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Klaus Engel - Siemens Healthcare Technology Center

Real-Time Monte-Carlo Path Tracing of Medical Volume Data

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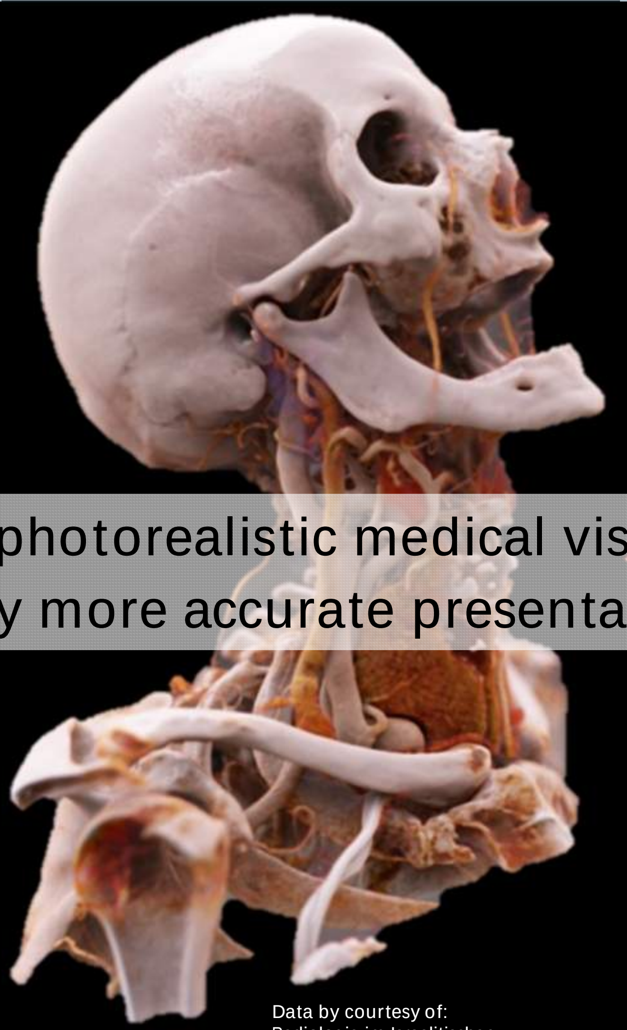
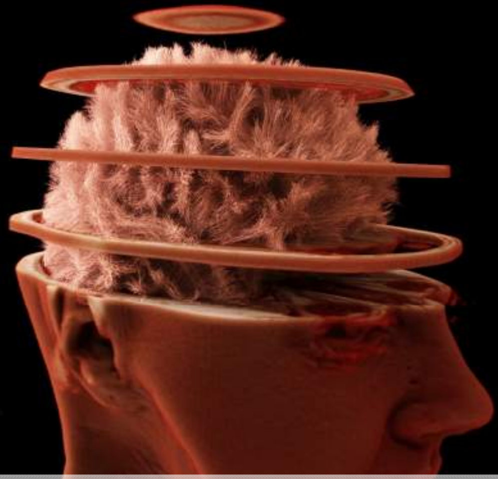
What is Cinematic Rendering?

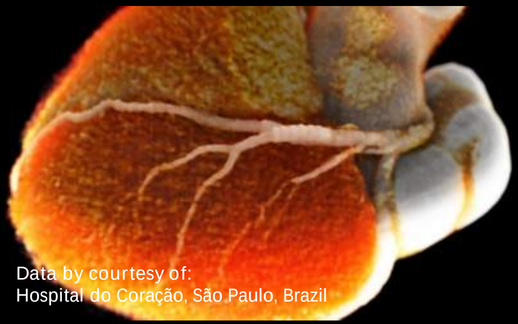
Data by courtesy of:
UMM Universitätsmedizin Mannheim, Germany





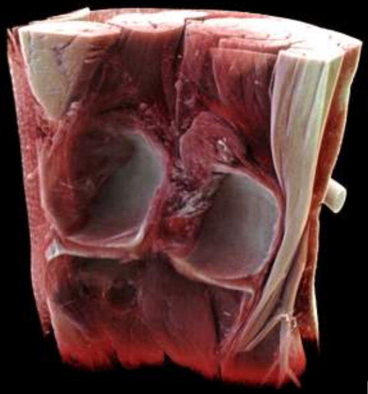
Data by courtesy of:
Max Planck Institute, Leipzig, Germany

- A new generation of photorealistic medical visualization based on light transport
- Natural and physically more accurate presentation of medical volume data



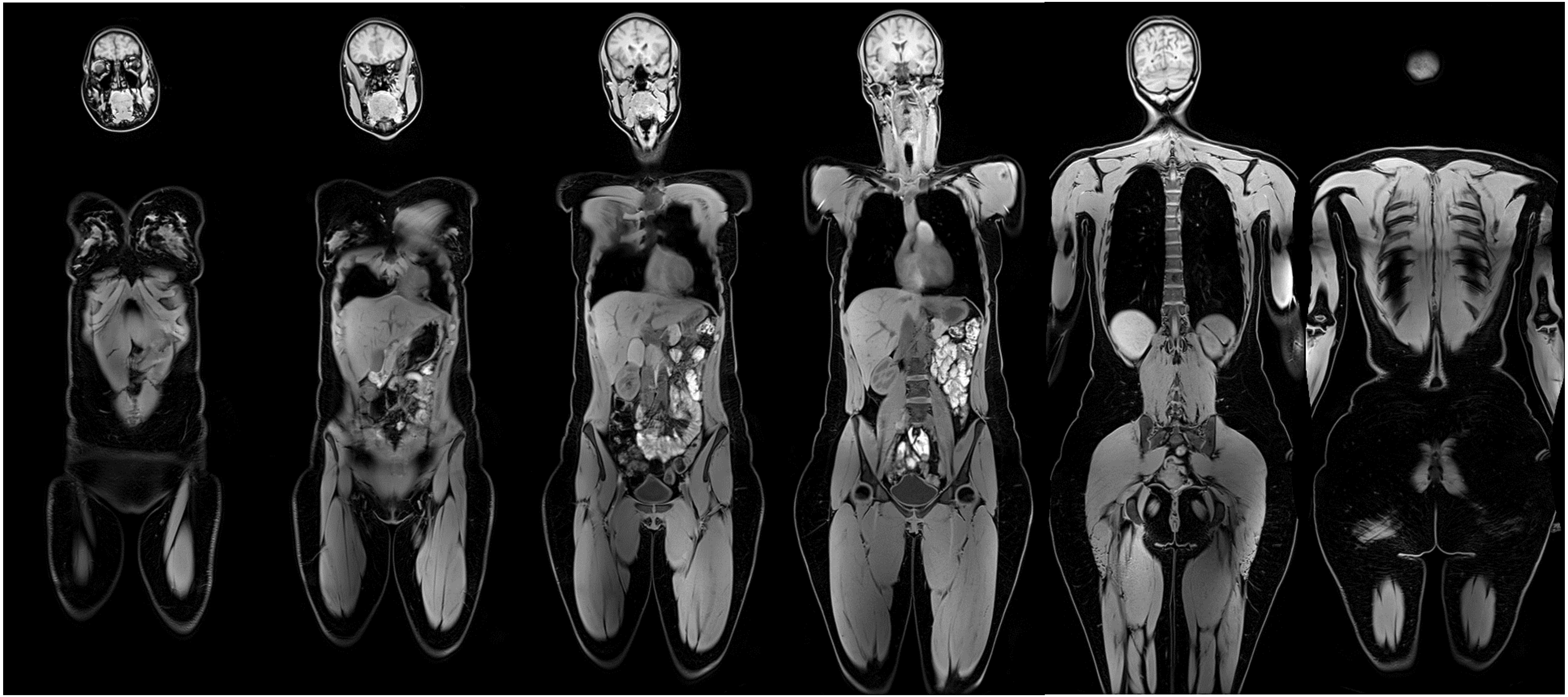
Data by courtesy of:
Hospital do Coração, São Paulo, Brazil

