Object oriented methods (shear warp)
  - Image oriented methods (ray casting)



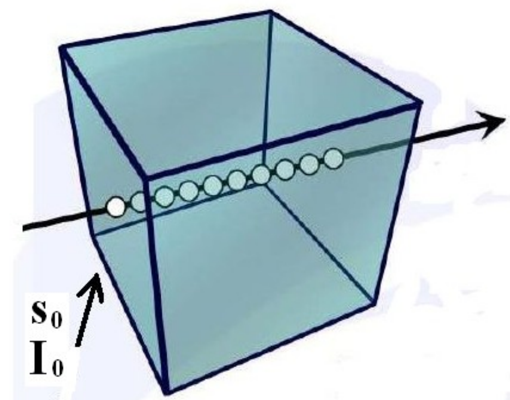




Volume rendering (3)

- Based on physical model
- Computational intensive
- Light ↔ environment = emission, absorption, (in-out)scatter
- Emission-absorption model
- Volume rendering integral

$$I(D) = I_0 e^{-\int_{s_0}^{D} \kappa(t)dt} + \int_{s_0}^{D} q(s) e^{-\int_{s}^{D} \kappa(t)dt} ds$$



- Absorption *κ(x)*, emission *q(x)*
- Numeric integration
- Iterative computation – composition

$$C_{dst} \leftarrow (1 - \alpha_{src})C_{dst} + C_{src}$$

$$C_{dst} \leftarrow C_{dst} + (1 - \alpha_{dst})C_{src}$$

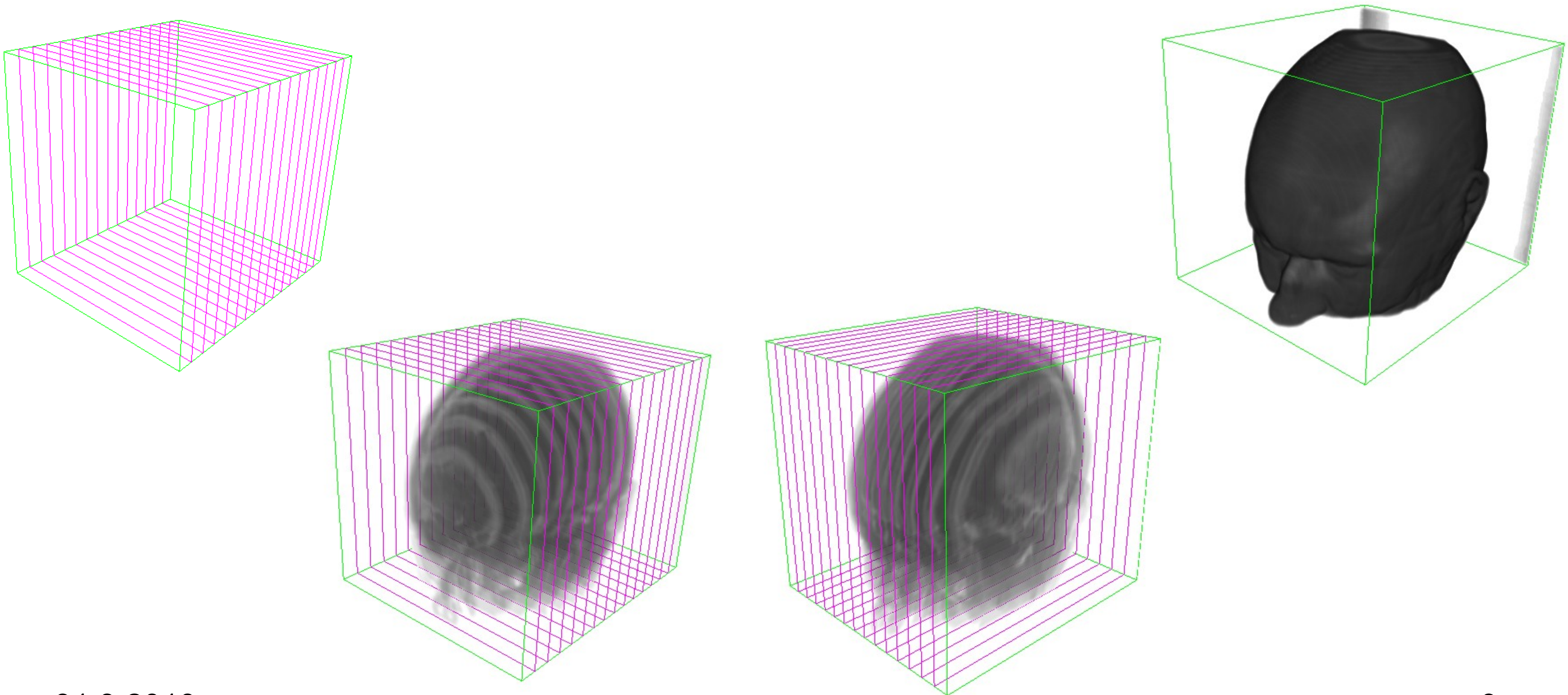
$$\alpha_{dst} \leftarrow \alpha_{dst} + (1 - \alpha_{dst})\,\alpha_{src}$$

GPU rendering

- 2D textures
- 3D textures
- Multi-textures
- Ray-casting
- Bricking
- Lighting
- Classification

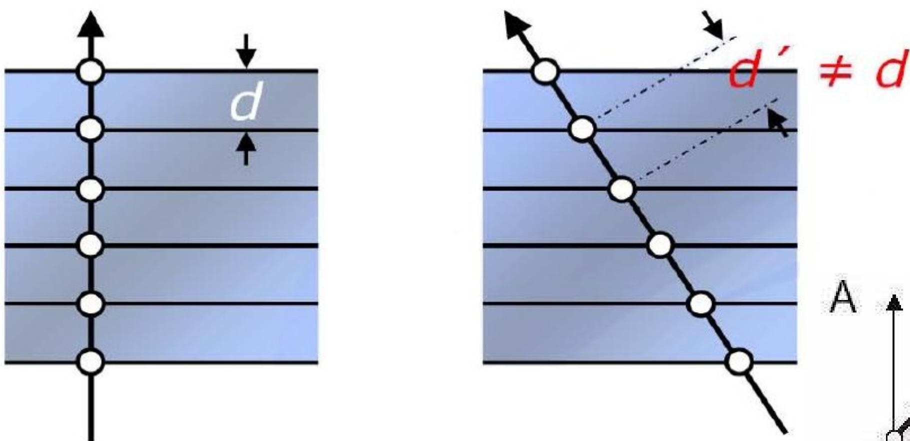
2D textures

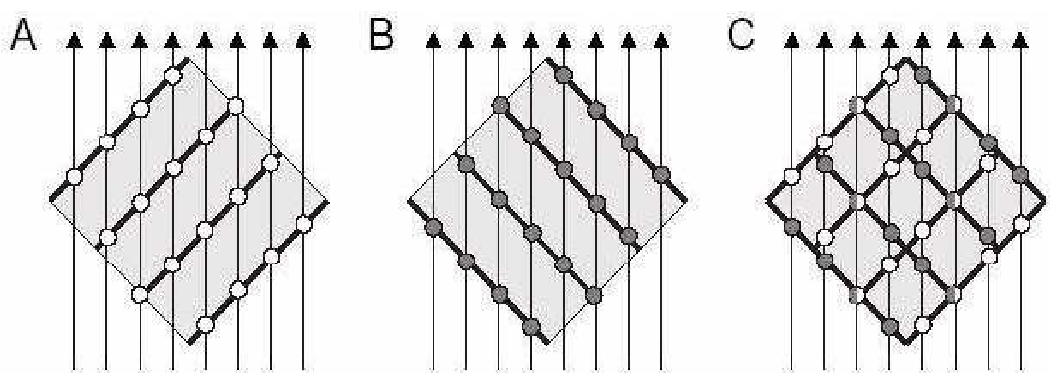
- Object aligned slices
- Polygonal primitives – CPU / GPU



2D textures (2)

