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sense and simplicity

3D Visualization @ Philips Healthcare, interventional X-Ray

Danny Ruijters

26 Juni 2012

About me

- Danny Ruijters
- Engineering degree: RWTH Aachen University of Technology
- MSc: ParisTech
- PhD: KU Leuven, TU/eindhoven
- With Philips since 2001
- Currently Principal Scientist @ interventional X-Ray innovation

Introduction

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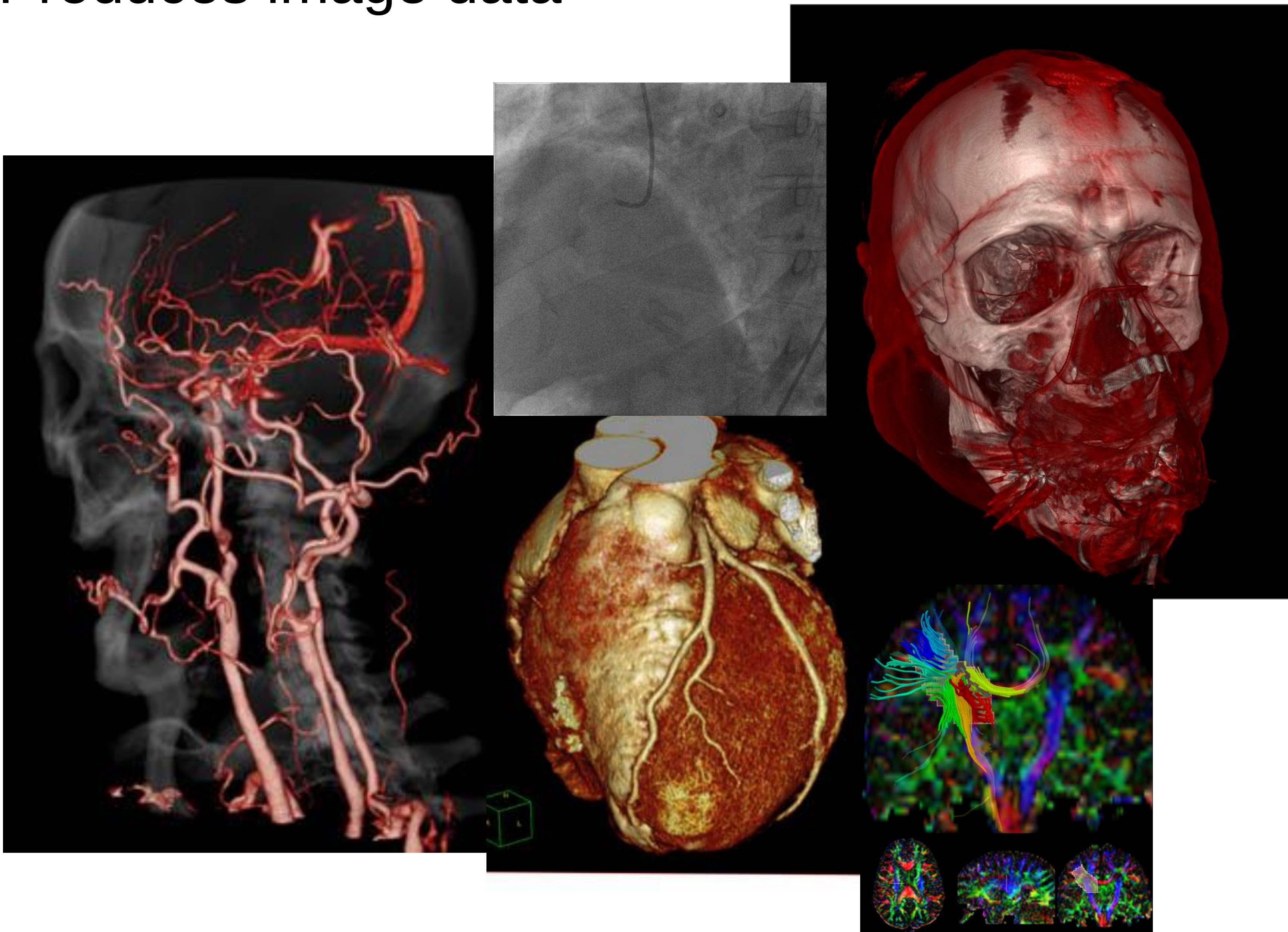
Philips Healthcare

Produces image data



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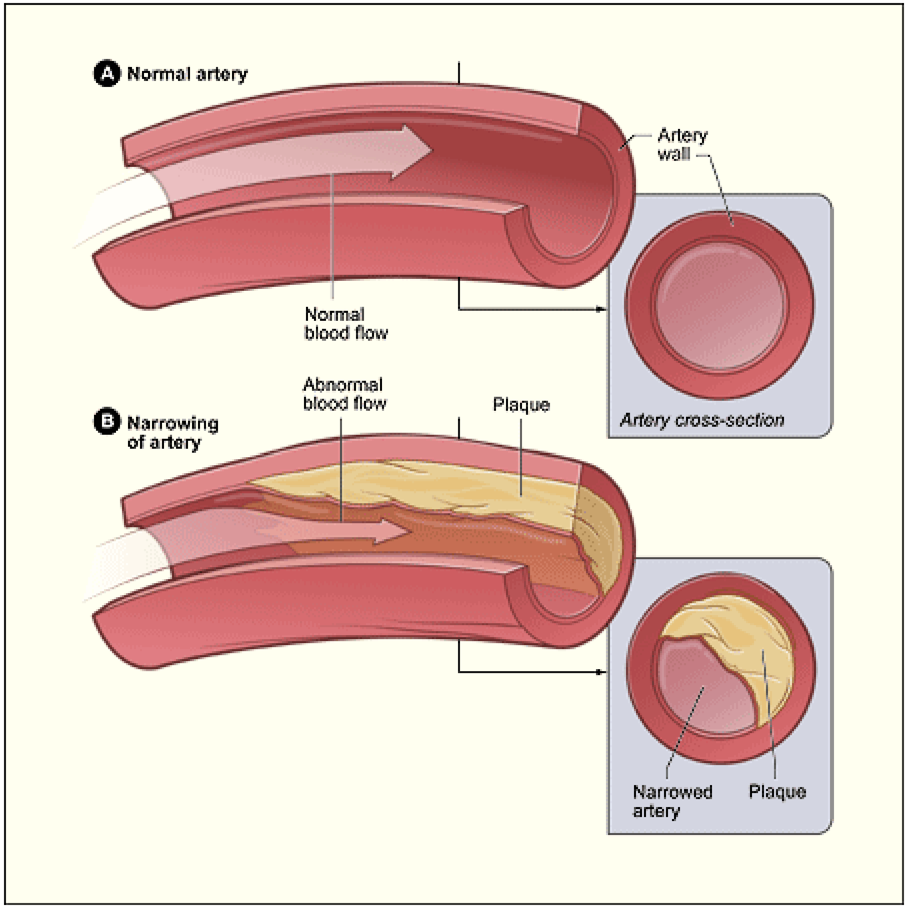
What is Coronary Artery Disease?

- Coronary Artery Disease (CAD) is a condition in which plaque builds up inside the coronary arteries. These arteries supply the heart muscle with oxygen-rich blood.
- Plaque is made up of fat, cholesterol, calcium, and other substances found in the blood. When plaque builds up in the arteries, the condition is called atherosclerosis.



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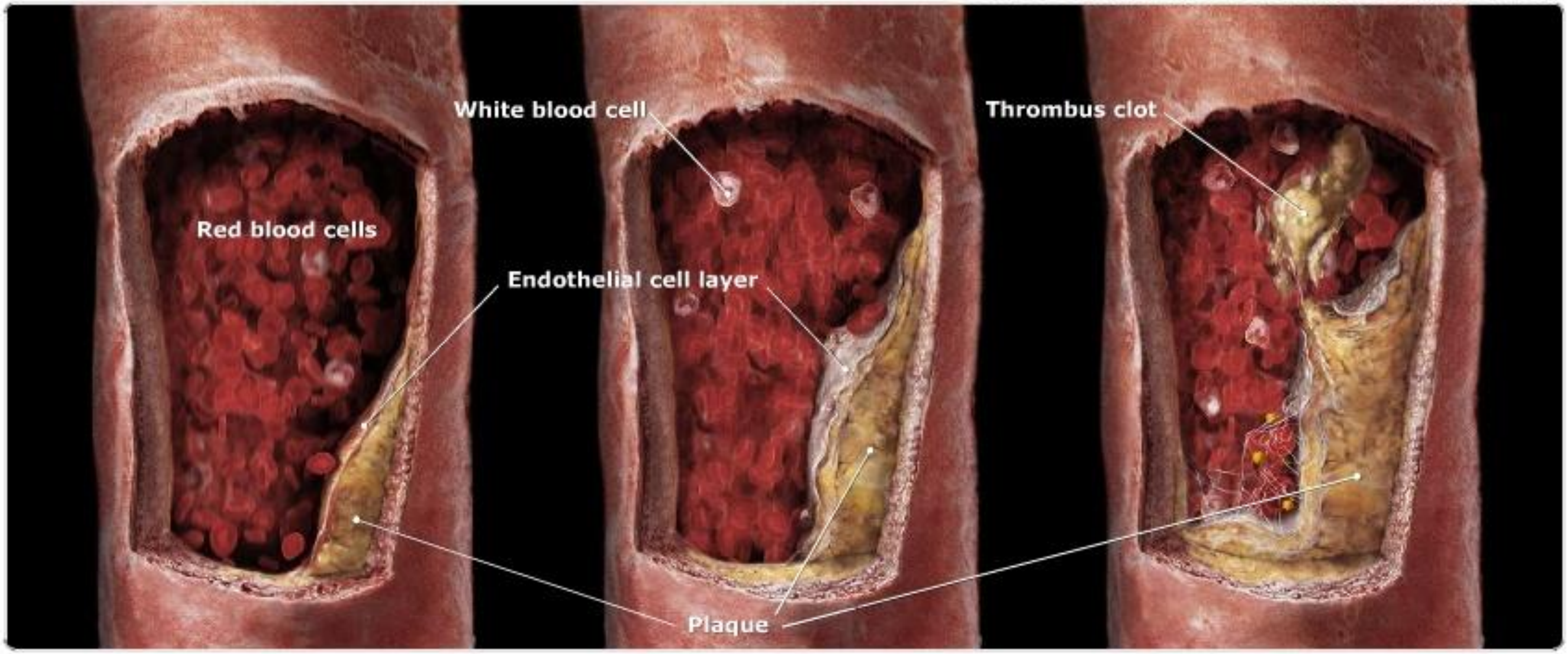
Buildup of plaque