Data by courtesy of:
Radiologie im Israelitischen
Krankenhaus / Hamburg, Germany



Data by courtesy of:
Dr. S. Trattnig, Medizinische Universität Wien, Austria

The Radiologist‘s View of the World



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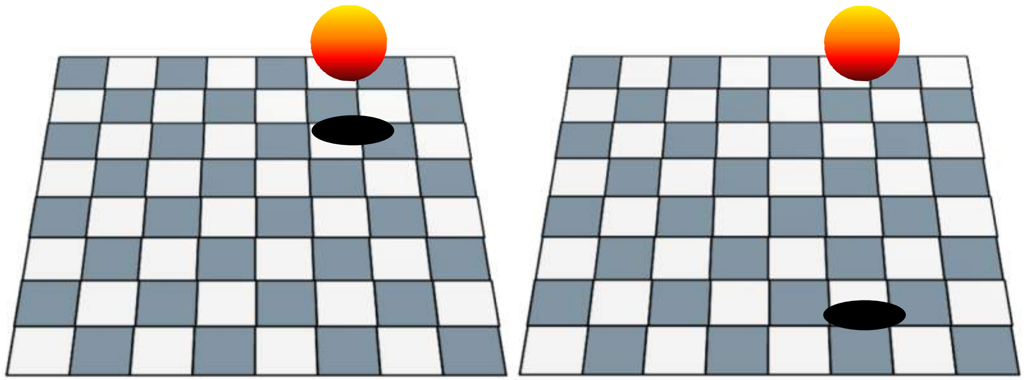
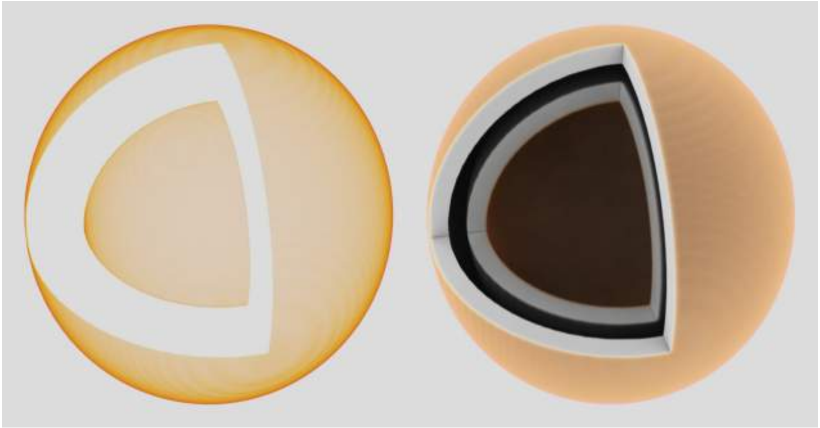
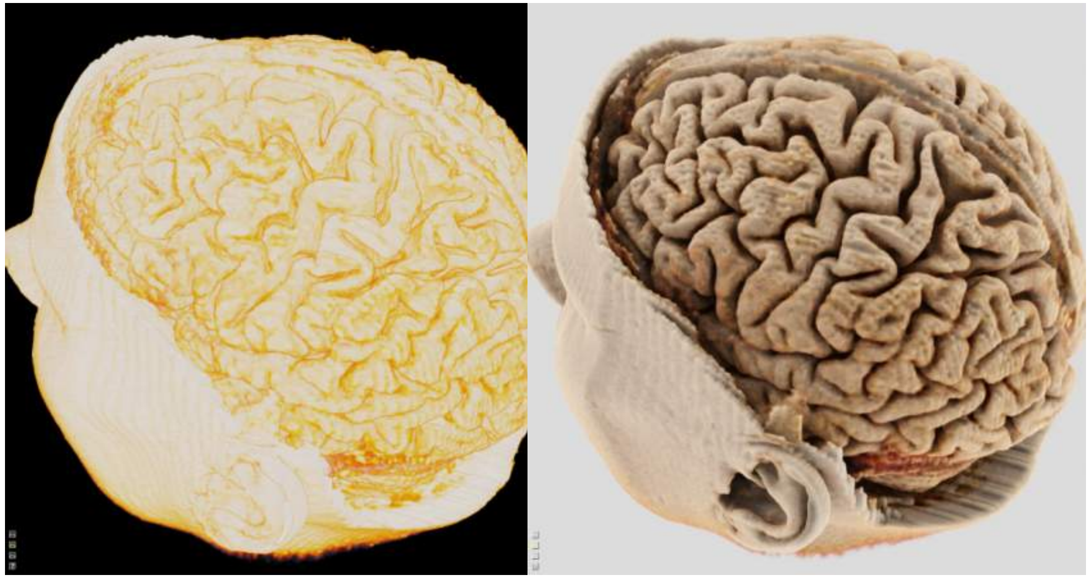
Why do we need photorealism in medical imaging?

Depth Perception



Shape Perception

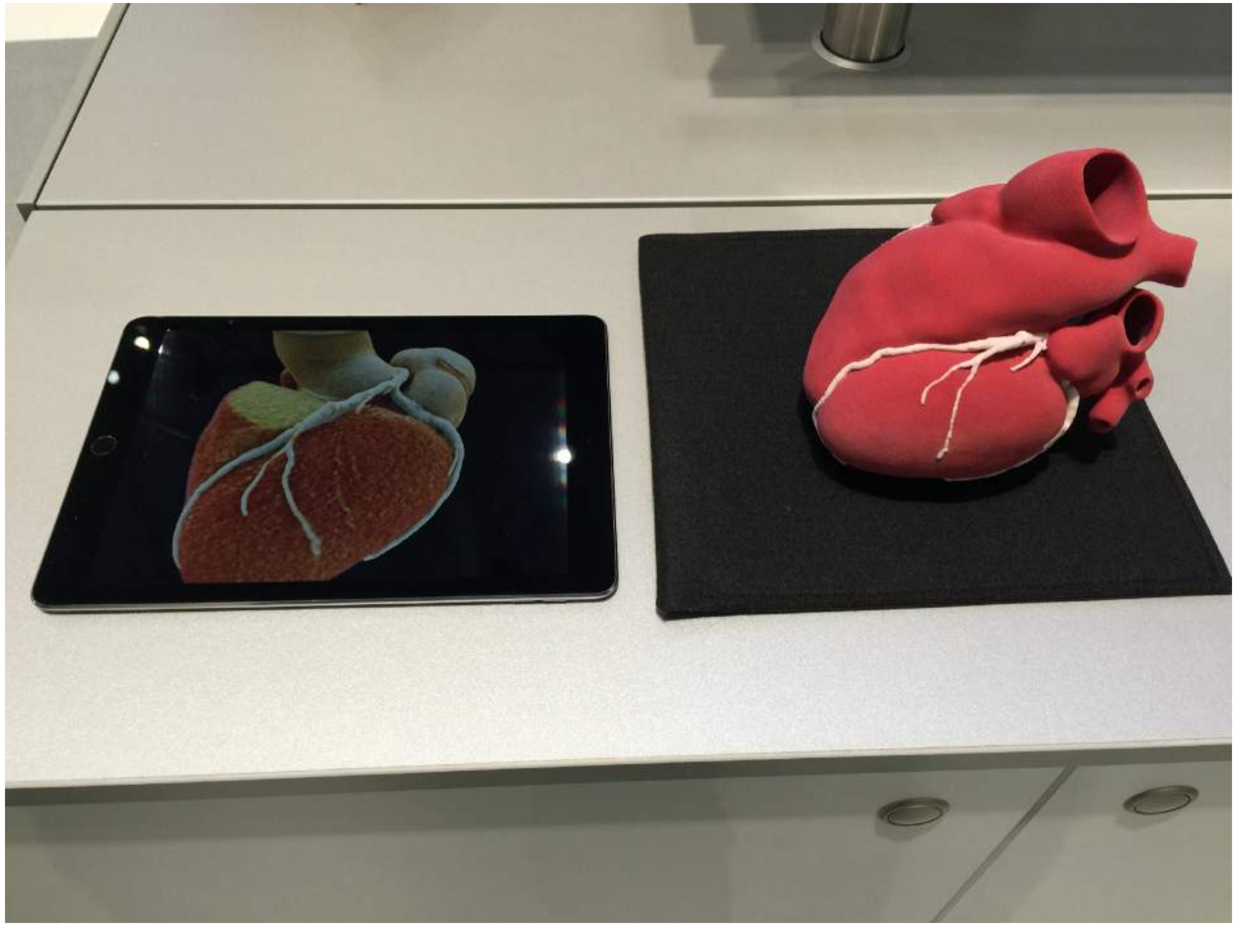




Why do we need photorealism in medical imaging?
Special Diagnostics

Why do we need photorealism in medical imaging?
Surgery Planning

Why do we need photorealism in medical imaging?
Communication



Why do we need photorealism in medical imaging?
Communication

Data by courtesy of:
Dr. Philip Alexander Glemser,
Working group leader Forensic Imaging,
German Cancer Research Center, Heidelberg