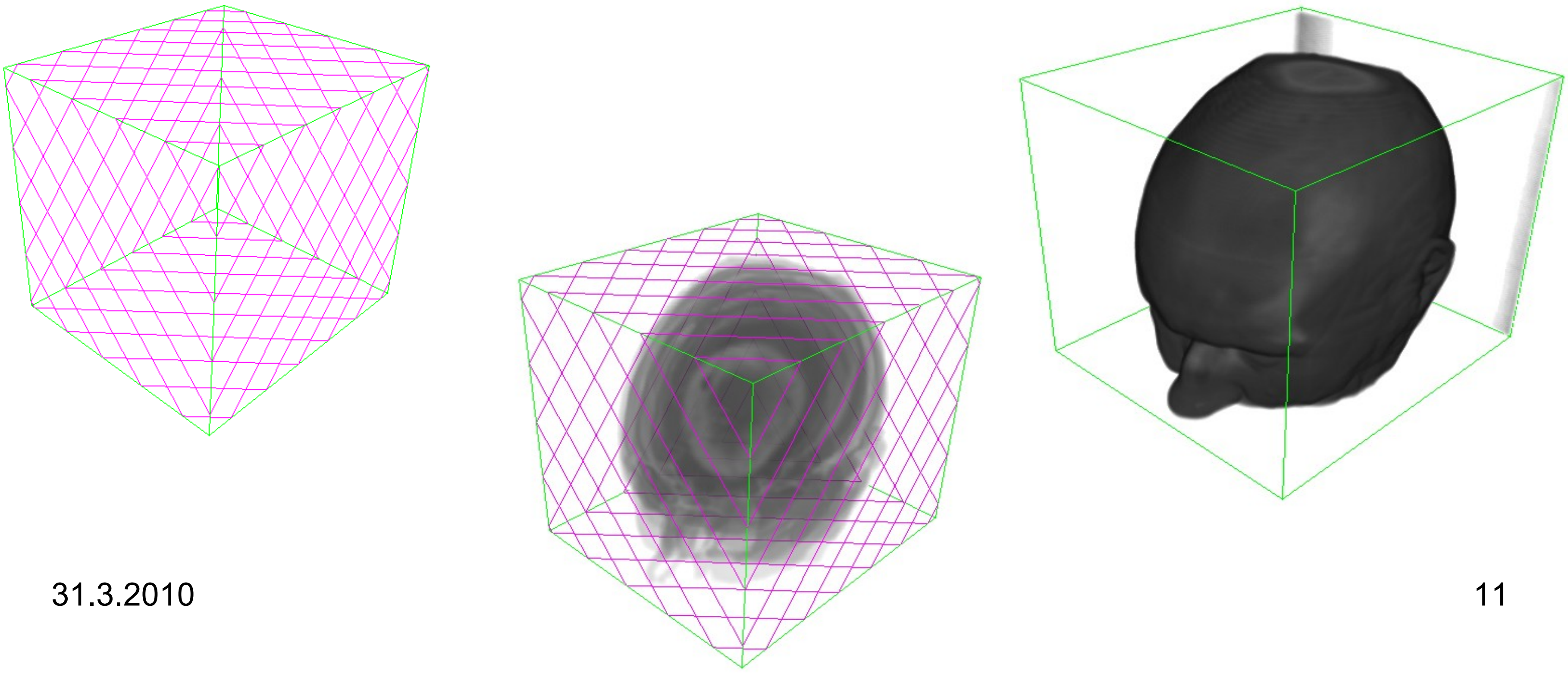
2D-Texture-Based Approach	
Pros	Cons
⊕ very high performance ⊕ high availability	⊖ high memory requirements ⊖ bilinear interpolation only ⊖ sampling artifacts ⊖ switching effects ⊖ inconsistent sampling rate





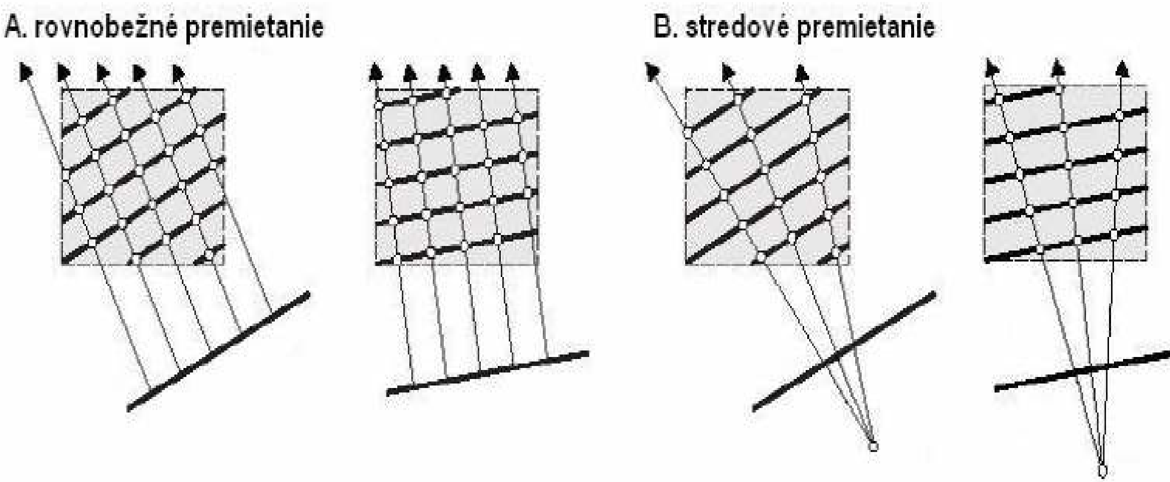
3D textures

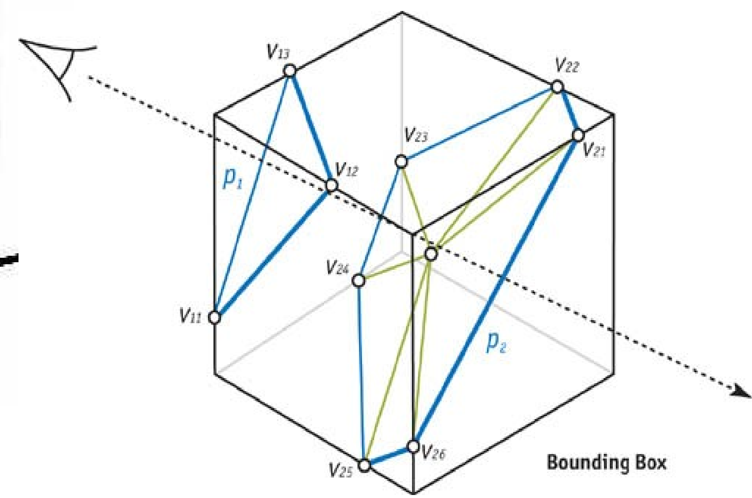
- View aligned slices
- Polygonal primitives – CPU / GPU



3D textures (2)

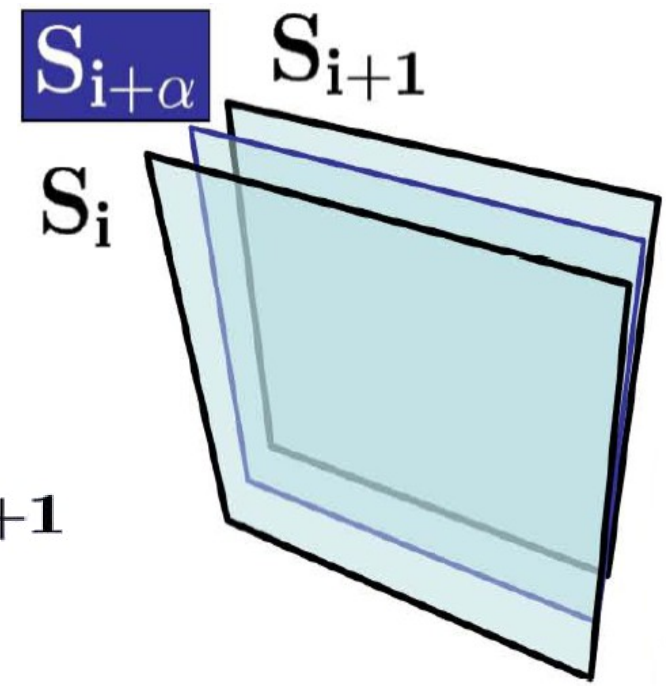
3D-Texture-Based Approach	
Pros	Cons
⊕ high performance ⊕ trilinear interpolation	⊖ availability still limited ⊖ inefficient memory management ⊖ inconsistent sampling rate for perspective projection