Plaque buildup and clot development in an artery



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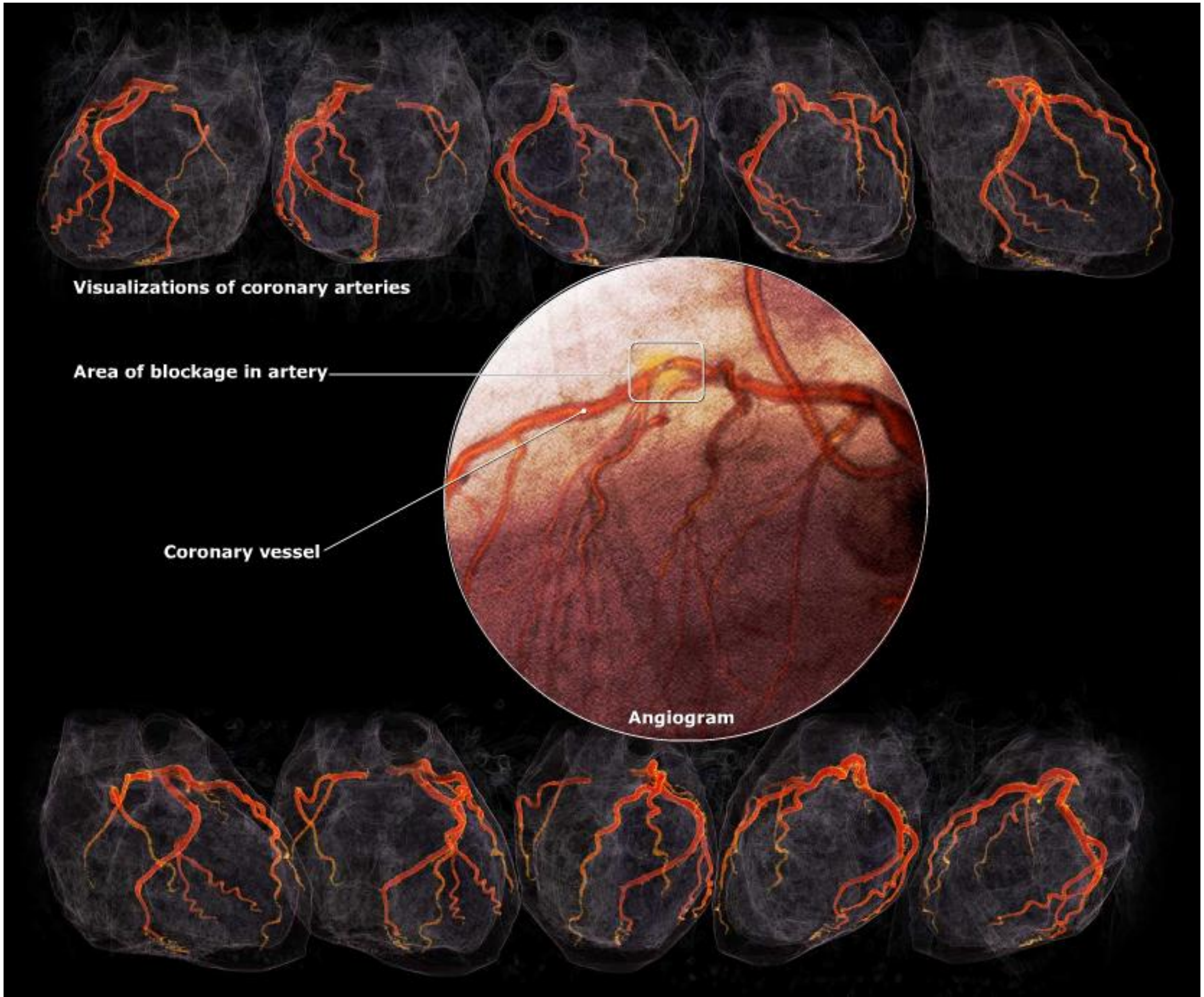
Stenosis of coronary arteries



Visualization

- Volume Rendering
- Fast Volume Rendering
- Fused Visualization

Volume Rendering @ Philips

- Own implementation, no VTK etc
- C++
- OpenGL
- Platform independent

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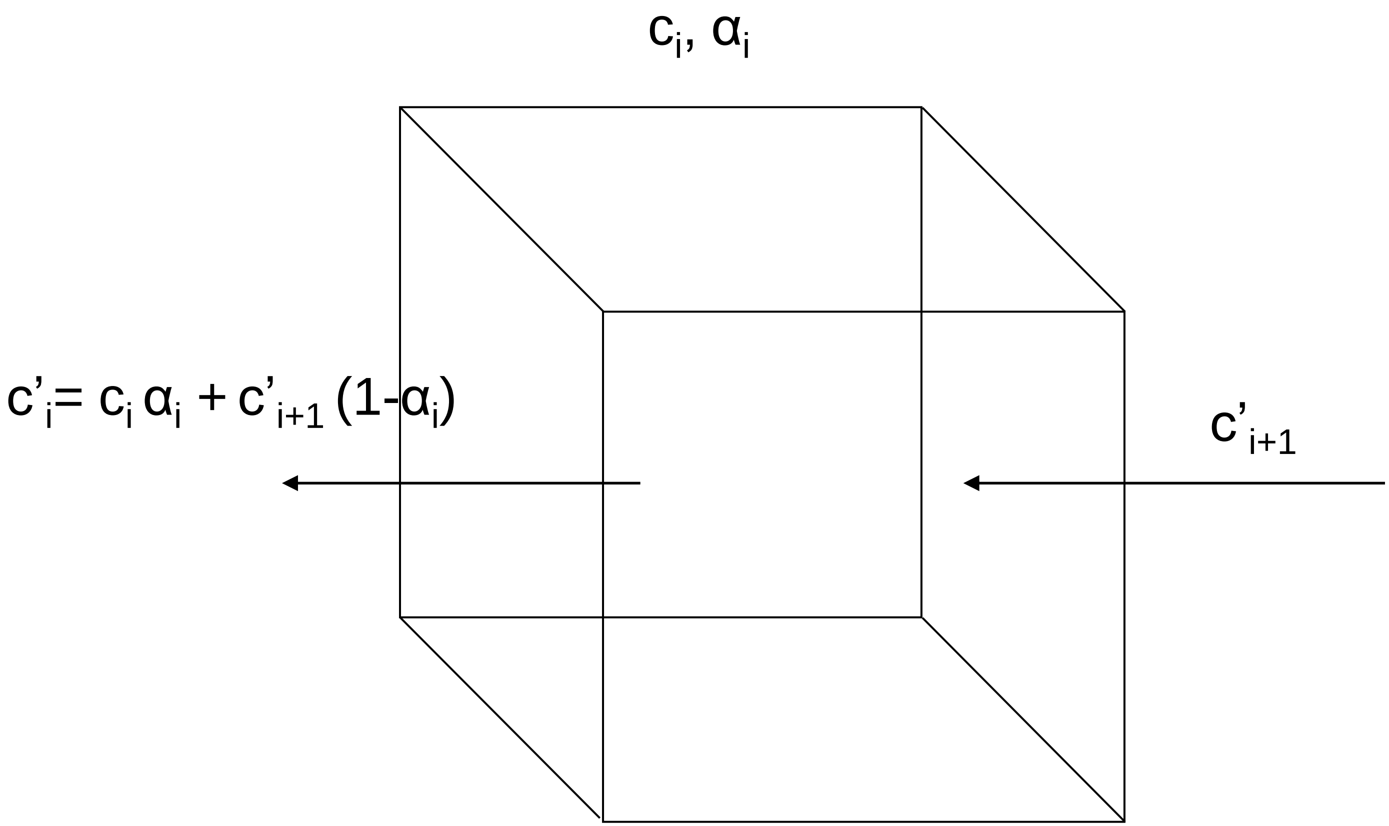
Volume rendering: infinitelly small element



Row of infinitelly small elements

$$c'_0 = c_0\,\alpha_0 + c'_1\,(1-\alpha_0)$$

$$c'_1 = c_1\,\alpha_1 + c'_2\,(1-\alpha_1)$$

$$c'_0 = c_0\,\alpha_0 + c'_1\,(1-\alpha_0)$$

$$= c_0\,\alpha_0 + (c_1\,\alpha_1 + c'_2\,(1-\alpha_1))(1-\alpha_0)$$

$$= c_0\,\alpha_0 + c_1\,\alpha_1(1-\alpha_0) + c'_2\,(1-\alpha_0)(1-\alpha_1)$$

$$= \Sigma\,(c_n\,\alpha_n\,\Pi(1-\alpha_m))$$

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$$\sum_{0}^{inf} (c_n \alpha_n \prod_{0}^{n-1}(1-\alpha_m))$$

Color contribution per element: $color_n = c_n \alpha_n$

Transparency per element: $\alpha_n = 1 - e^{-\alpha'}$

$$\prod(1-\alpha_m) = \prod e^{-\alpha'} = e^{-\Sigma\alpha'}$$

$$\sum_{0}^{inf} (c_n \alpha_n \prod_{0}^{n-1}(1-\alpha_m)) = \sum_{0}^{inf} (color_n \cdot e^{-\Sigma\alpha'})\ {}_{0}^{n-1}$$

$$\downarrow$$

$$\int_0^D color(\vec{x}(\lambda)) \cdot e^{-\int_0^{\lambda} alpha(\vec{x}(\lambda'))d\lambda'} d\lambda$$

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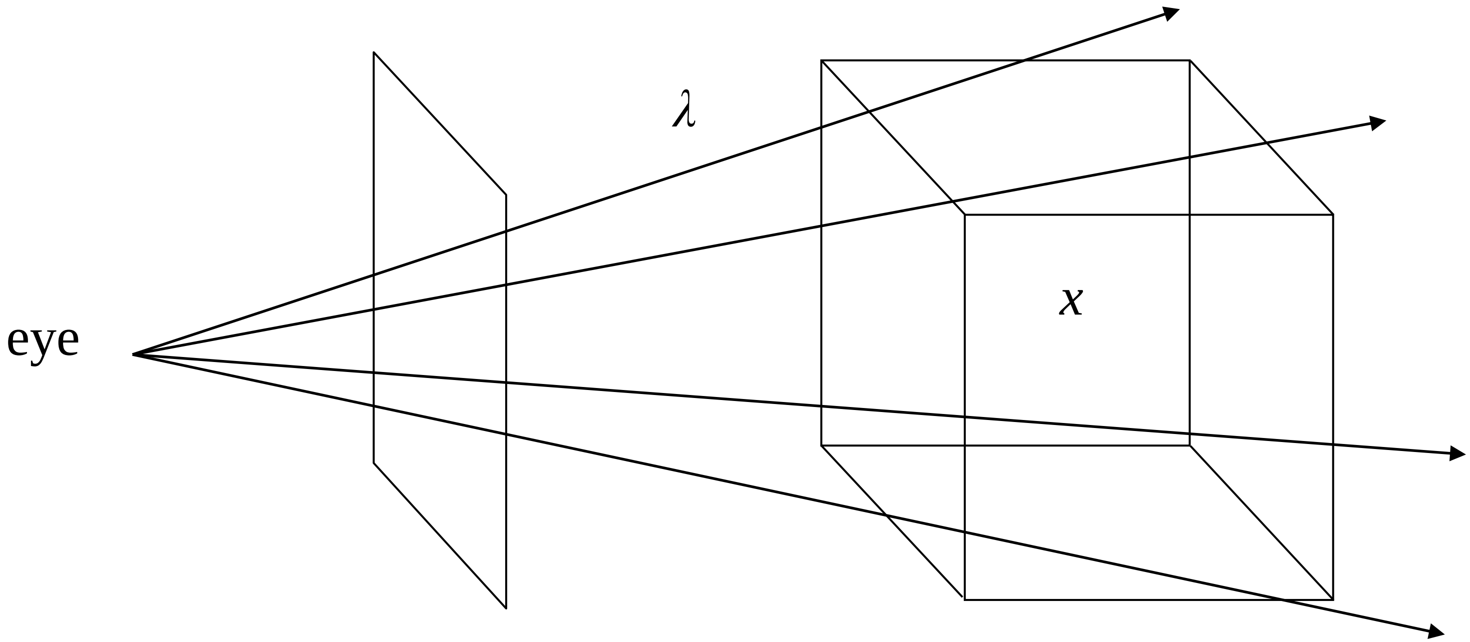

$$\int_0^D color(\vec{x}(\lambda)) \cdot e^{-\int_0^{\lambda} alpha(\vec{x}(\lambda'))d\lambda'} d\lambda$$