Why do we need photorealism in medical imaging?
Education

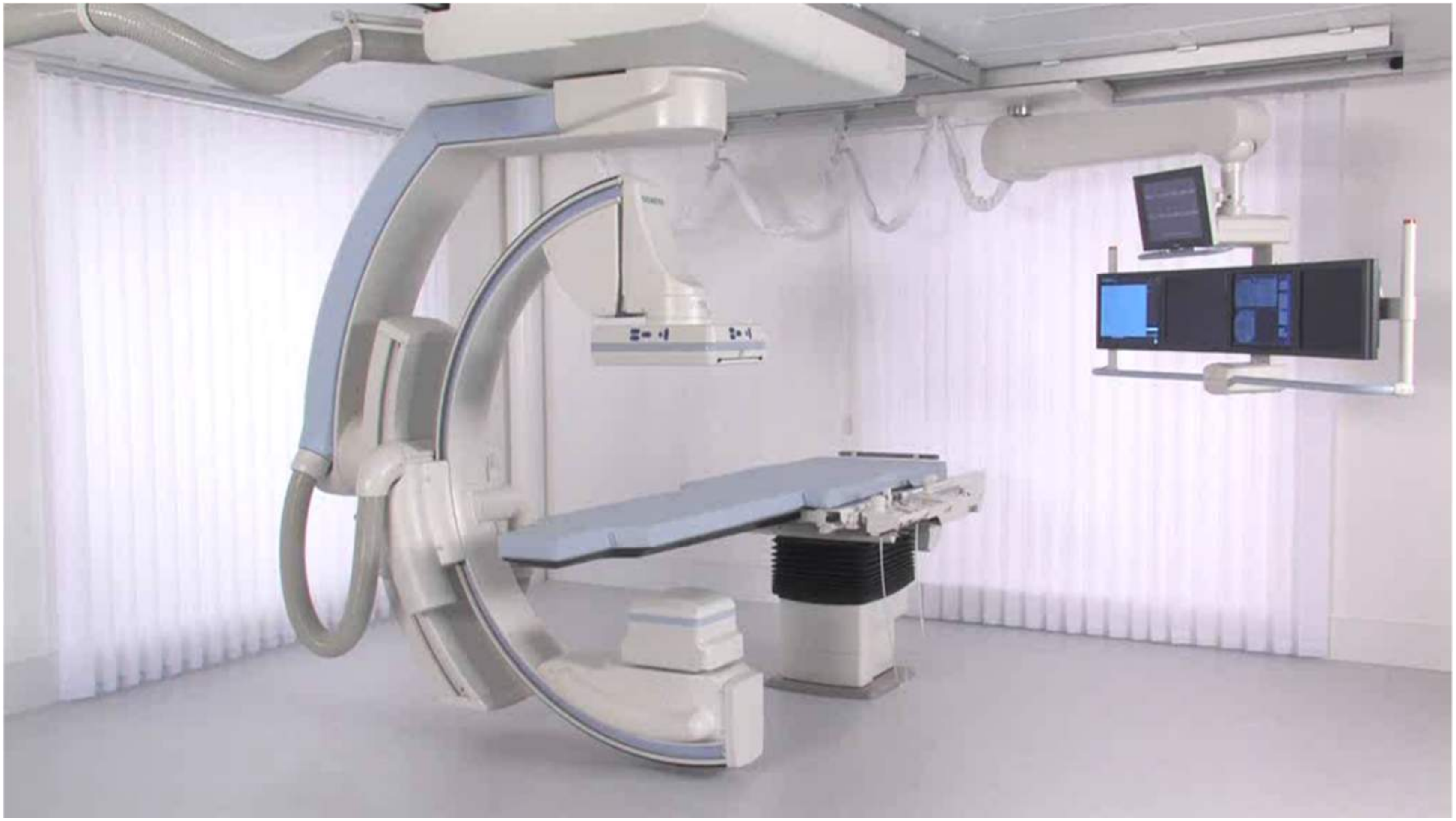

Credit: Florian Voggeneder


Credit: Magdalena Leitner

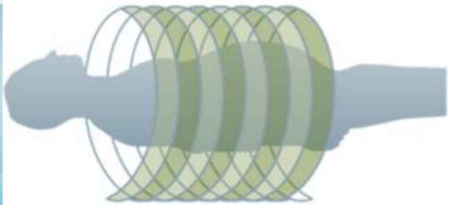

Credit: Martin Hieslmair

Cinematic Rendering Video

From X-Ray projection to 3D volume data



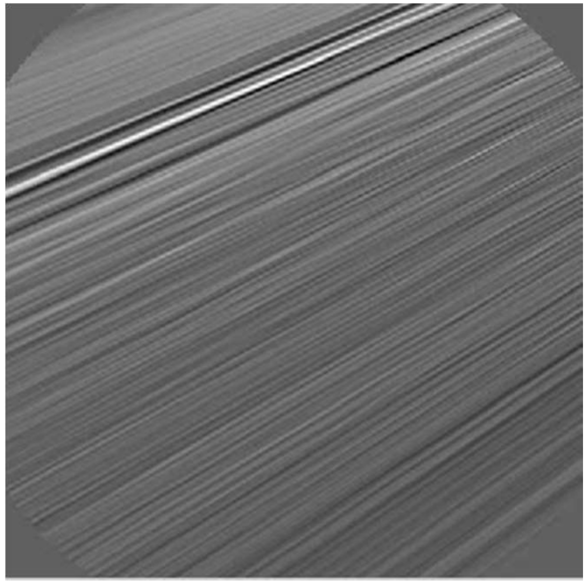
projection images (pelvis)