2D Multi-textures

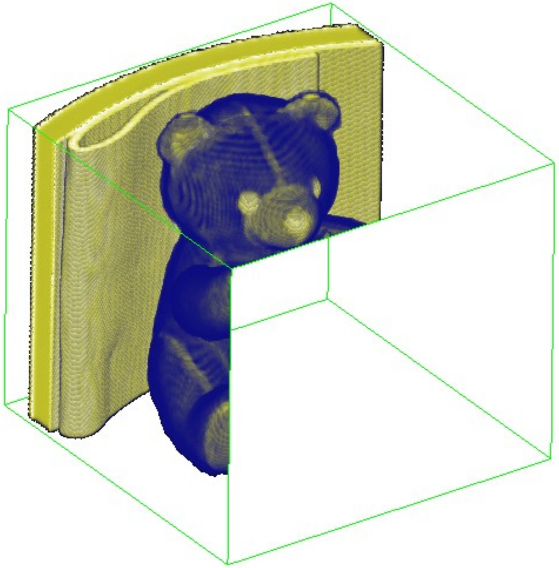
- Usage of multi-textures (2 textures per polygon) to implement trilinear interpolation
- Blending of two adjacent slices
- Trilinear interpolation
- Constant sampling rate

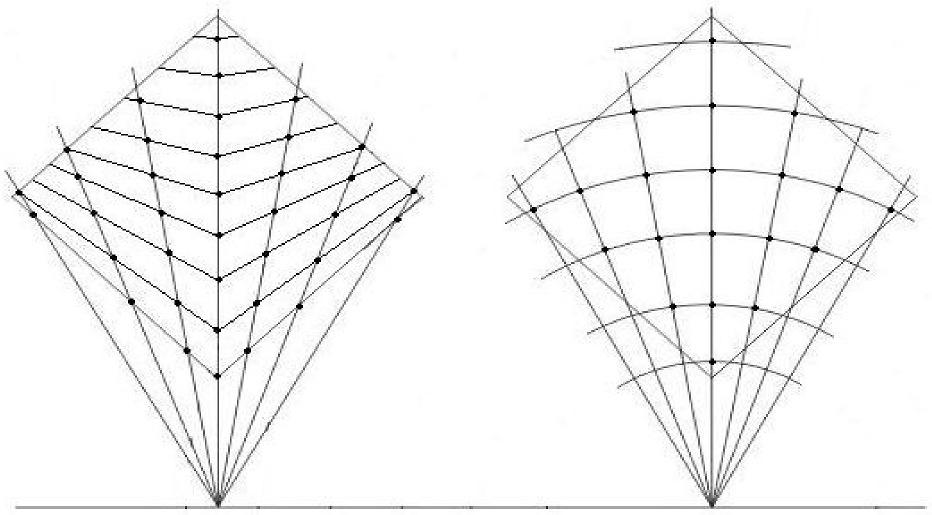


$$\boxed{\mathbf{S_{i+\alpha}}} = (\mathbf{1} - \alpha)\mathbf{S_i} + \alpha \cdot \mathbf{S_{i+1}}$$

Ray-casting

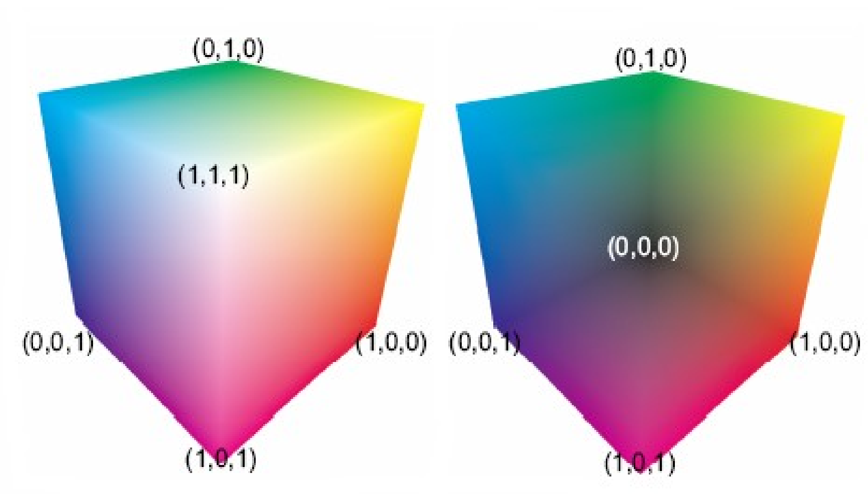
- BBox faces rendered
- Early ray termination
- Empty space skipping
- Adaptive sampling
- Non-uniform grids (tetrahedra)
- Front to back composition





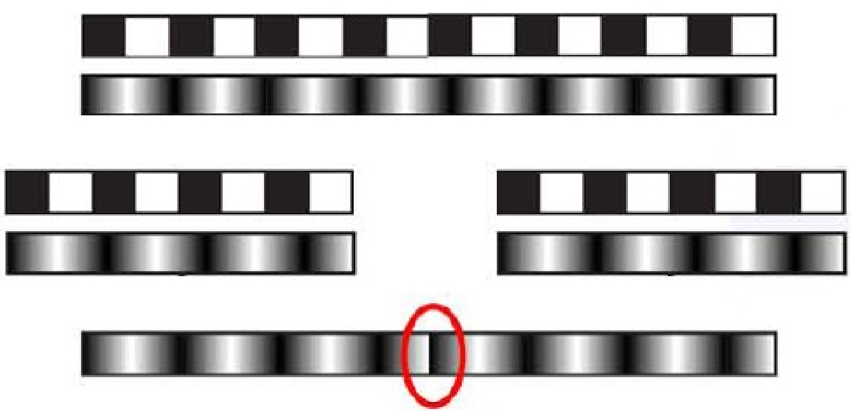
Ray-casting

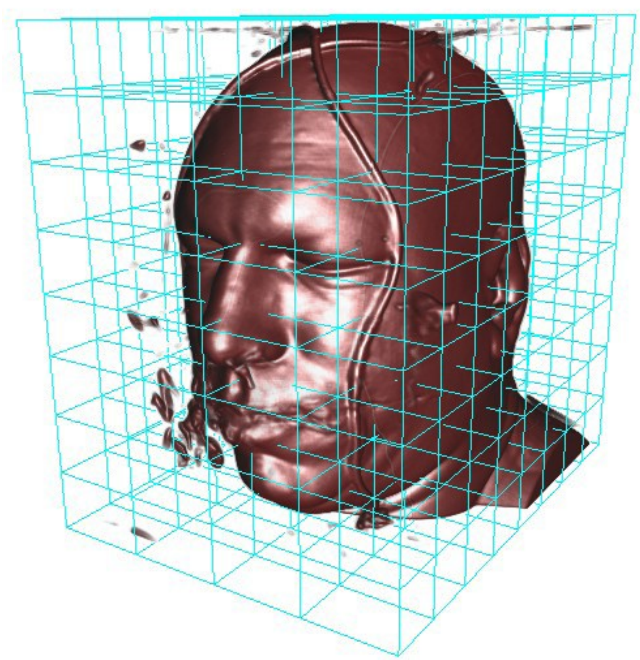
- Multi-pass rendering
  - Render front/back faces to the 2D textures
  - Pass1: determine entry point (front faces)
  - Pass2: determine ray direction (back faces)
  - outer loop: pass 3 to n
- Complete volume integral in one fragment prog.
- Shader Model 3.0 – Single-pass rendering



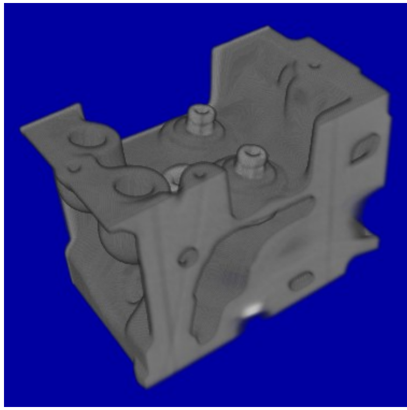
Bricking

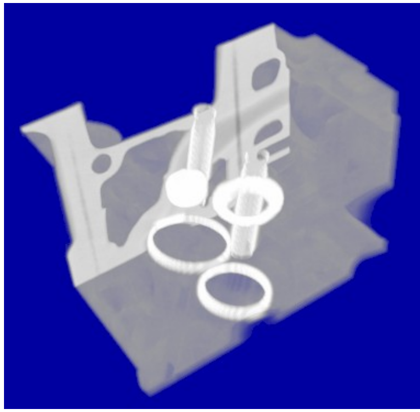
- The data set is split into smaller chunks (bricks)
- Problem: interpolation on boundaries – voxel(s) must be duplicated
- Problem: bus-bandwidth – more than one brick must fit into memory