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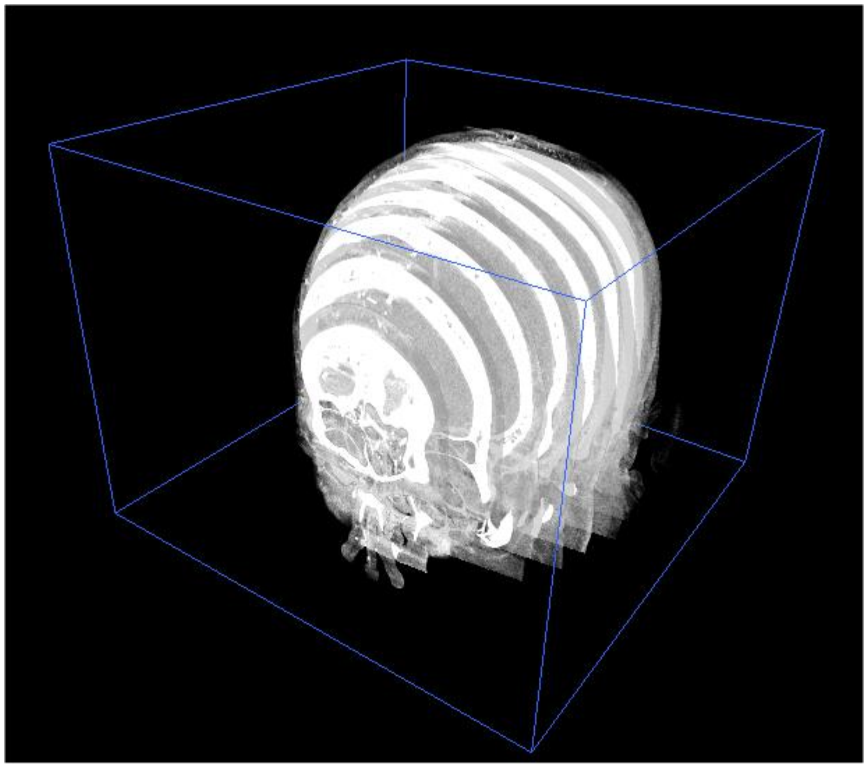
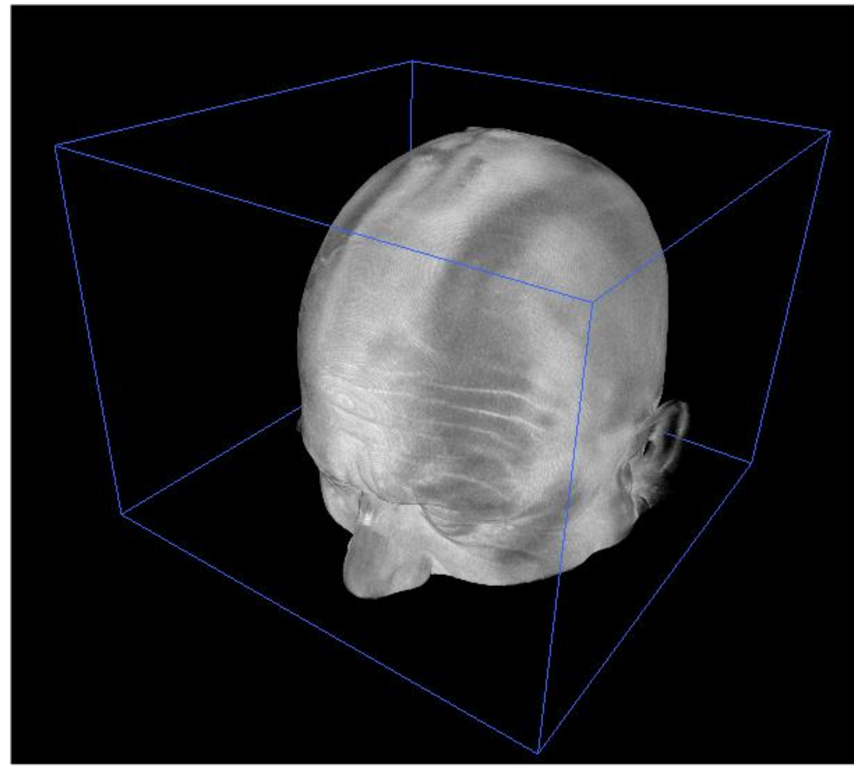
GPU Volume Rendering

$$i = \sum_{n=0}^{N} \left(\alpha_n \, c_n \cdot \prod_{n'=0}^{n} (1 - \alpha_{n'}) \right)$$





Engel and Ertl: “Interactive high-quality volume rendering with flexible consumer graphics hardware,” Eurographics 2002

Visualization

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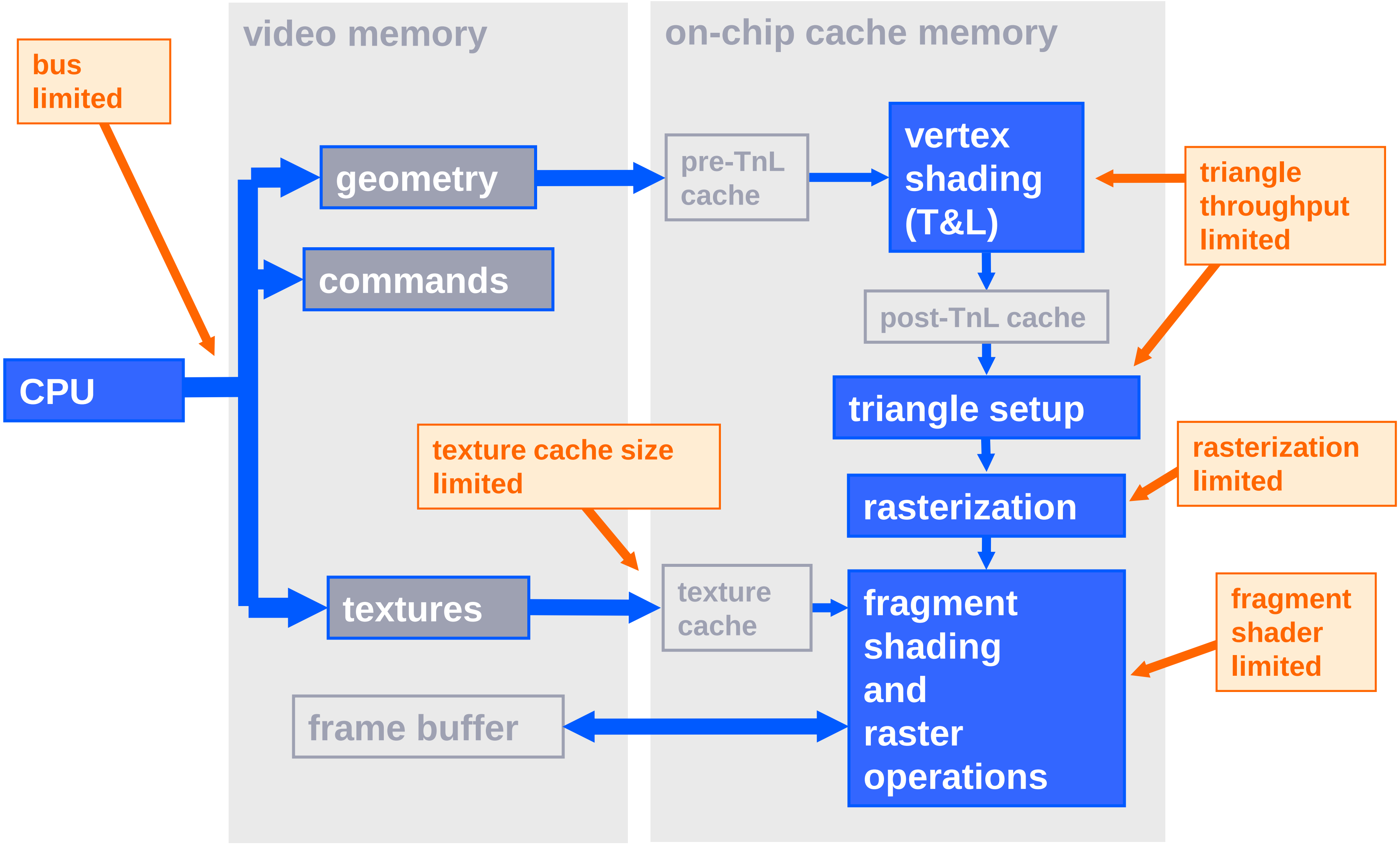
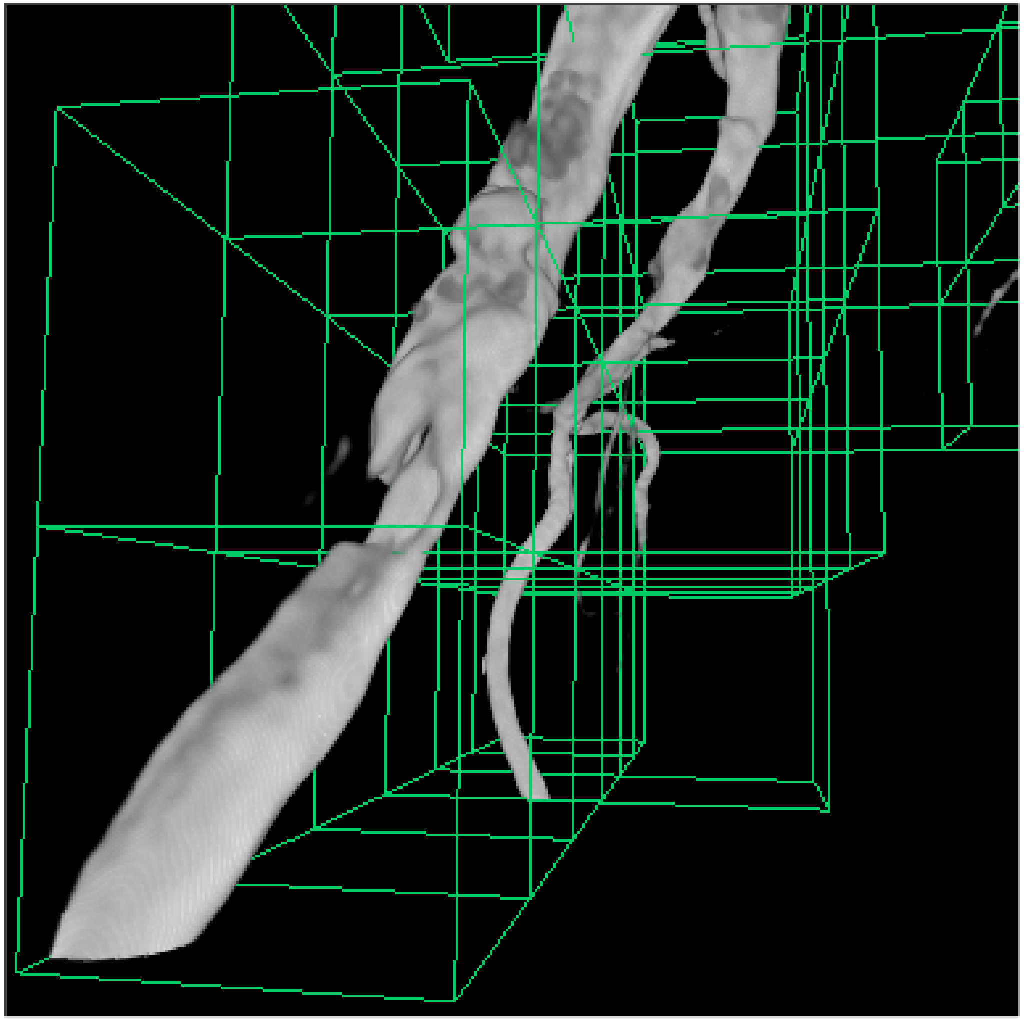
GPU Bottlenecks