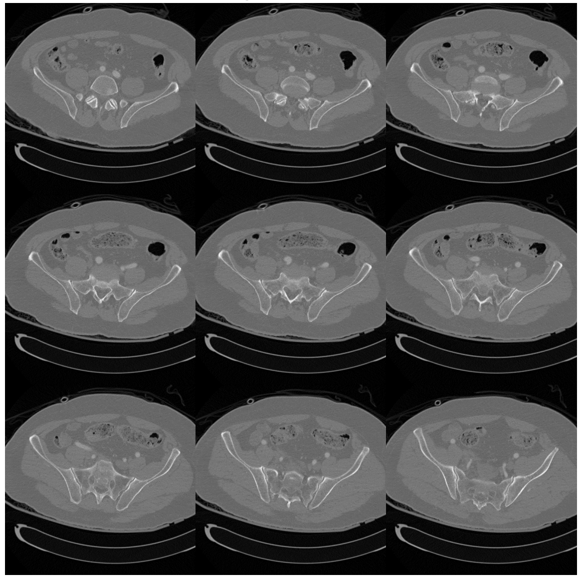
From X-Ray projection to 3D volume data

Reconstruction: Computes a 3D X-Ray density volume from many projections

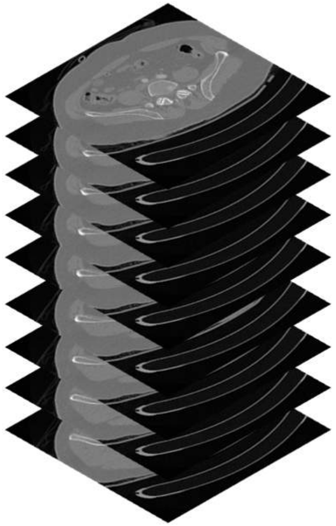
Reconstruction of
a slice



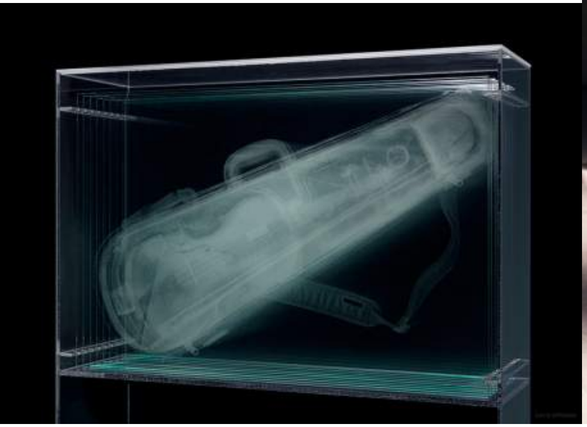
Reconstruction of
many slices

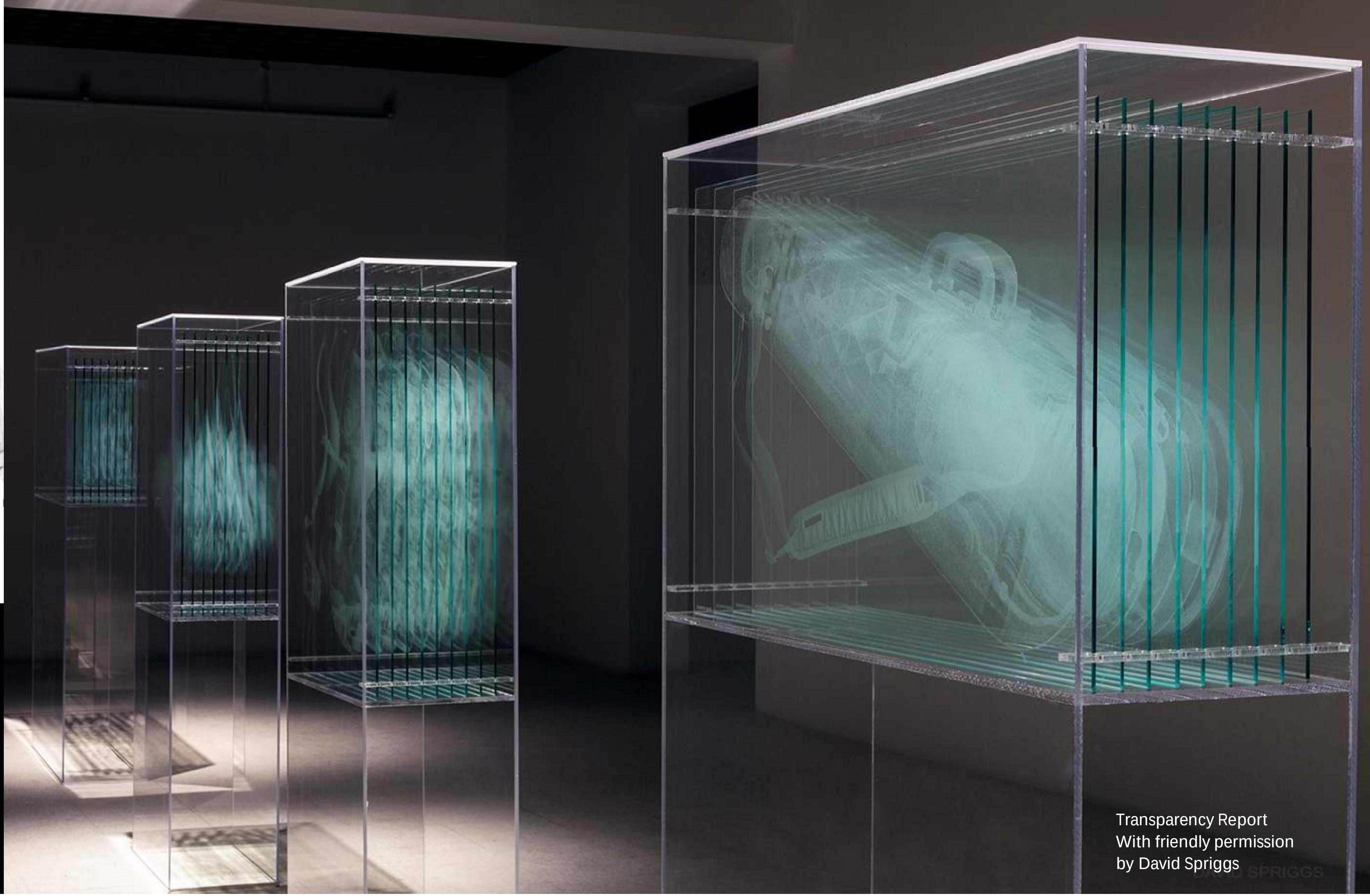


Volume



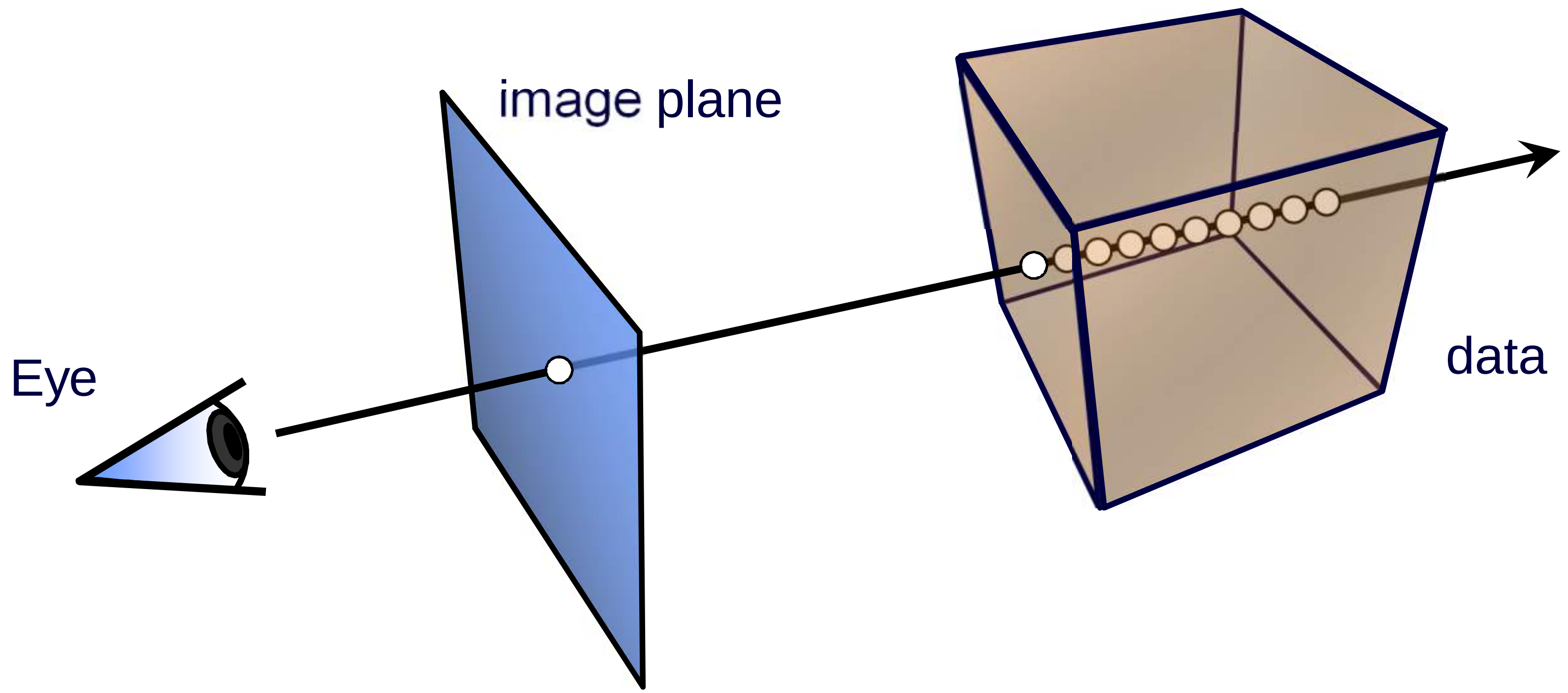
Radon-Transformation (Johann Radon, 1917)
Hounsfield, 1971





Transparency Report
With friendly permission
by David Spriggs

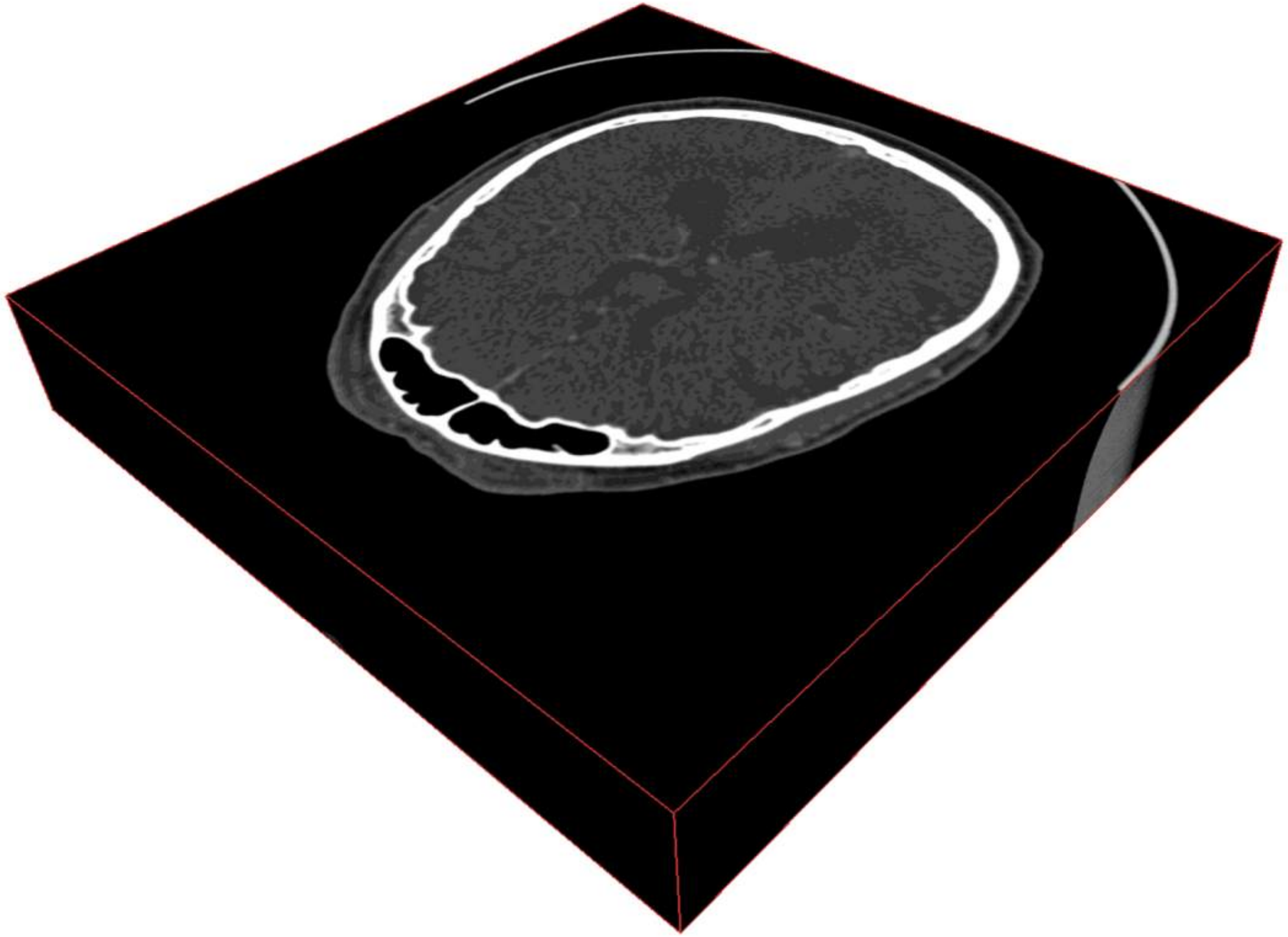
Traditional Ray Casting



Algorithmic Steps (for each sample along the rays):

- Compute interpolated density value
- Classification: Density → (R, G, B, alpha)
- Gradient computation, Shading, ...
- Numerical Integration (Combination of R, G, B, and alpha values)