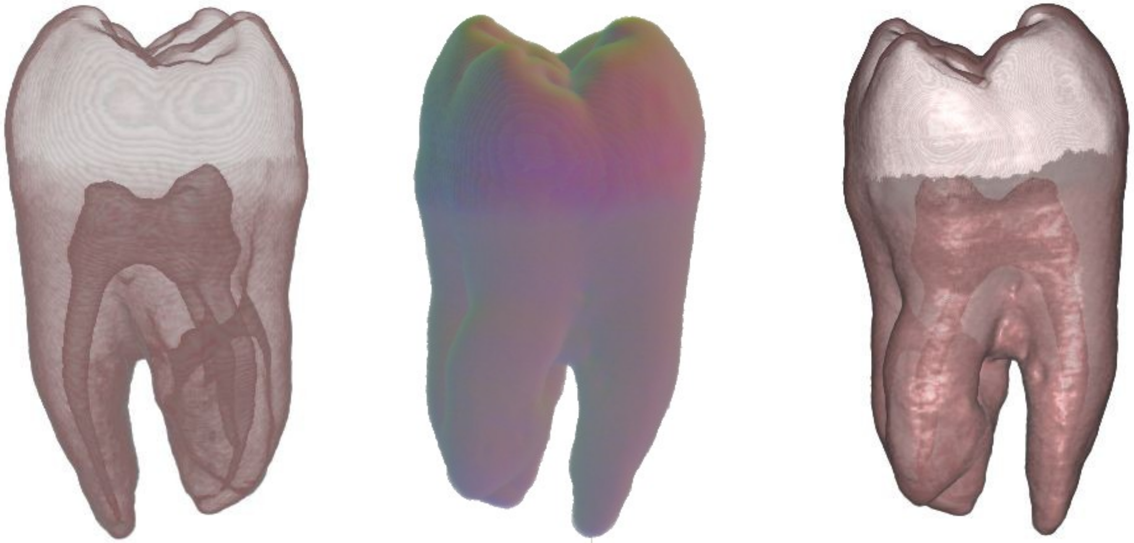
Compositing, Lighting





- Blending equations – add, maxip, minip
- C' = (Cs * As) + (Cd *(1-As))
- RGBA – colour, transparency

- Lighting model in fp (Phong)
- Gradient - on the fly / pre-processing



Classification

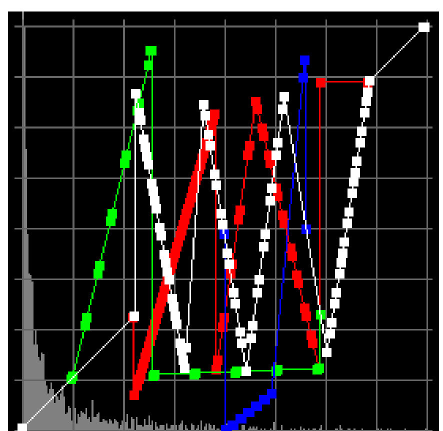
- Emission, absorption → colour values
- Transfer functions → modify colour, transp.
- Underline special properties in data
- One/Multi-dimensional (intensity, gradient, …)

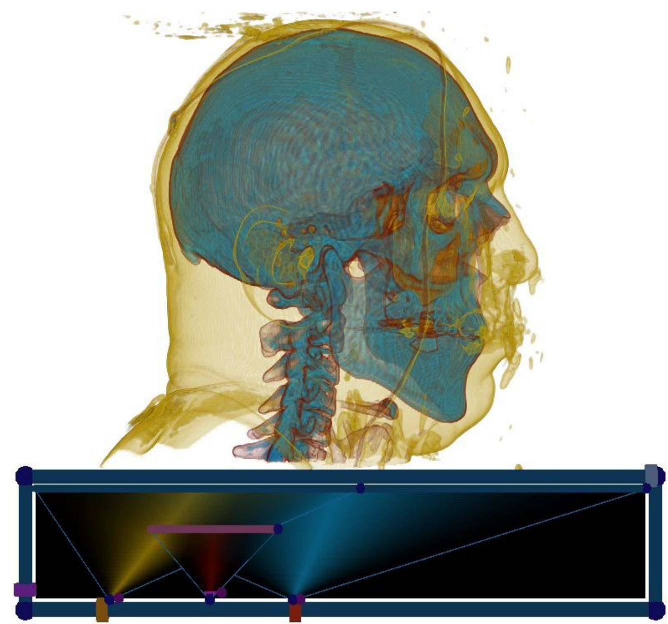
- Pre-classification → before interpolation
- Post-classification → after interpolation
- Pre-integration → after interpolation

- High frequencies → high sampling rate

Transfer Function

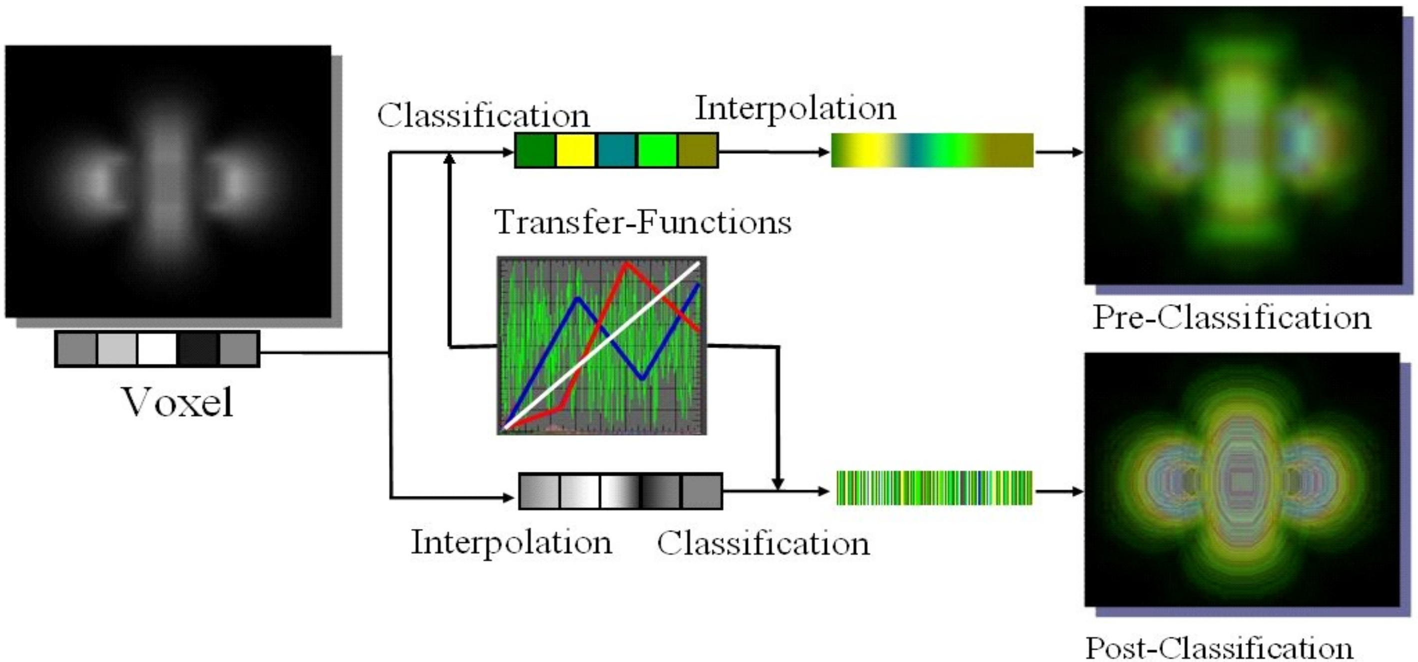
- Trial-error
- Data-centric (contour spectrum, iso-surfaces, curvature, boundary detection, LH histogram…)
- Image-centric (genetic alg., design galleries, …)
- Others (learning classifier, …)