Bricking



- Raw data
- One texture per brick
- Skip “empty” bricks
- Overlap: 0/1/2 voxels
- Memory overhead

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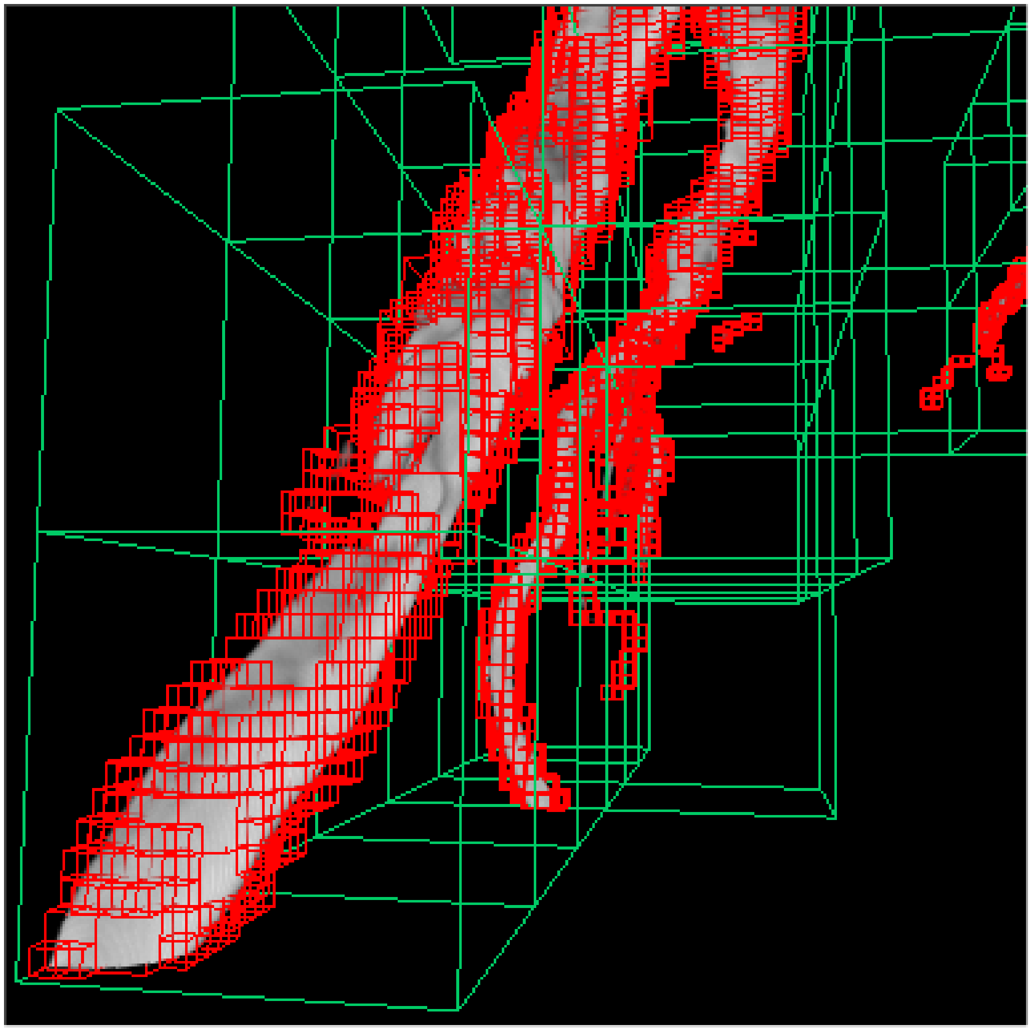
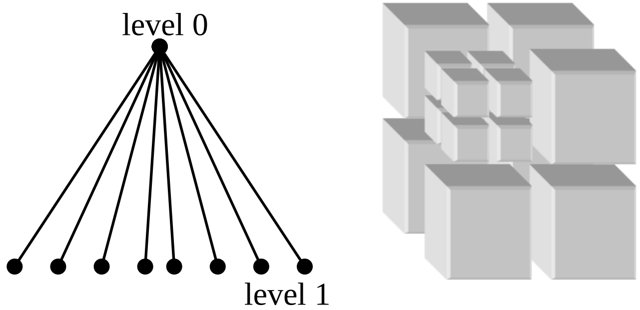
Octree

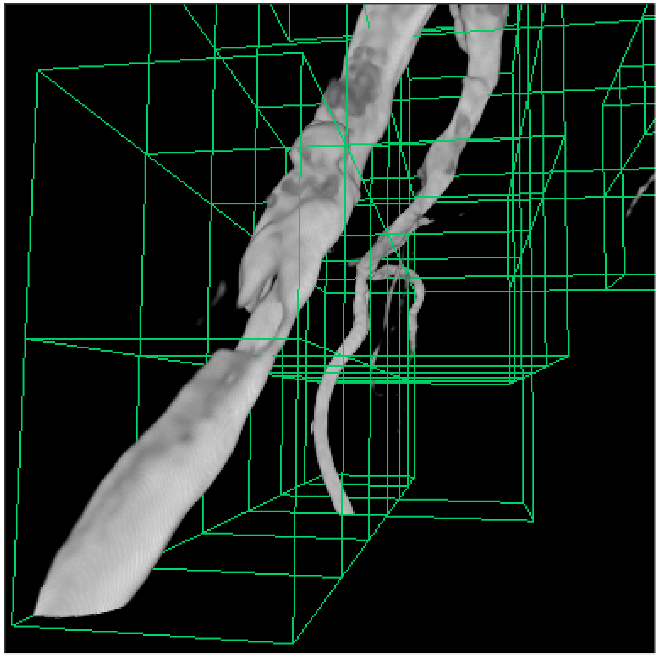


- One octree per brick
- Transfer function
- Traverse hierarchy
- Smallest octree level



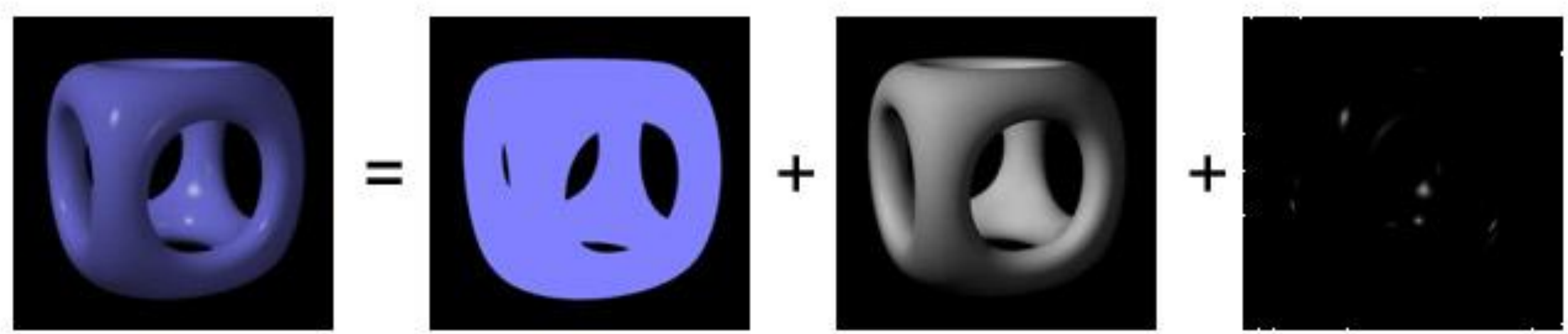
Early ray termination

$$C_{i+1} = (1 - A_i) \cdot \alpha_i \cdot c_i + C_i$$
$$A_{i+1} = (1 - A_i) \cdot \alpha_i \qquad + A_i$$



- Front-to-back rendering: under operator
- Front faces of each brick
- Early z-test
- Polygons are still rasterized…
- But prevents texture lookups and fragment shader execution
- Not useful for (very) sparse data sets