Classification



Data by courtesy of:
Universitätsklinikum Erlangen, Germany

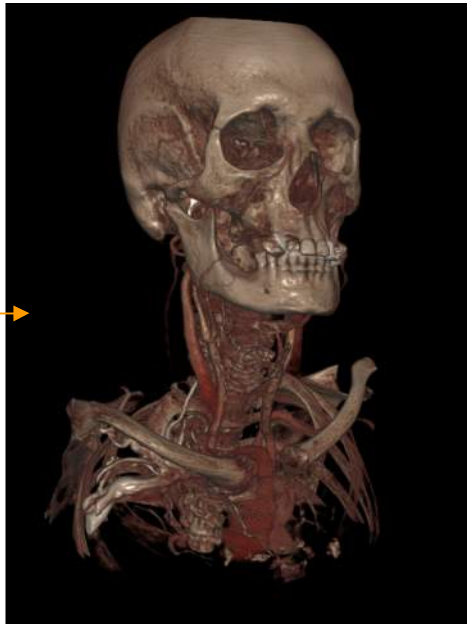
Shading

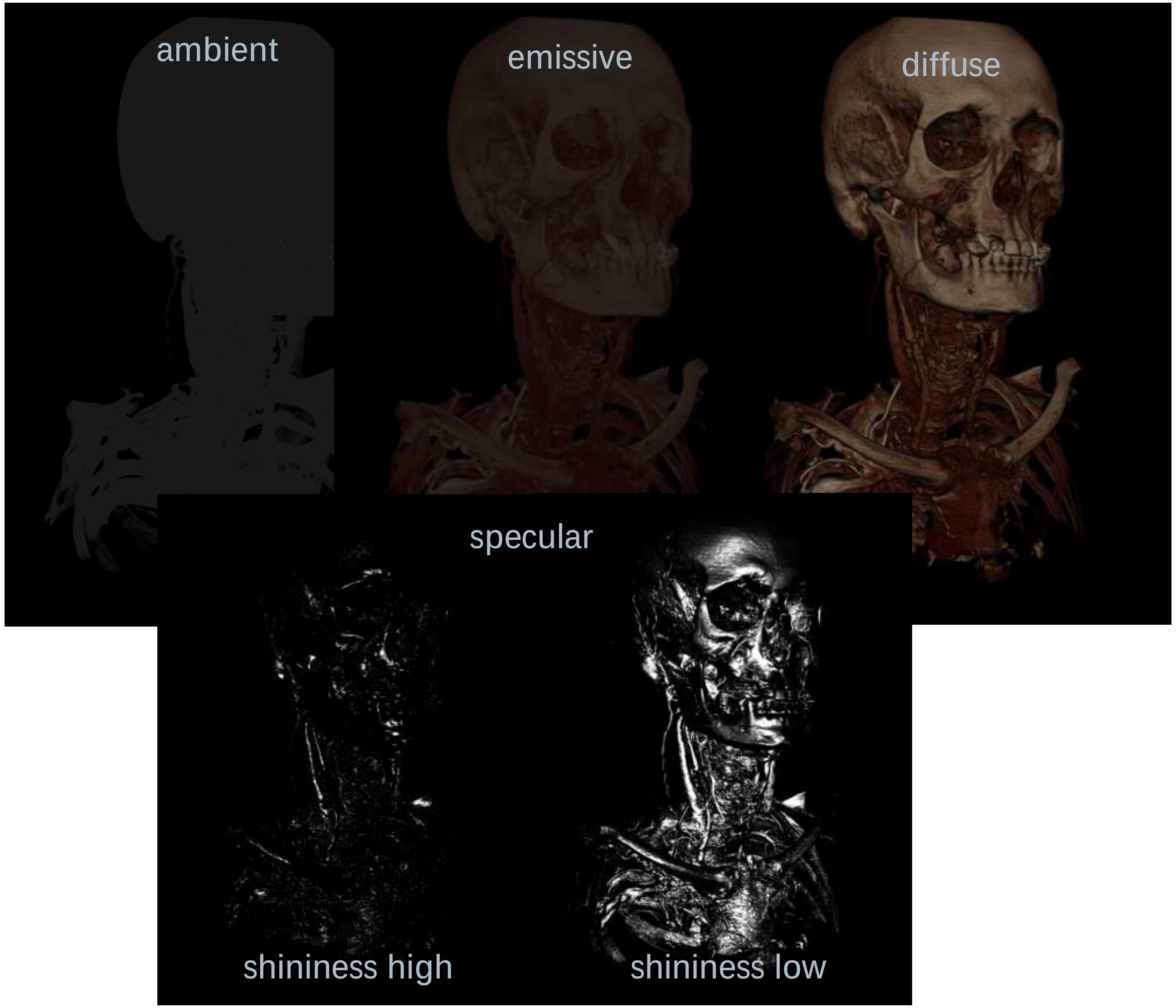
$$\nabla f(\mathbf{x}) = \begin{pmatrix} \frac{\partial f(\mathbf{x})}{\partial x} \\ \frac{\partial f(\mathbf{x})}{\partial y} \\ \frac{\partial f(\mathbf{x})}{\partial z} \end{pmatrix}$$