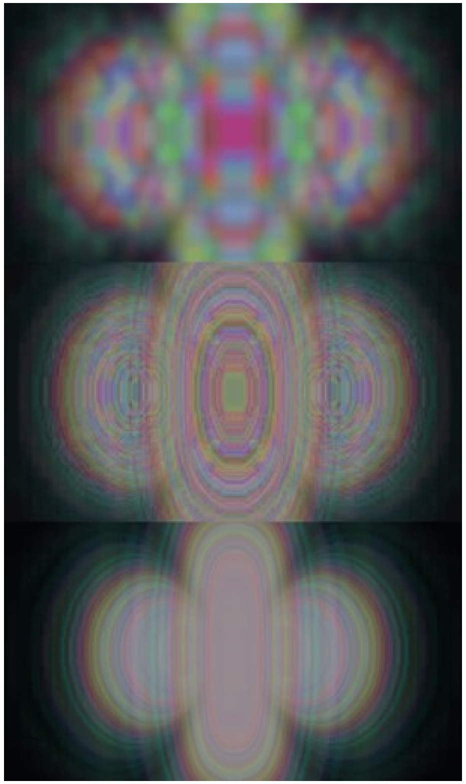




Classification (2)

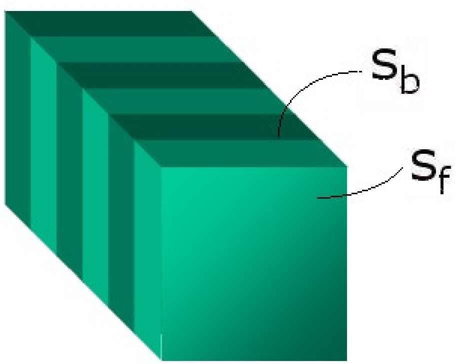
- Pre/Post classification
  - Look-up table → texture

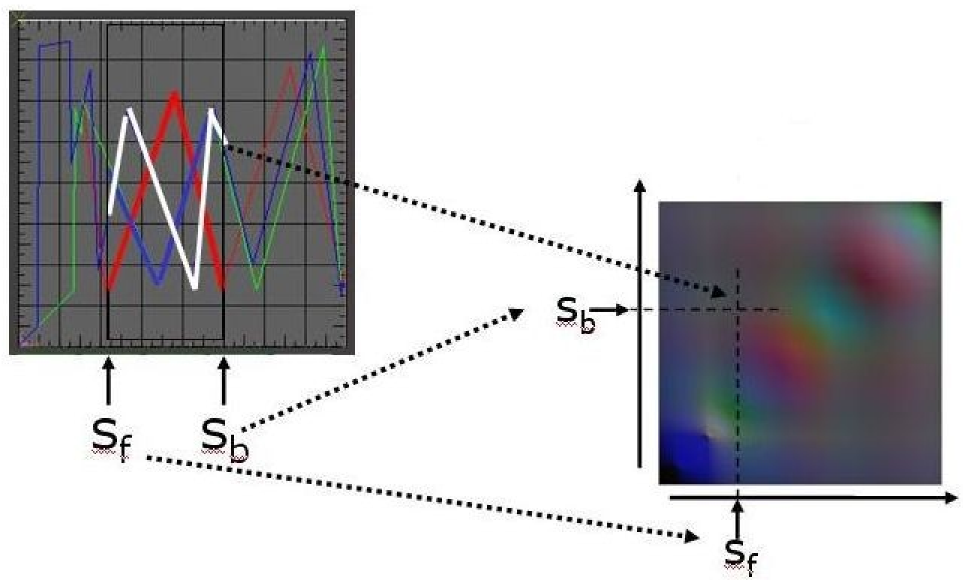




Classification – pre-integration

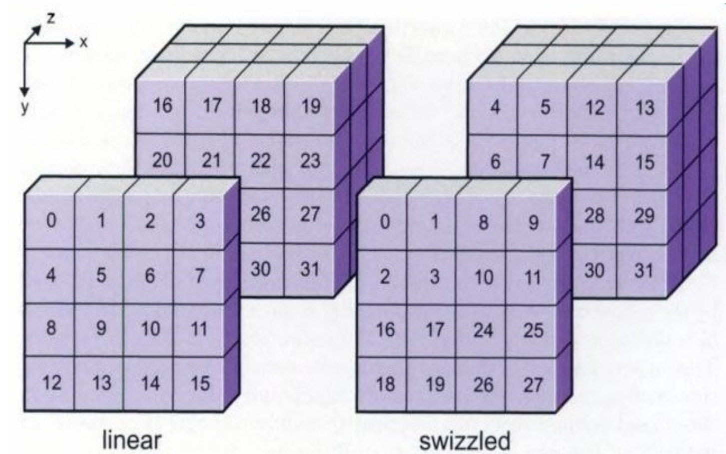
- Slab by slab rendering
- Pre integration of all possible combinations
- Lookup table

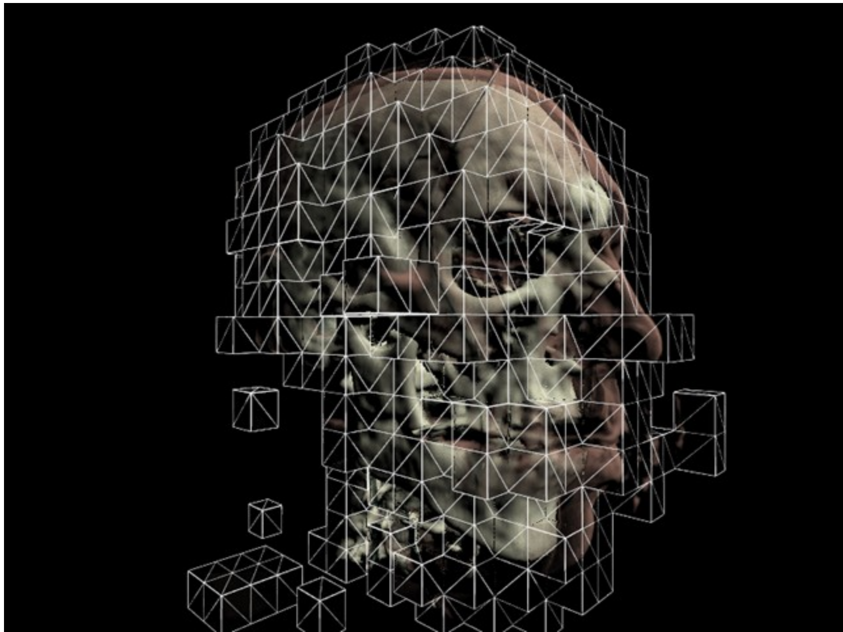




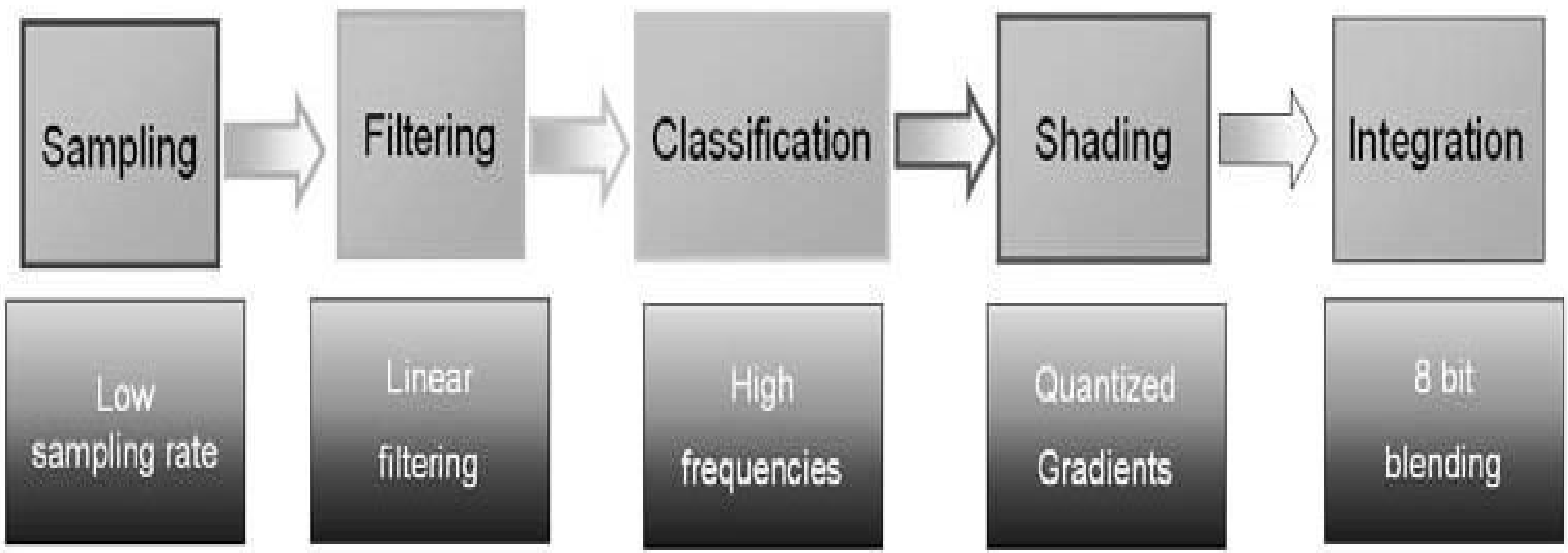
Speed-up techniques

- Memory management (swizzling, mipmapping)
- Asynchronous data upload
- Bi / Tri-linear filtering
- Empty-space leaping
- Occlusion culling
- Early ray termination
- Image downscaling