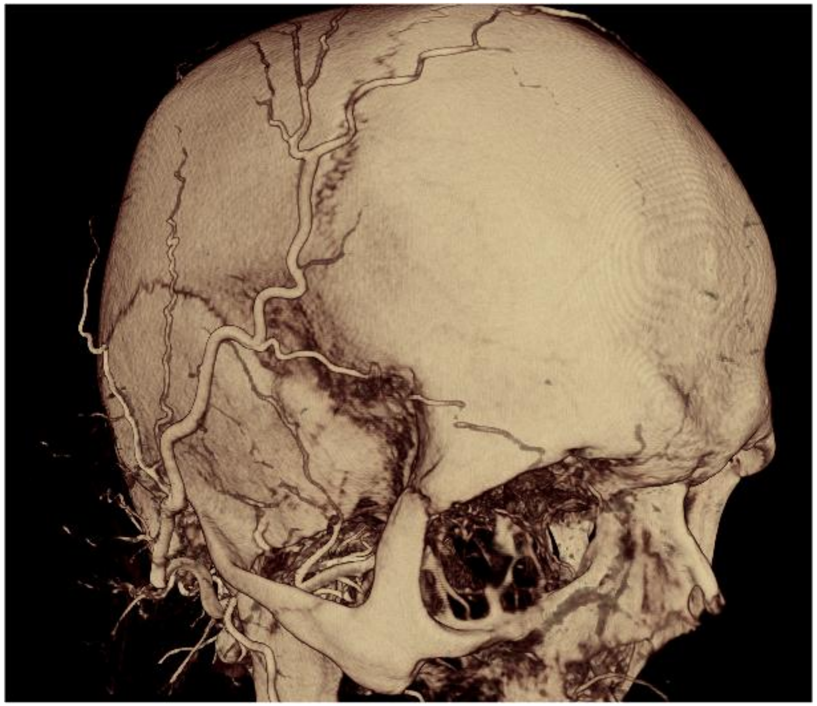
Phong Shading

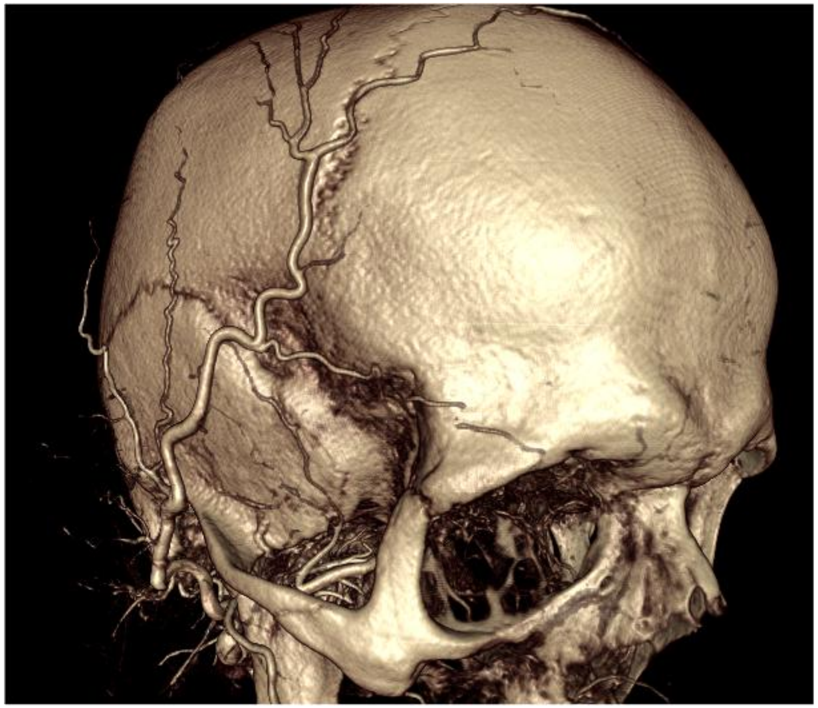


color and ambient   diffuse   specularity

$$I = I_a k_a + I_i(k_d(L \cdot N) + k_s(R \cdot V)^n)$$

To phong or not to phong?



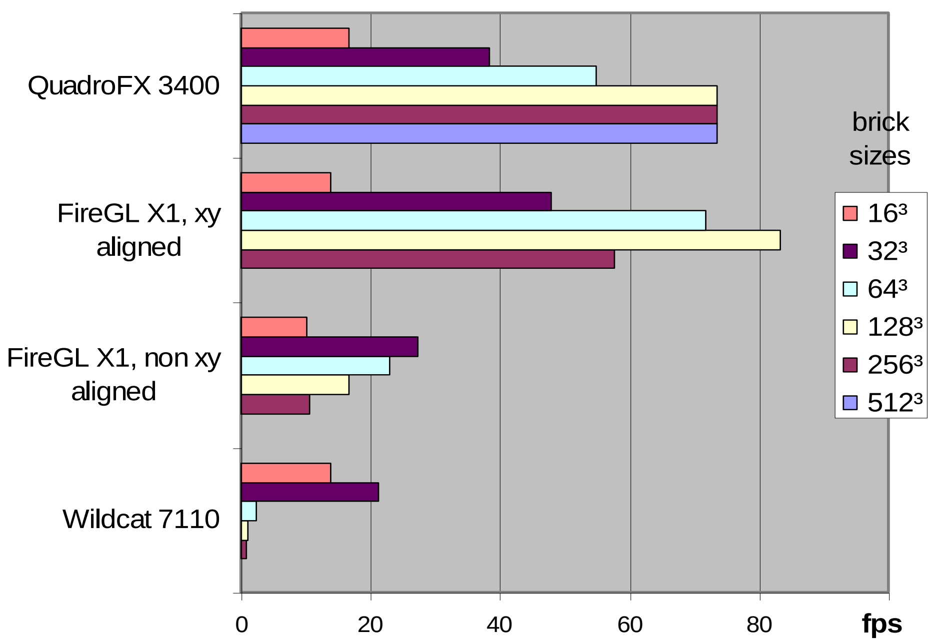


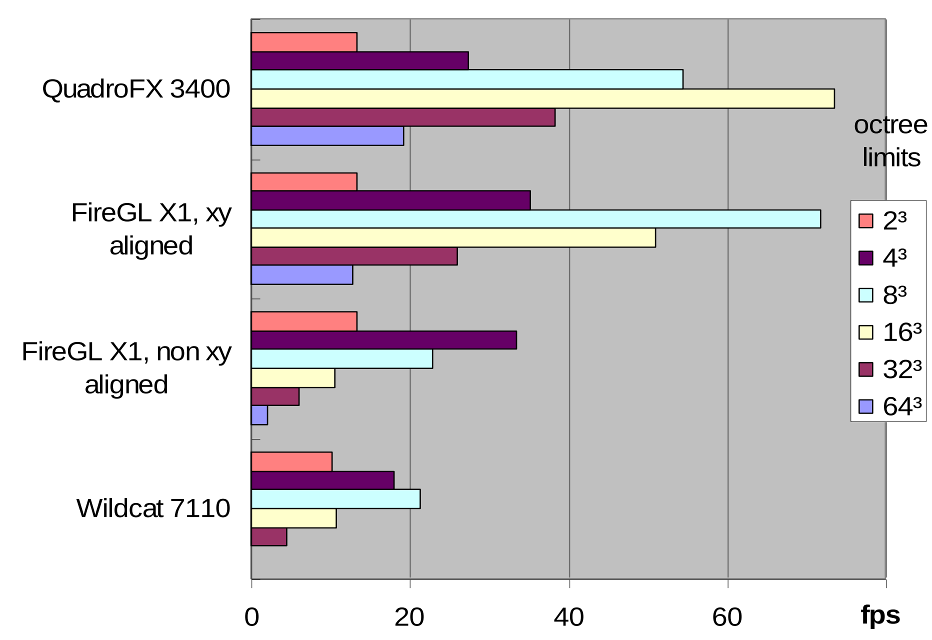
$$I = I_a k_a + I_i \left(k_d (L \cdot N) + k_s (R \cdot V)^n\right)$$

Results

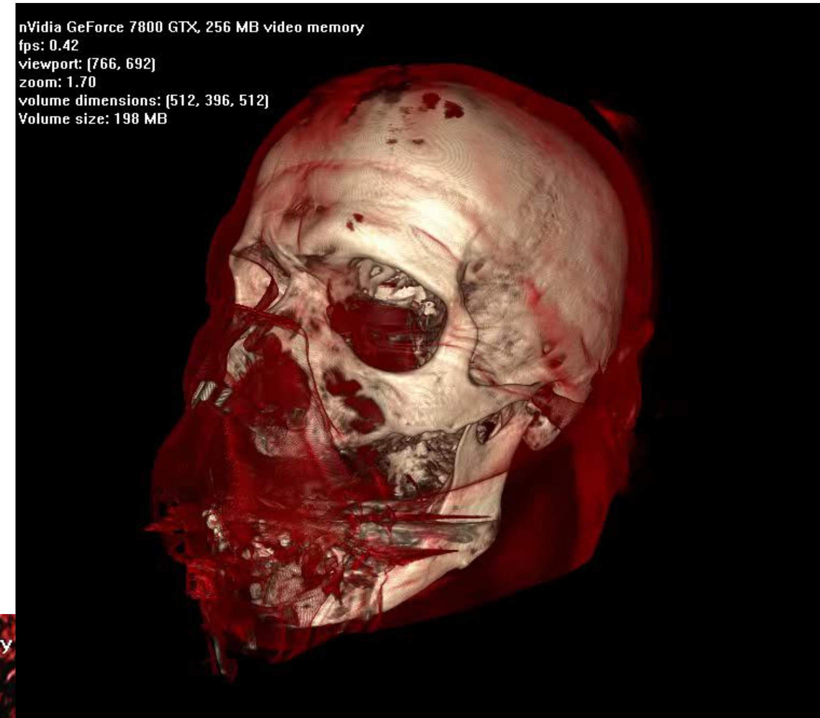
Ruijters and Vilanova: “Optimizing GPU volume rendering, Journal WSCG,” 14(1):9-16

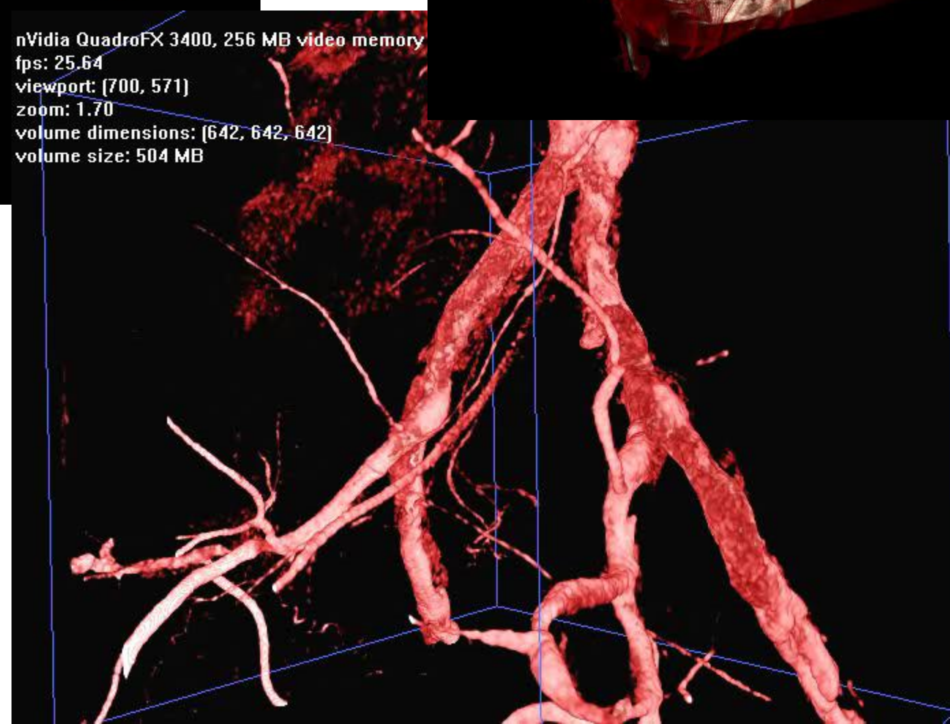
Graphics card	(a) Optimized	(b) Non-optimized	(a) / (b)
nVidia QuadroFX 3400	73.5 fps	9.6 fps	7.66
ATi FireGL X1, xy aligned	83.3 fps	0.23 fps	362
ATi FireGL X1, non xy aligned	27.4 fps	0.23 fps	119
3Dlabs Wildcat 7110	21.3 fps	0.38 fps	56.1






fps: 14.58
viewport: (800, 800)
zoom: 2.10
volume dimensions: (512, 512, 333)
voxel size: (0.43, 0.43, 0.33)
www.fraps.com


nVidia GeForce 7800 GTX, 256 MB video memory
fps: 0.42
viewport: (766, 692)
zoom: 1.70
volume dimensions: (512, 396, 512)
Volume size: 198 MB


nVidia QuadroFX 3400, 256 MB video memory
fps: 25.64
viewport: (700, 571)
zoom: 1.70
volume dimensions: (642, 642, 642)
volume size: 504 MB