partial derivative *in x-direction*

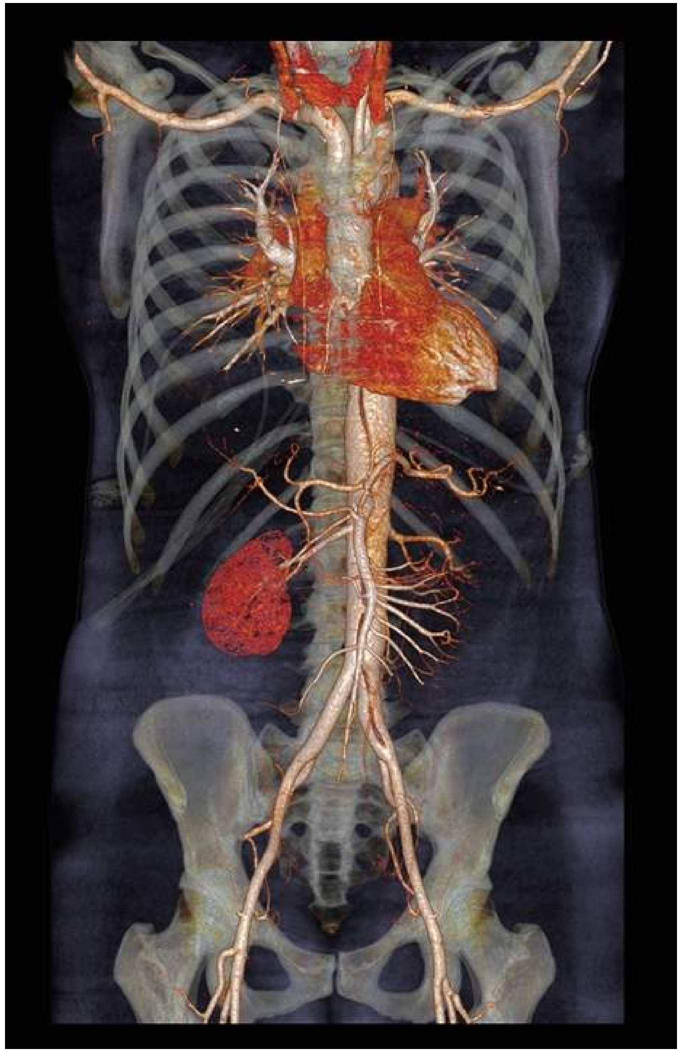
partial derivative *in y-direction*

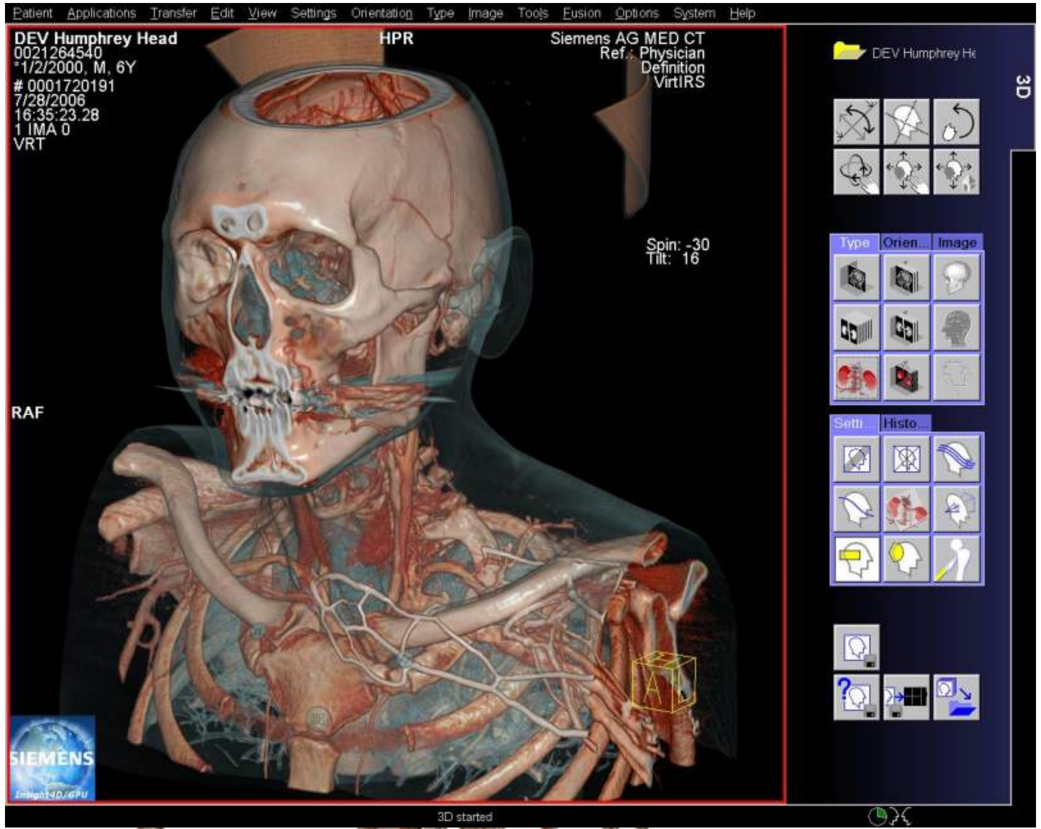
partial derivative *in z-direction*

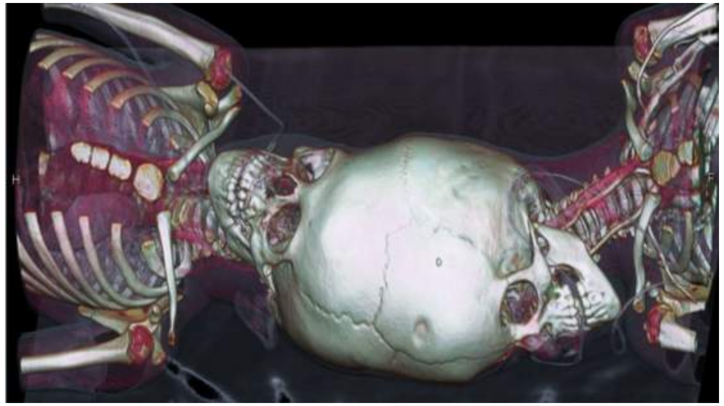


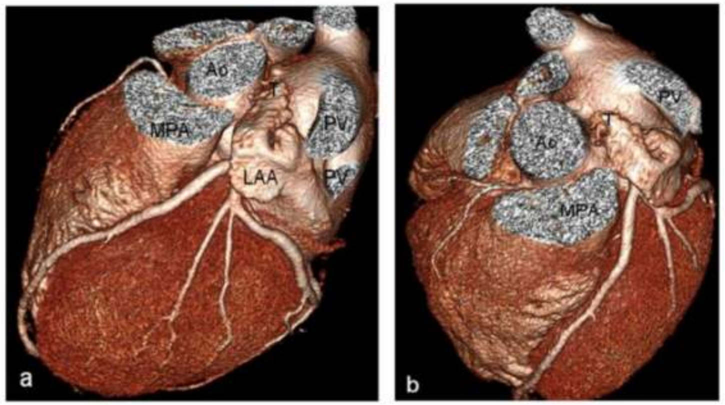


Ray Casting Results









Physics of light transport

Geometric Optics

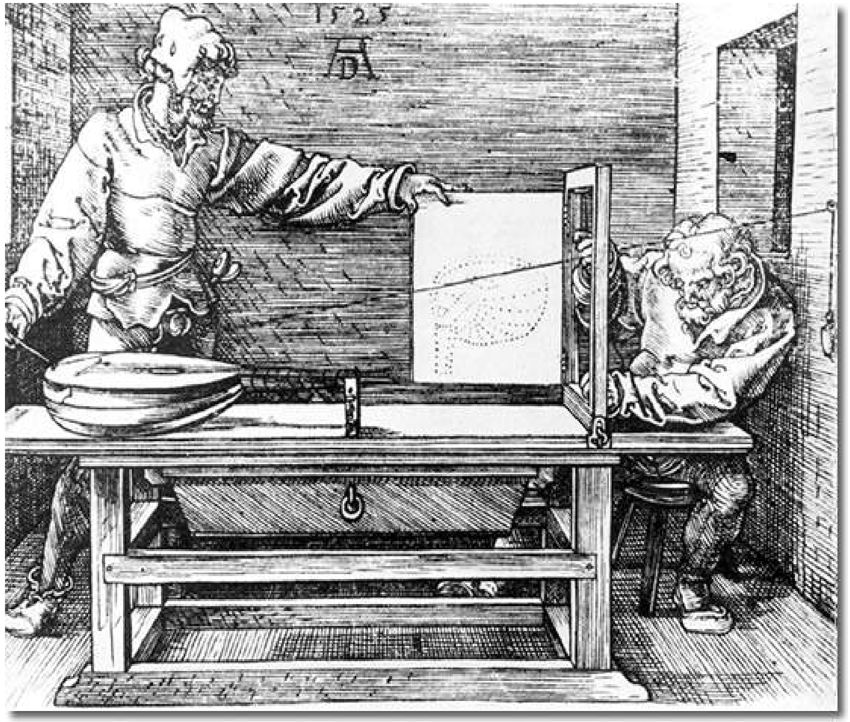


Image Source: Wikipedia

Albrecht Dürer
„Underweysung der Messung mit dem Zirckel un Richtscheyt“, 1525

Wave Optics

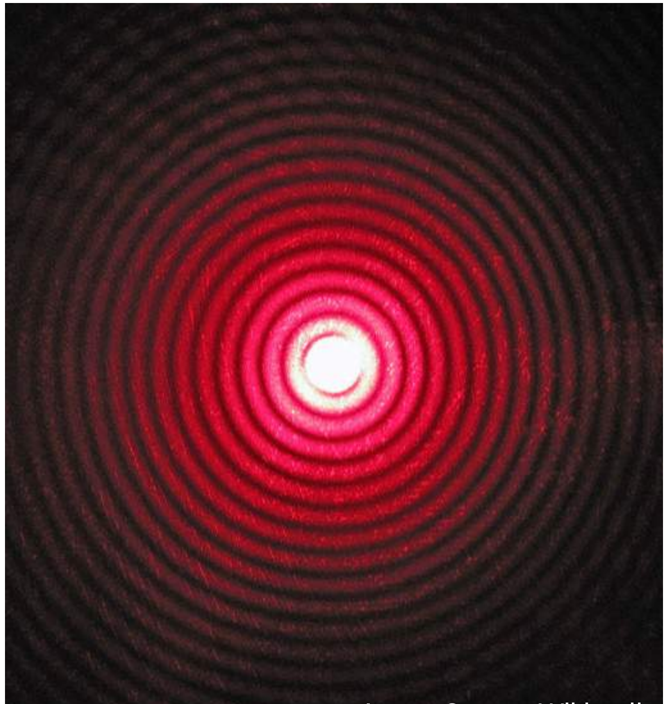


Image Source: Wikipedia

Diffraction

Interference

Polarization

Aberration

Quantum Optics

Image Source: Wikipedia

Photoelectric Effect

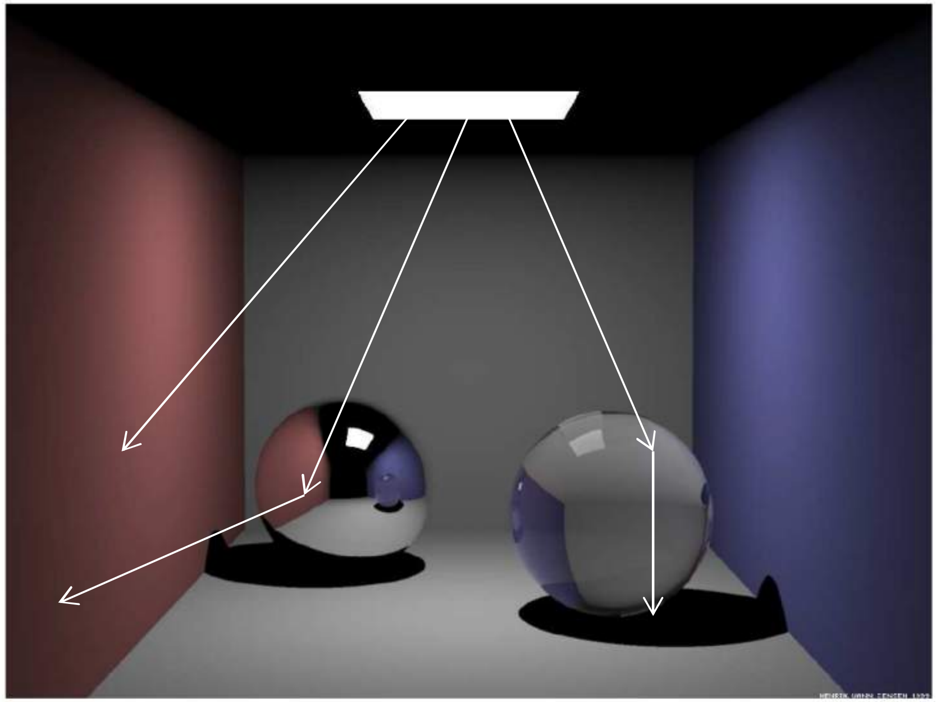
Laser

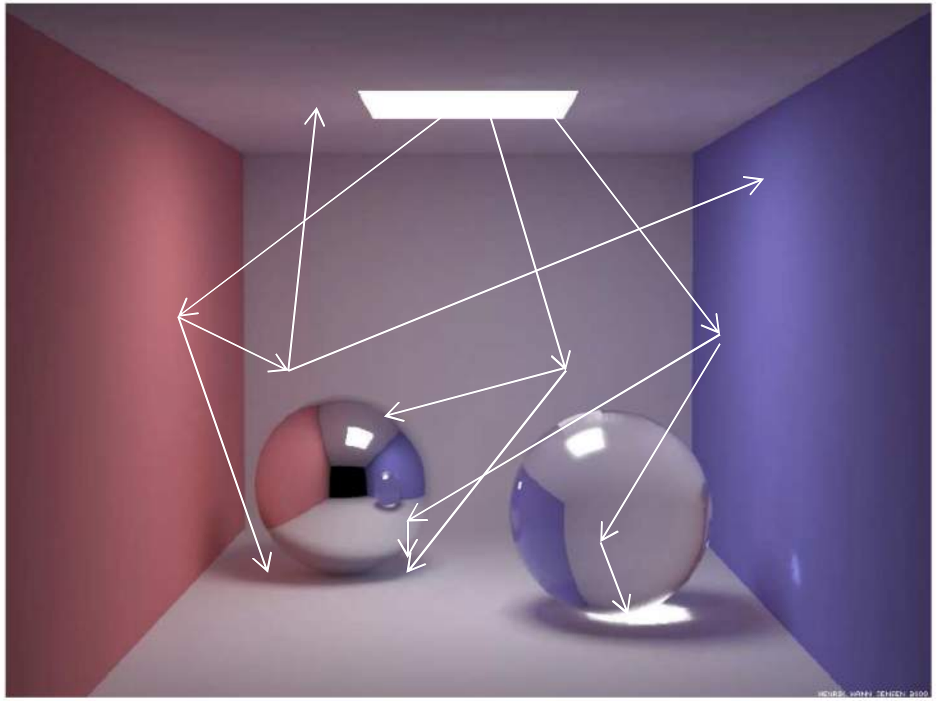
Maser

Physics of light transport

Deterministic: Light takes a single path

Probabilistic: Light can take many paths



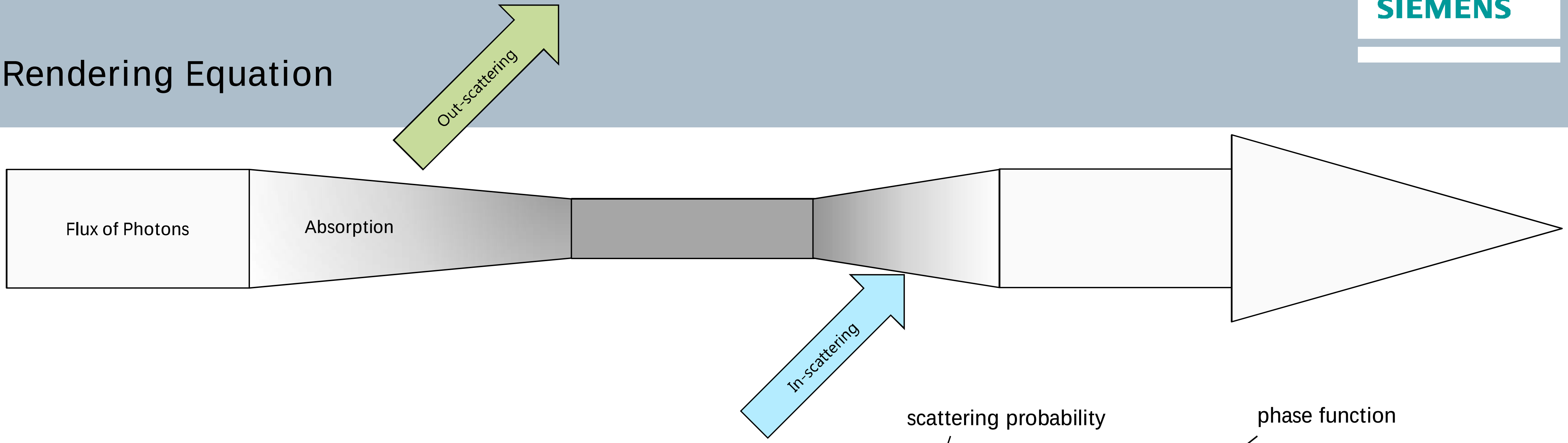


Images courtesy of Henrik Wann Jensen, University of California, San Diego, USA

Classic Ray Tracing

Path Tracing

Rendering Equation



Integral difficult to evaluate:

- Multi-dimensional
  - Sample/scatter positions
  - Light directions
- Non-continuous
  - Highlights
  - Occluders
  - Transfer Function

$$L(x,\boldsymbol{\omega}) = \int_0^D e^{-\tau(x,x')}\sigma_S(x')\left[\int_{\Omega_{4\pi}} p(\boldsymbol{\omega},\boldsymbol{\omega}')L_i(x',\boldsymbol{\omega}')d\boldsymbol{\omega}'\right]dx'$$

$$\tau(x,x') = \int_x^{x'} \sigma_t(t)dt$$

radiance at distance x

scattering probability

phase function

all directions

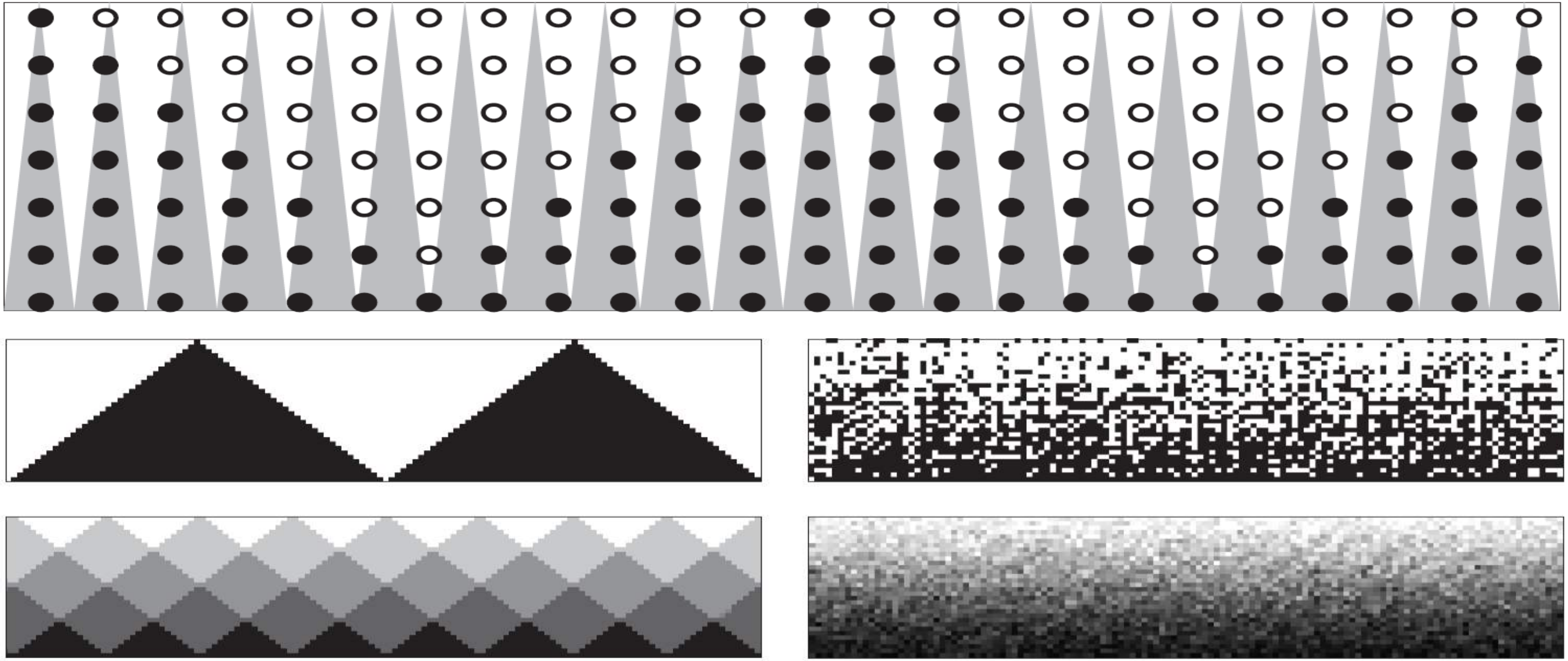
extinction coefficients

In-scattering

extinction

optical depth

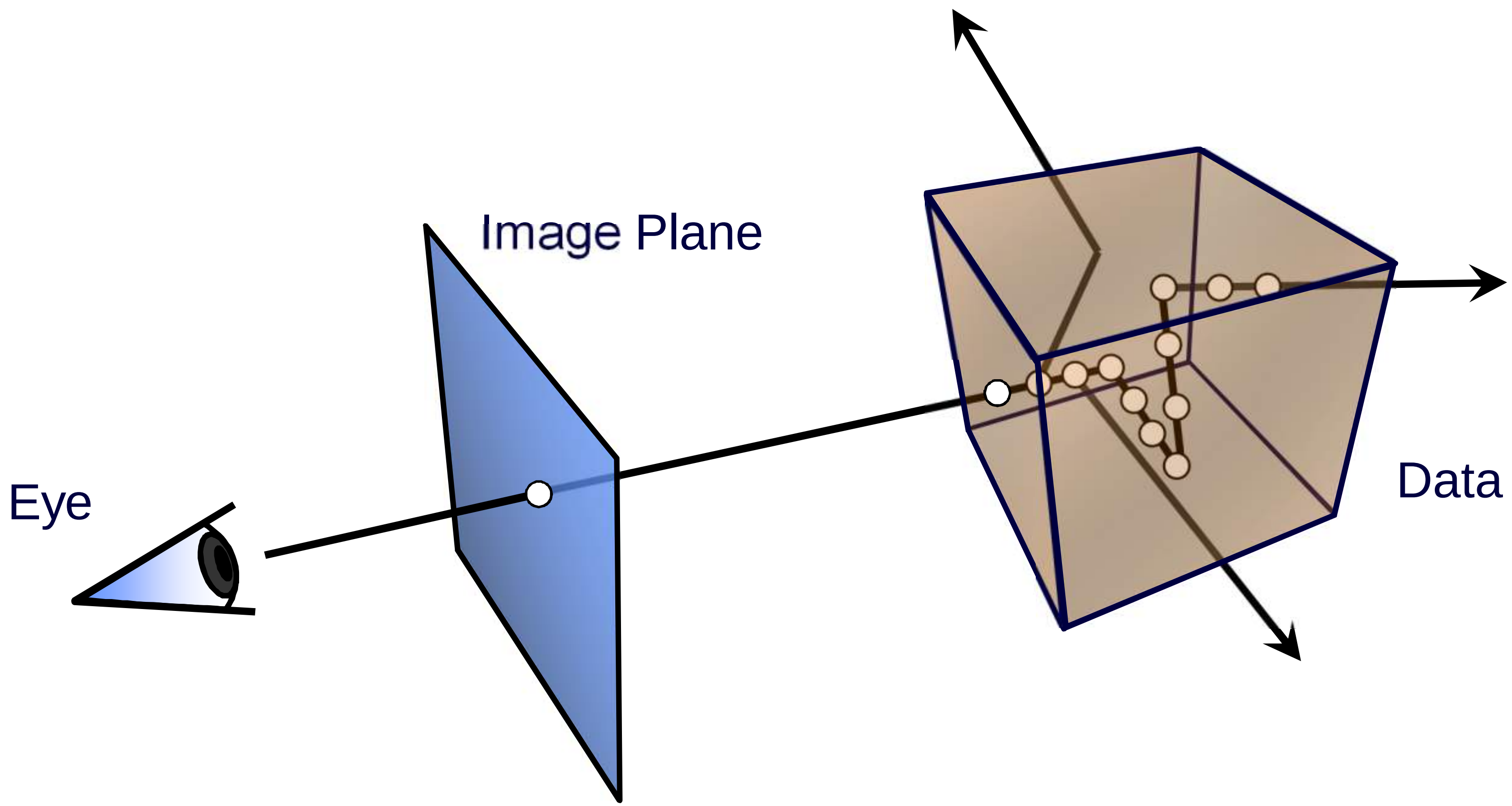
Monte-Carlo Integration



Riemann

Monte-Carlo

Volumetric Monte-Carlo Path Tracing

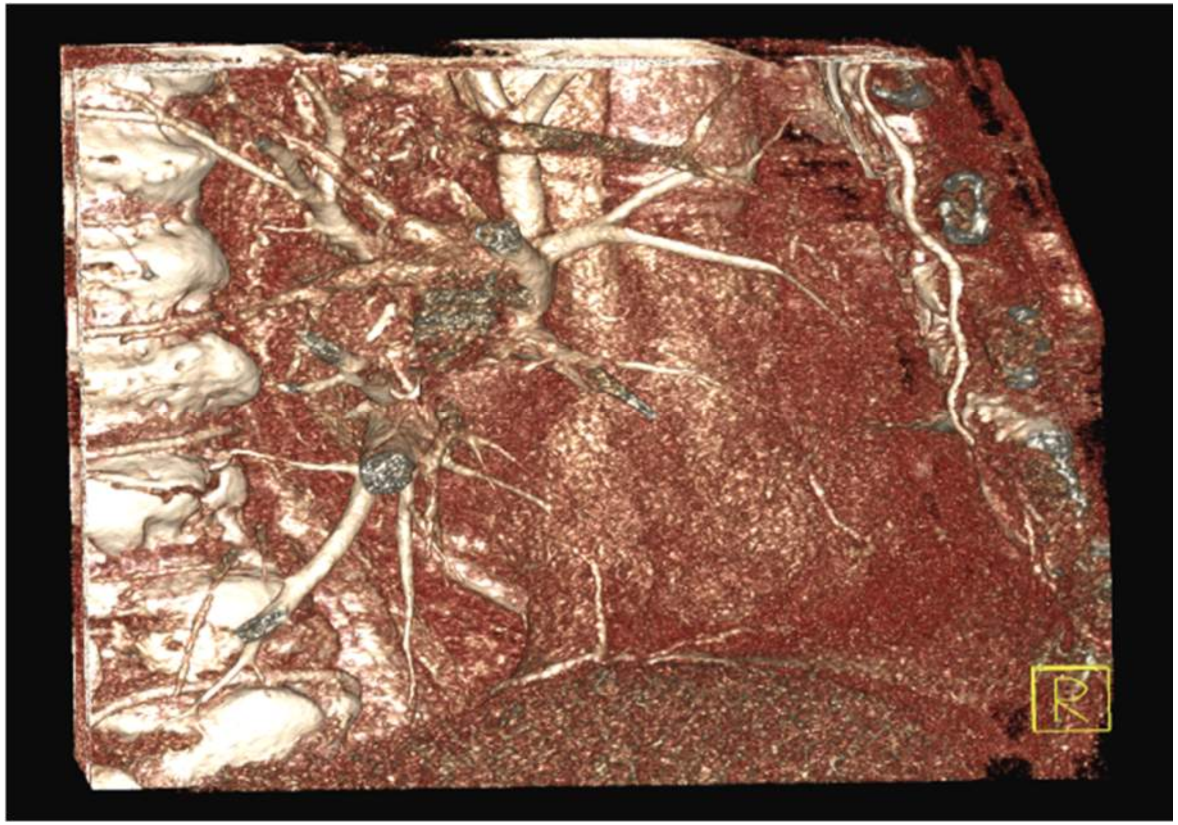