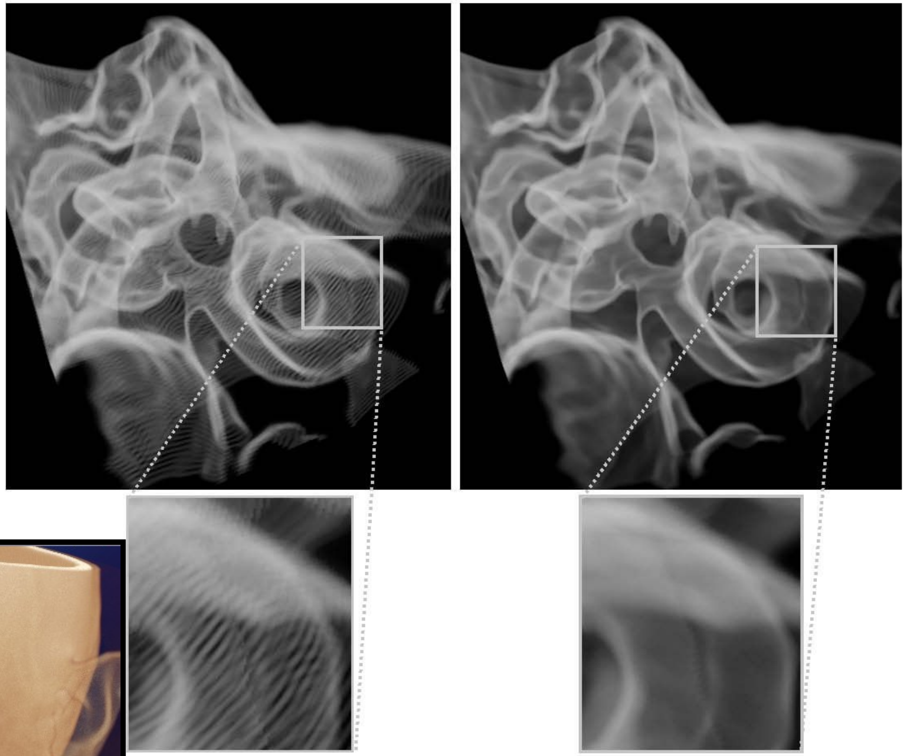


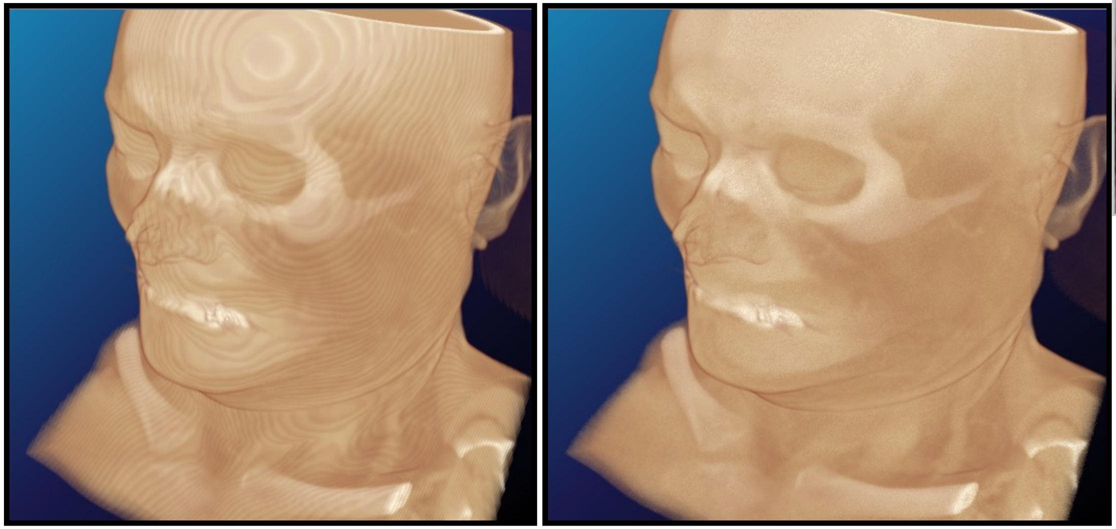
Improving Quality



Sampling Artefacts

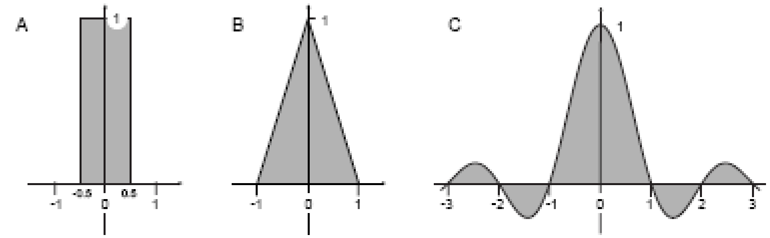
- Adaptive sampling
- Opacity correction
- Stochastic jittering

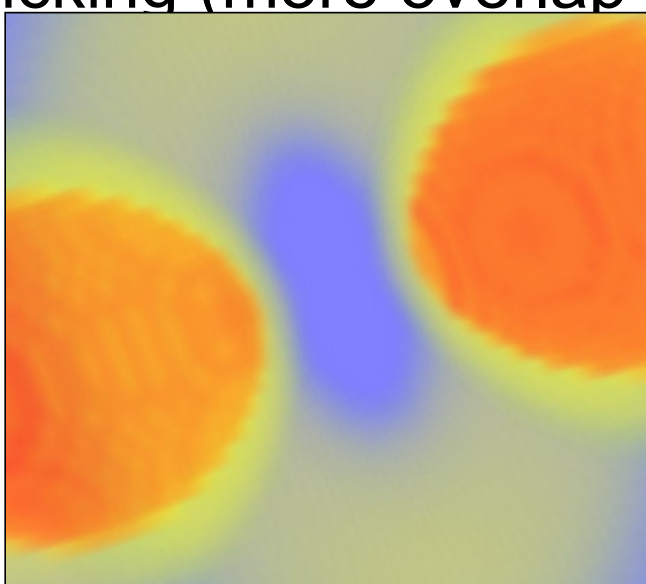


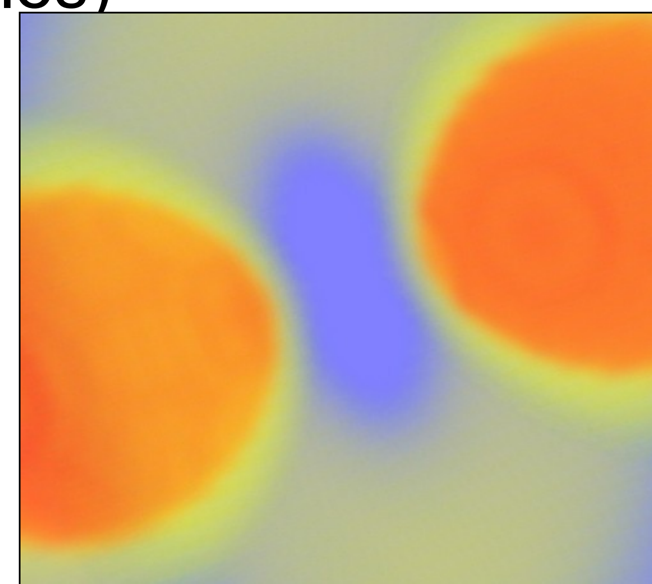


Filtering Artefacts

- Discrete data → continuous signal
  - Internal filtering precision
  - Linear filter
- HQ filtering
  - Convolution (bspline, gauss, sinc, …)
  - Bricking (more overlap samples)