504 MB

Visualization

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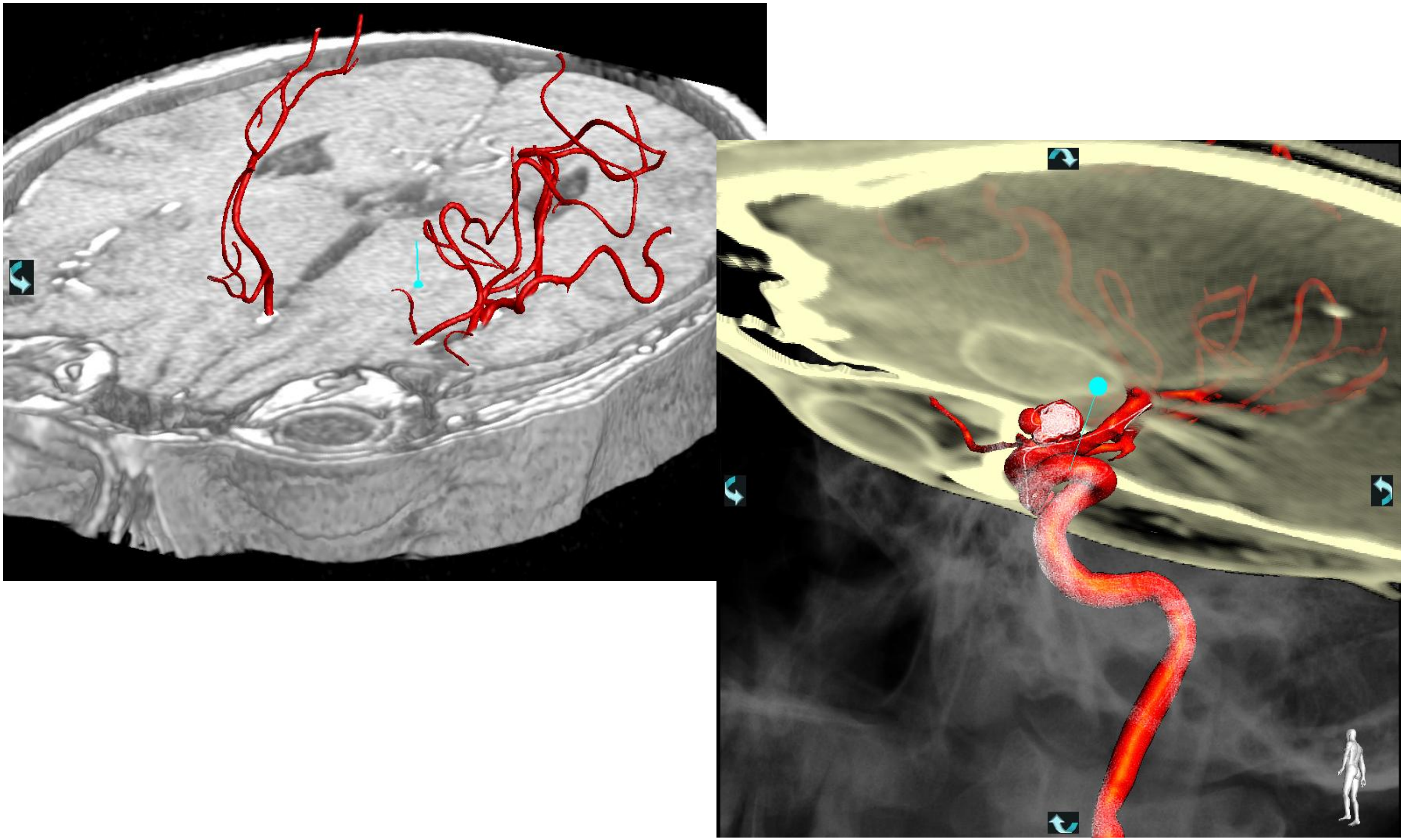
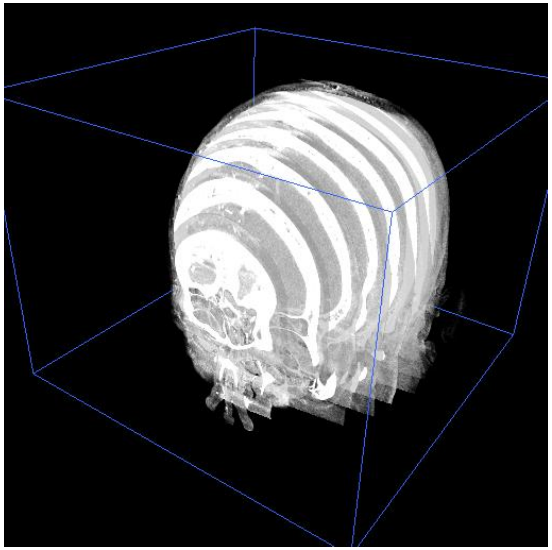
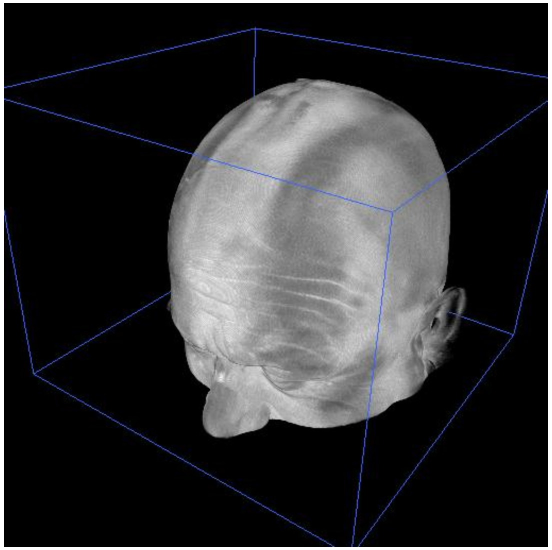
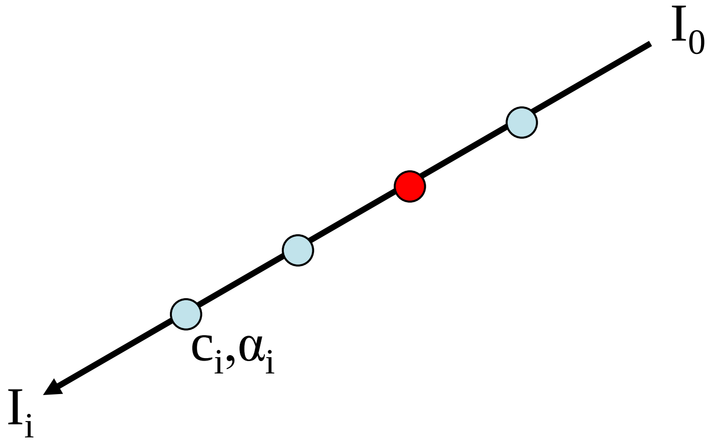
Fused visualization



Back to Front Volume Rendering







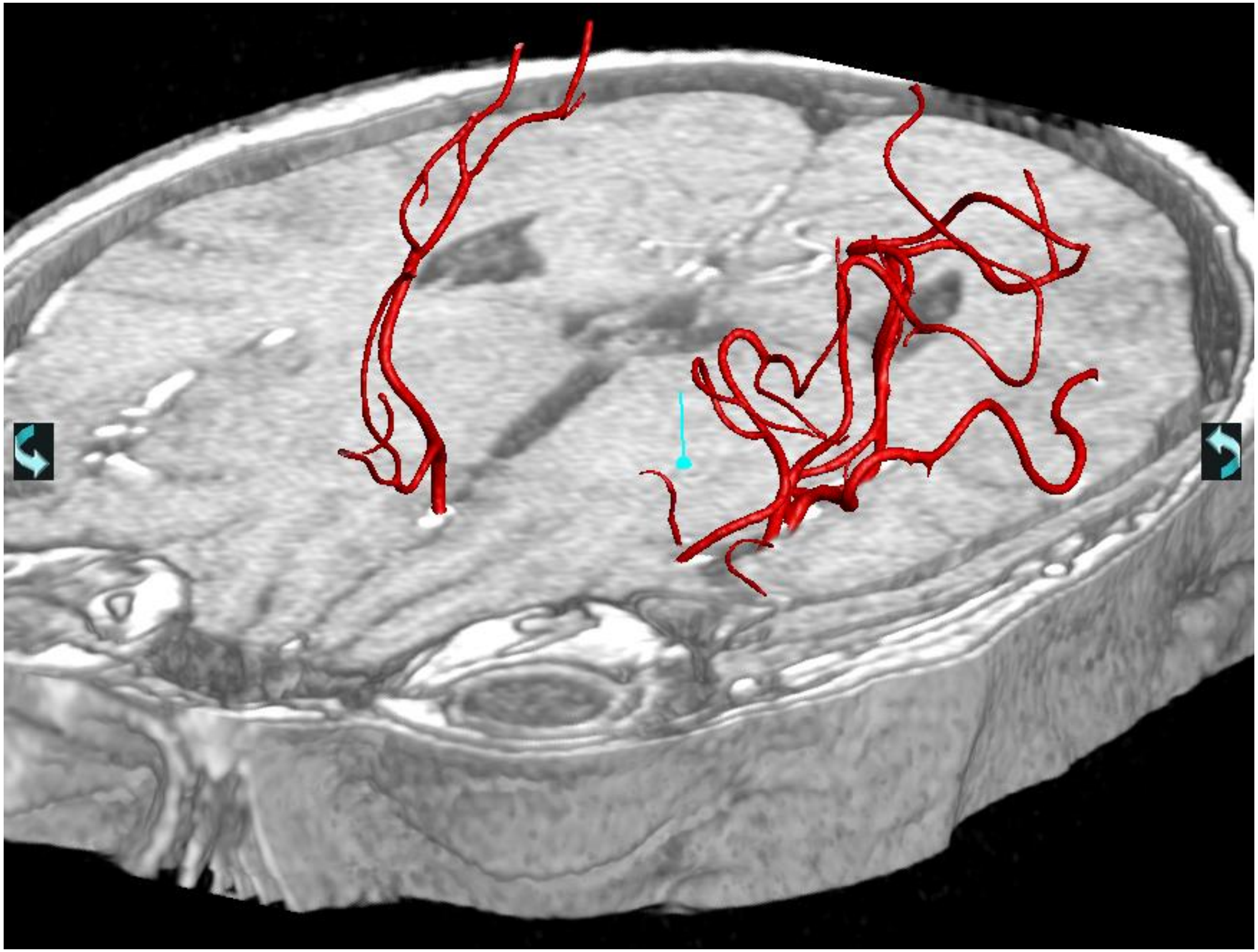
Over-operator:

$$I_i = c_i \, \alpha_i + I_{i-1} \, (1-\alpha_i)$$

Z-buffer determines whether a sample origins from the mesh, or the voxel data.