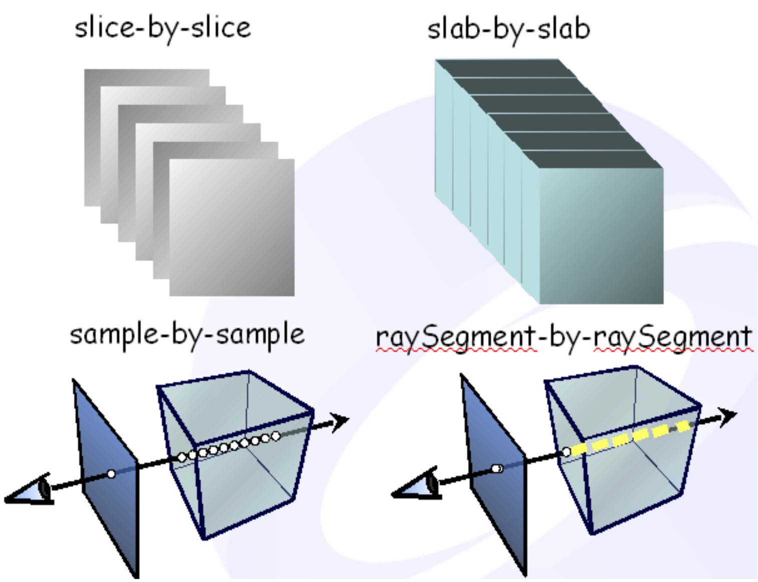


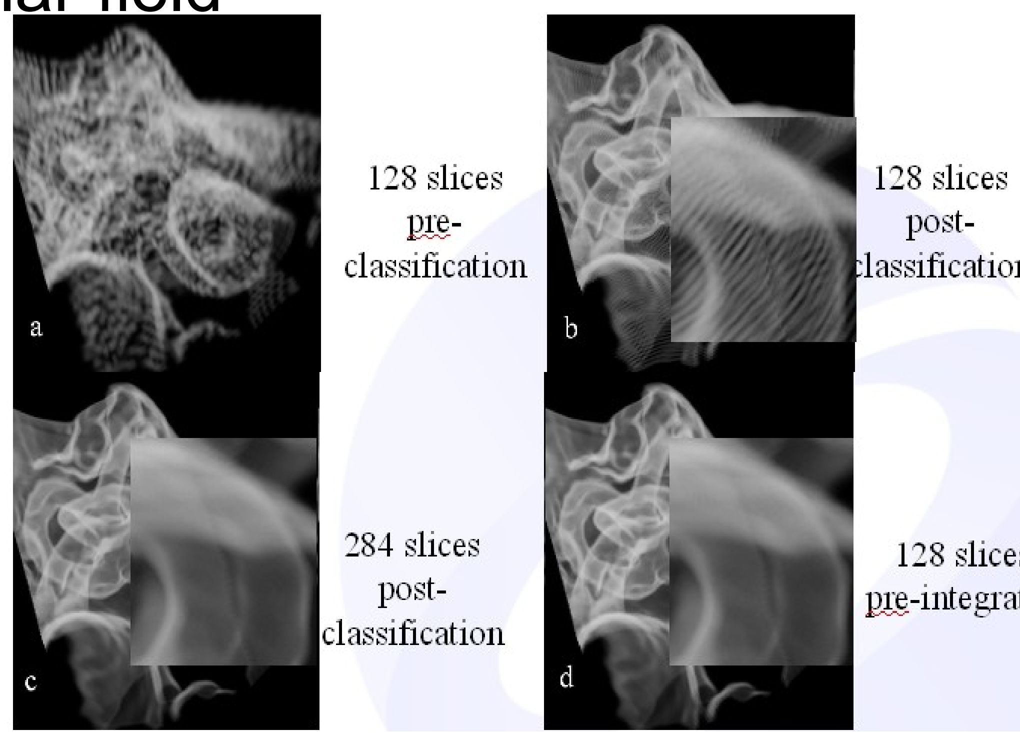




Classification Artefacts

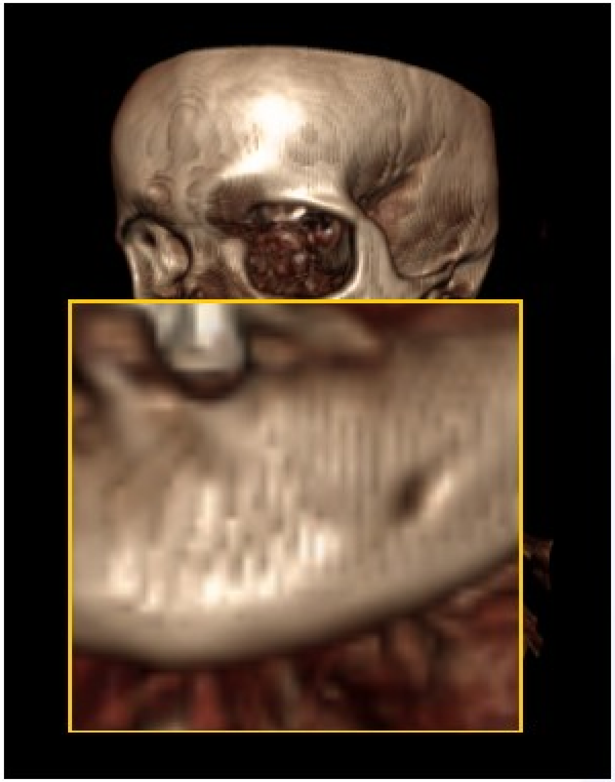
- High freq. in the TF → increase sampling rate
- Pre-integrated classification
  - Pre-integration for TF
  - Integration for the scalar field
  - Still not „correct“





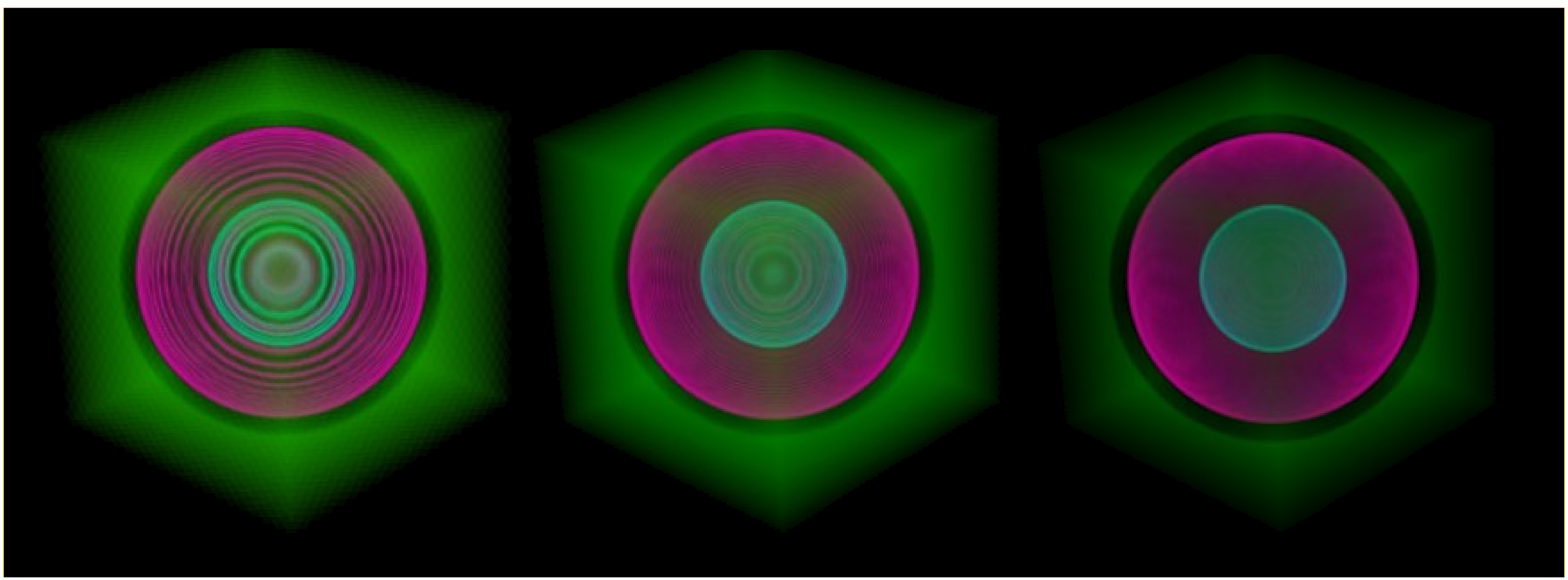
Shading Artefacts

- Limited gradient precision
  - Pre-computation (16/32bit, Sobel operator)
  - On the fly