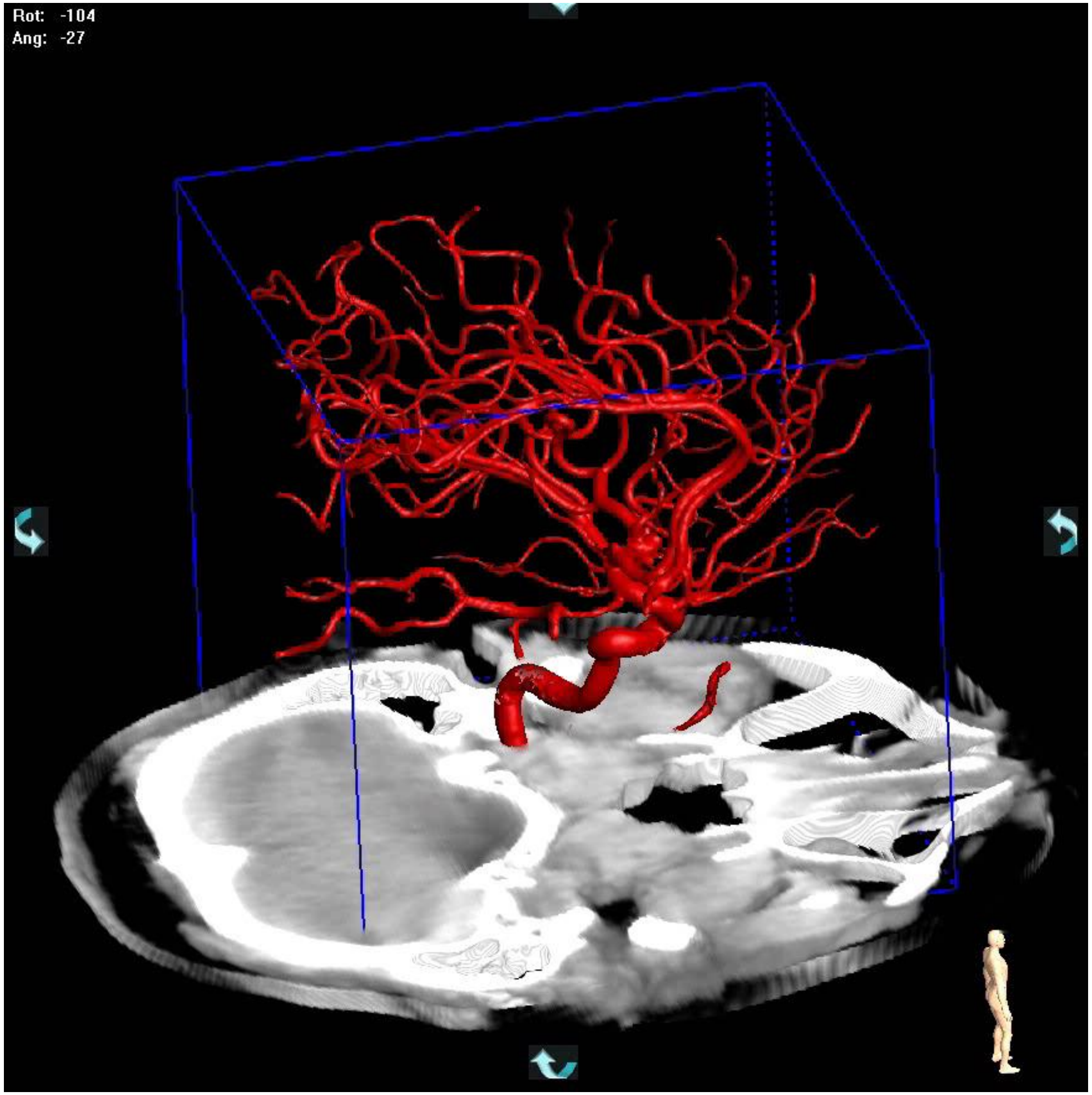
First render mesh

Then draw a slab of the morphological dataset



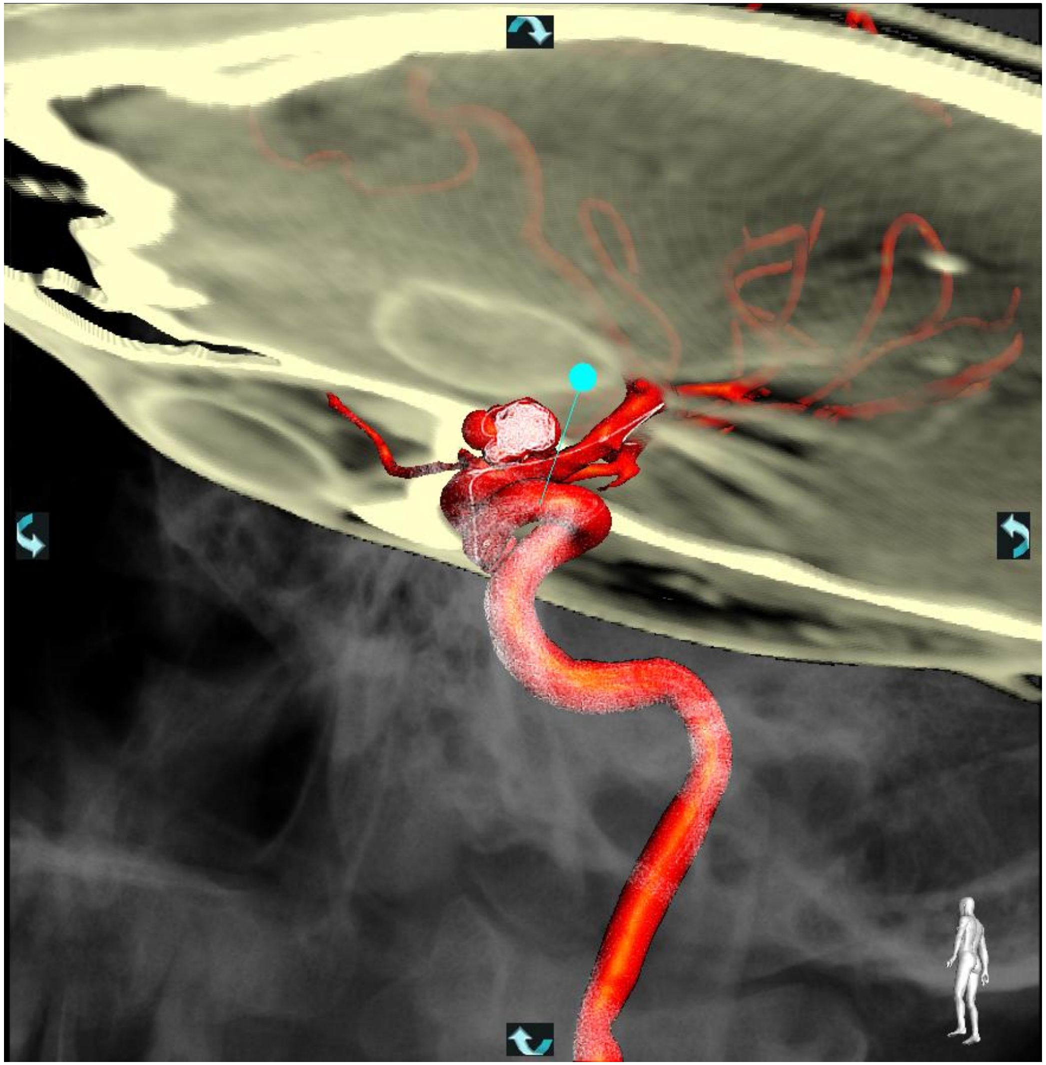
Ruijters, Babic, ter Haar Romeny, Suetens: “Silhouette Fusion of Vascular and Anatomical Data,” ISBI'06, pp. 121-124

Example



Stencil buffer

Fused Visualization



38 fps
nVidia QuadroFX 3400

Ruijters, Babic, Homan, Mielekamp, ter Haar Romeny, Suetens:

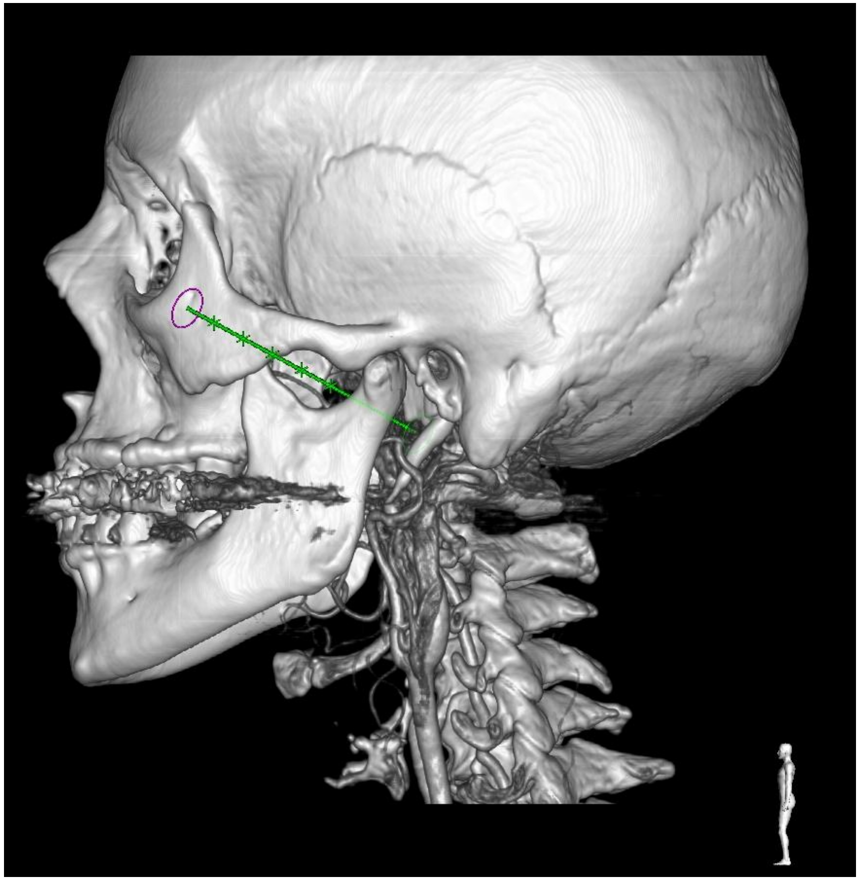
"Real-time integration of 3-D multimodality data in interventional neuroangiography",

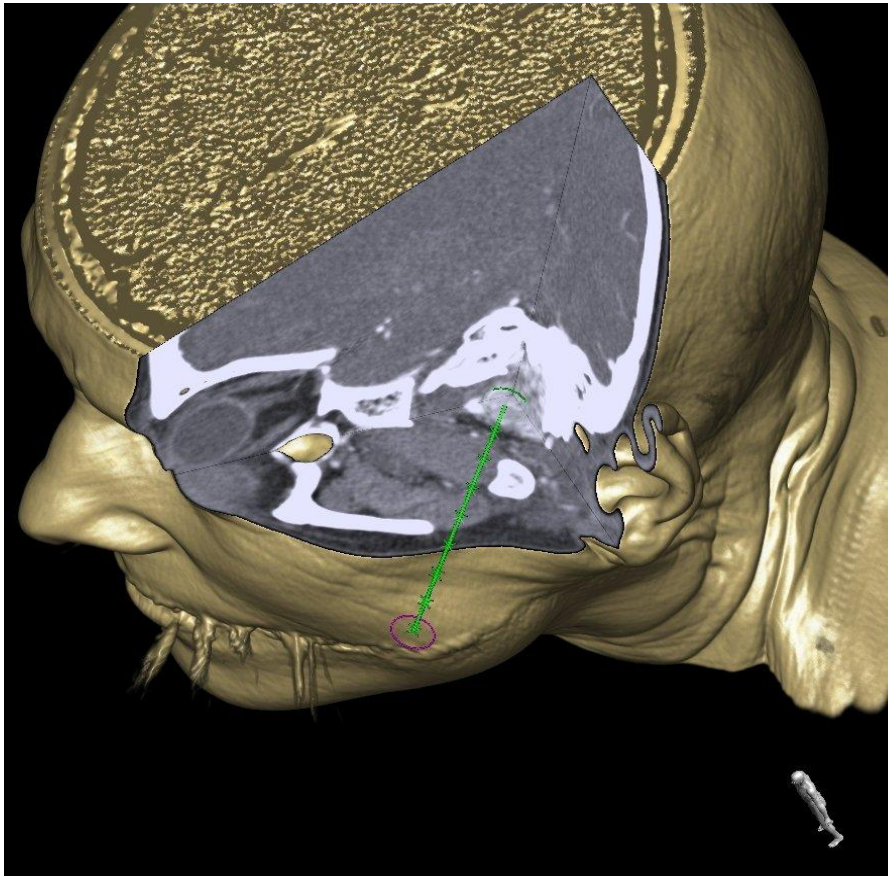
J. Electronic Imaging 18(3), 2009

Clinical Applications

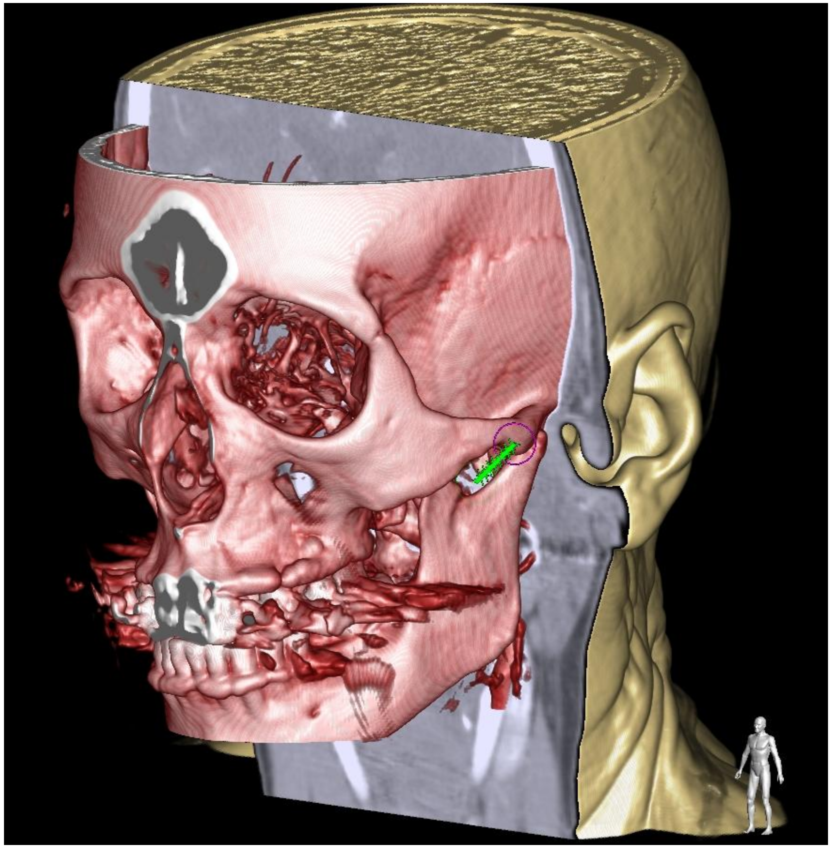
- Needle guidance

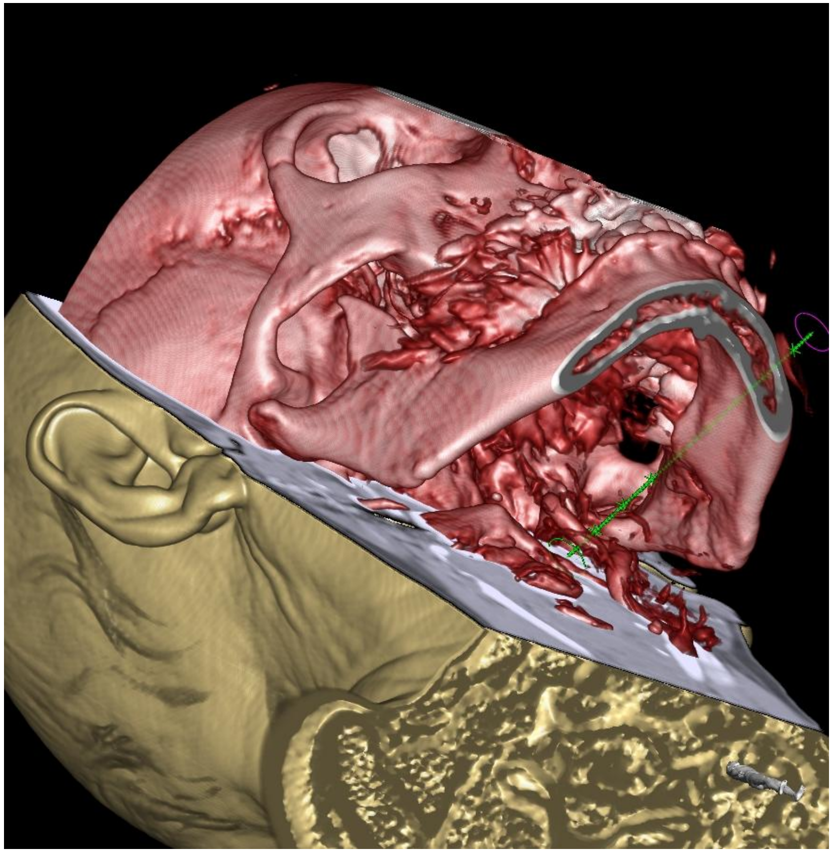
Needle planning



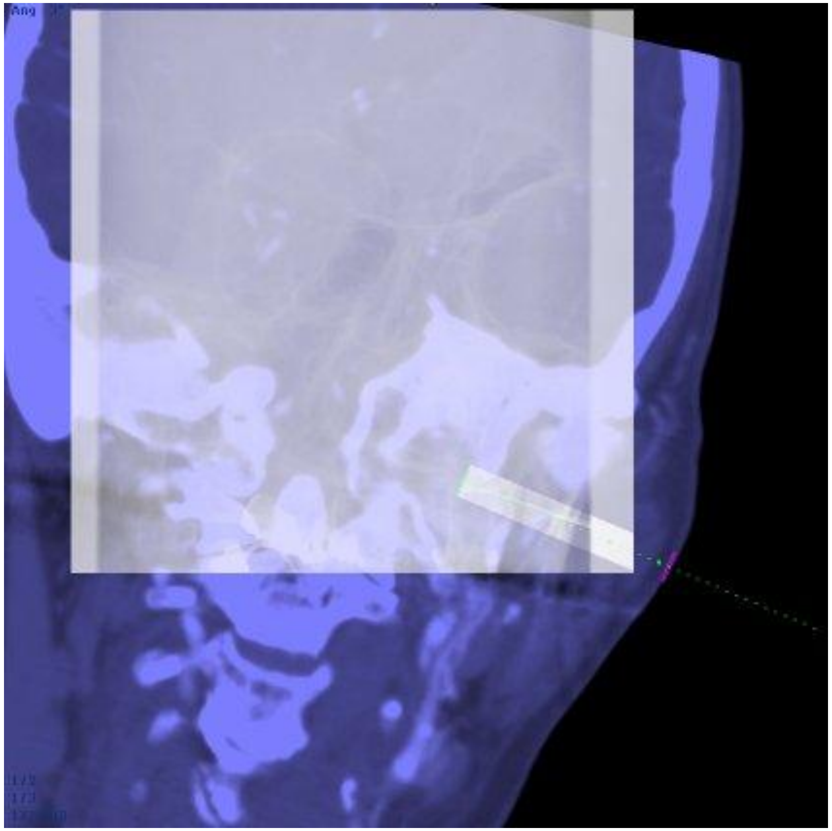


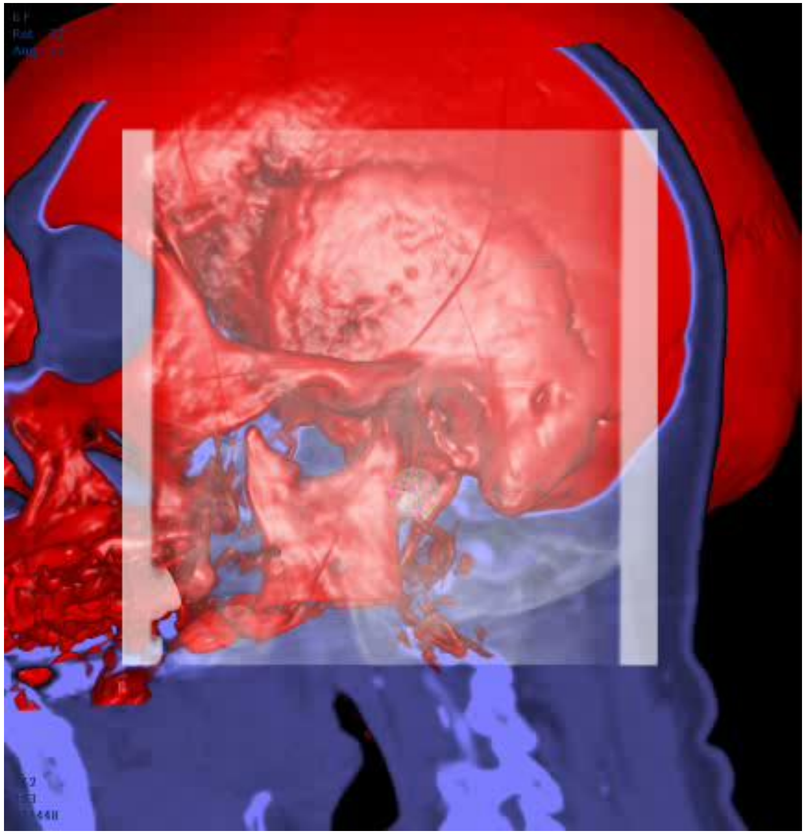
Intra-operative registration





Needle Navigation





Ruijters, Spelle, Moret, Babic, Homan, Mielekamp, ter Haar Romeny, Suetens:
"XperGuide: C-arm Needle Guidance", ECR 2008, Eur. Radiol. 18, Suppl 1, p. 459

Conclusions

Conclusions

- Fast volume rendering is important during interventions
- Volume rendering can be accelerated by smart tailoring towards the graphics hardware
- Fused visualization can be used to present multiple datasets in one combined image
- This enables new clinical procedures

Thank you!!!

Questions?