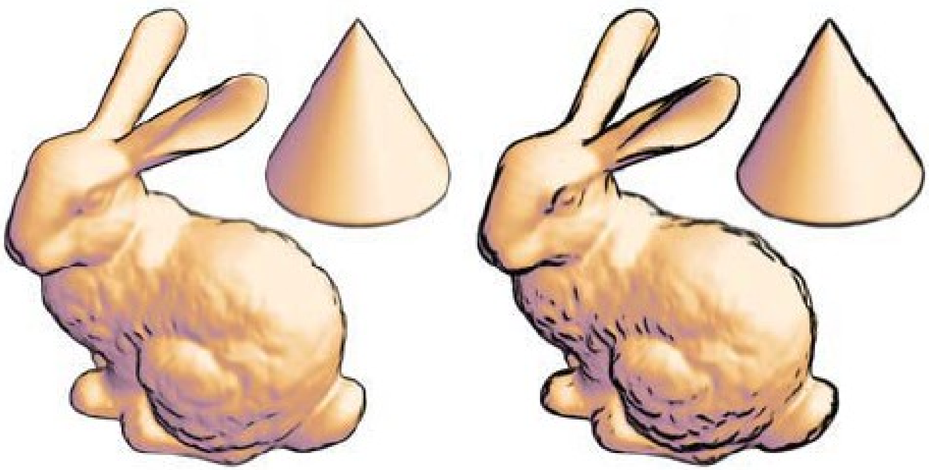
Blending Artefacts

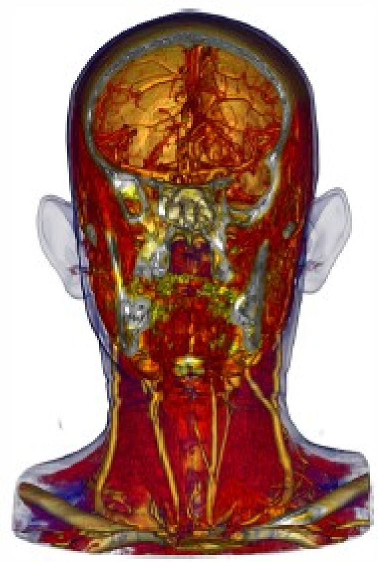
- Limited precision (hw support)
  - Own blending
  - Ping-pong scheme

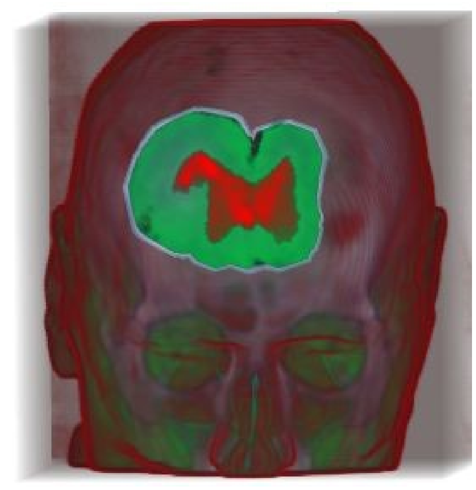


Other techniques

- Focus & context
- Non photorealistic rendering



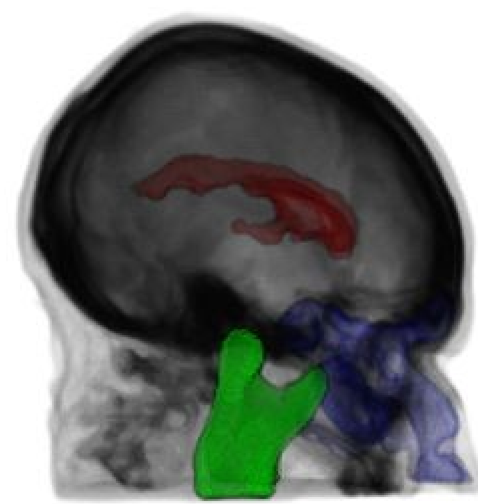




Other techniques (2)

- Segmentation
- Global lightning

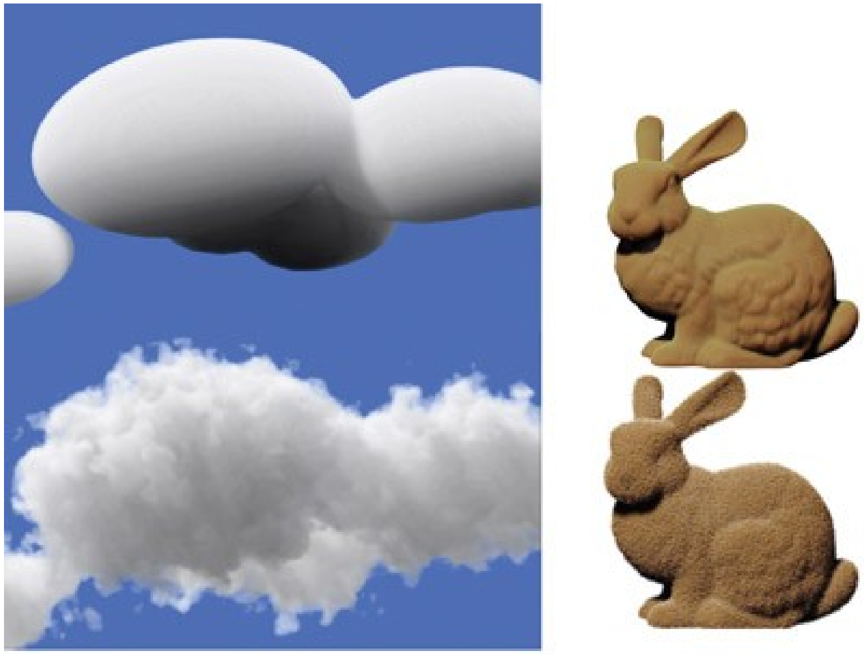
(a) (b)



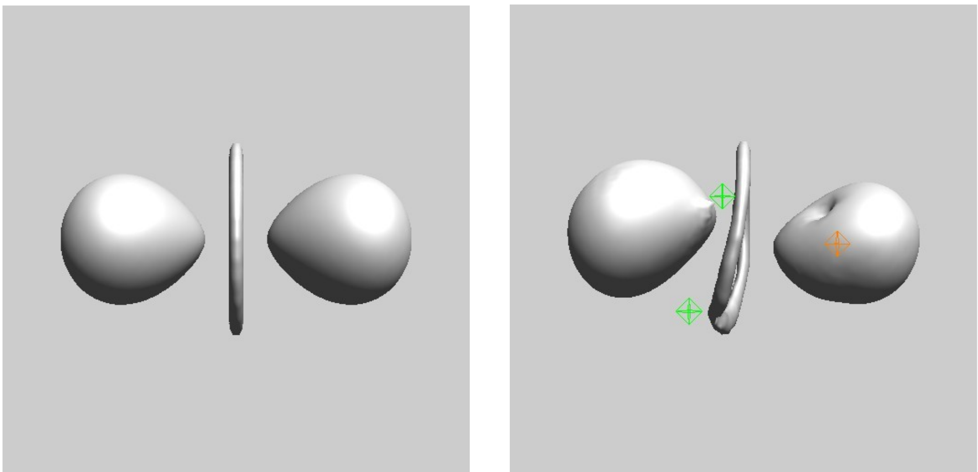
Other techniques (3)

- Effects
- Deformations

(a) (b)



(a) (b)



- www.cse.cuhk.edu.hk/%7Ettwong/papers/asc/asc.html
- http://www.wikipedia.org/
- http://developer.nvidia.com
- http://medvis.vrvis.at
- http://graphicsrunner.blogspot.com/2009/02/volume-rendering-201-op

- Real-time volume graphics
  - http://delivery.acm.org/10.1145/1110000/1103929/cs28.pdf?key1=1

Thank you for your attention.