Ray Casting vs Path Tracing

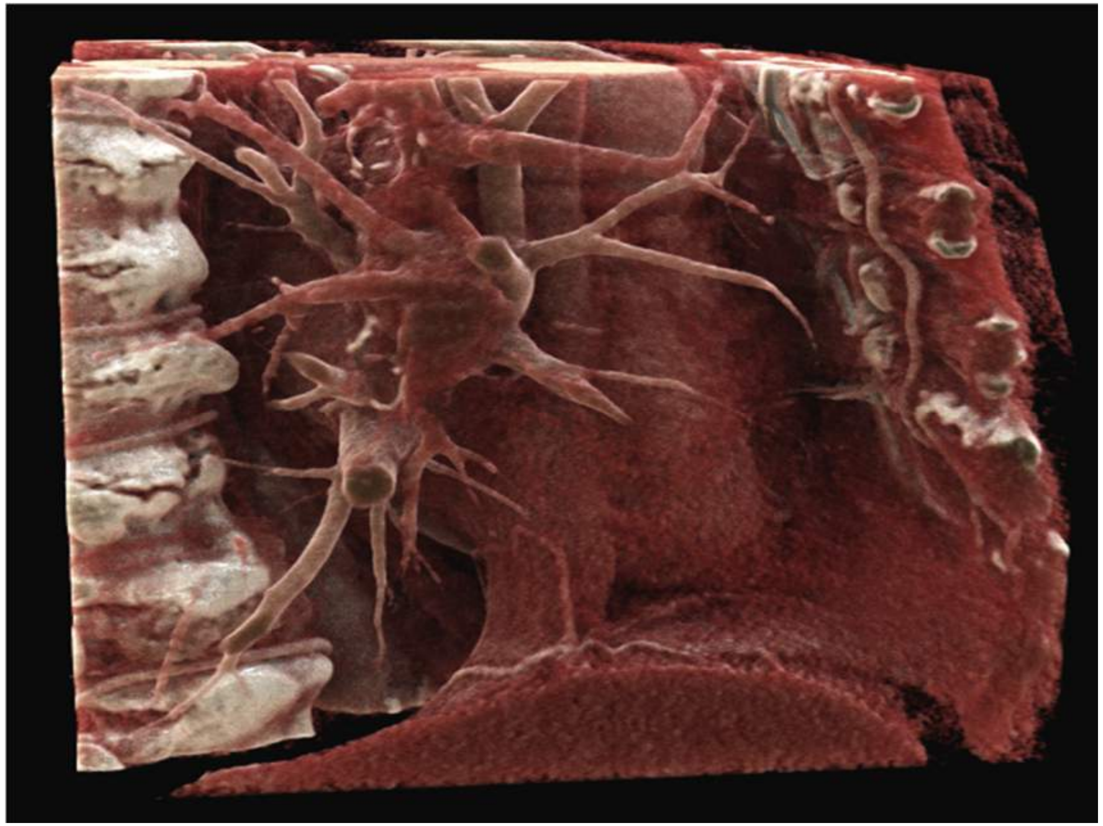
Data by courtesy of: Vancouver General Hospital, Canada

How Light Interaction is Modeled in Renderers

Traditional Rendering (single scattering)



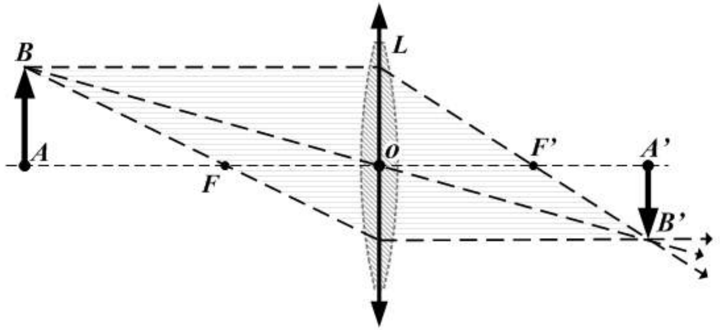
Cinematic Rendering (multi scattering)

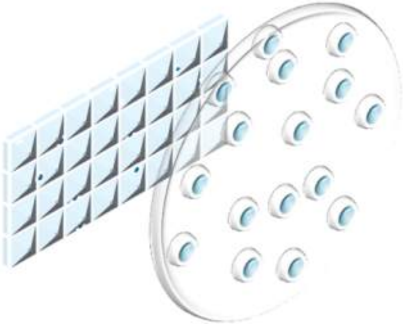


Improving visualization of noisy (low-dose) CT data using Cinematic Rendering

Camera Model

Thin Lens camera with aperture





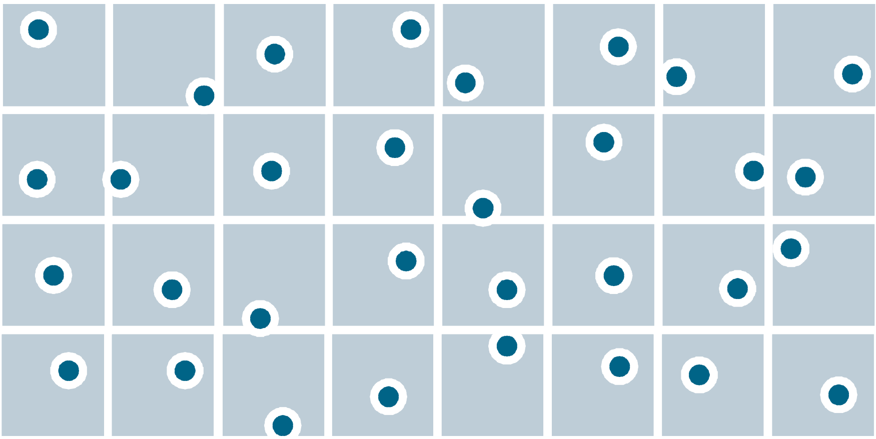
Aperture control

Pinhole camera

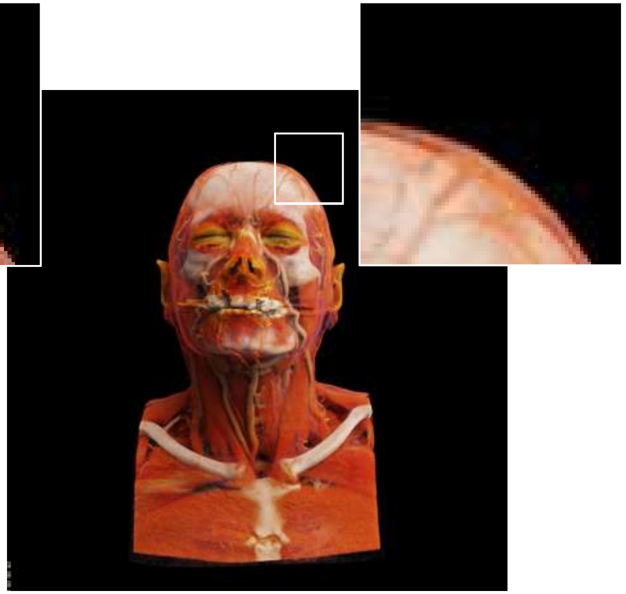
Camera with aperture
Focal plane on coronaries

Camera with aperture
Focal plane on heart center

Stratified sampling of the detector pixels



Anti-aliasing

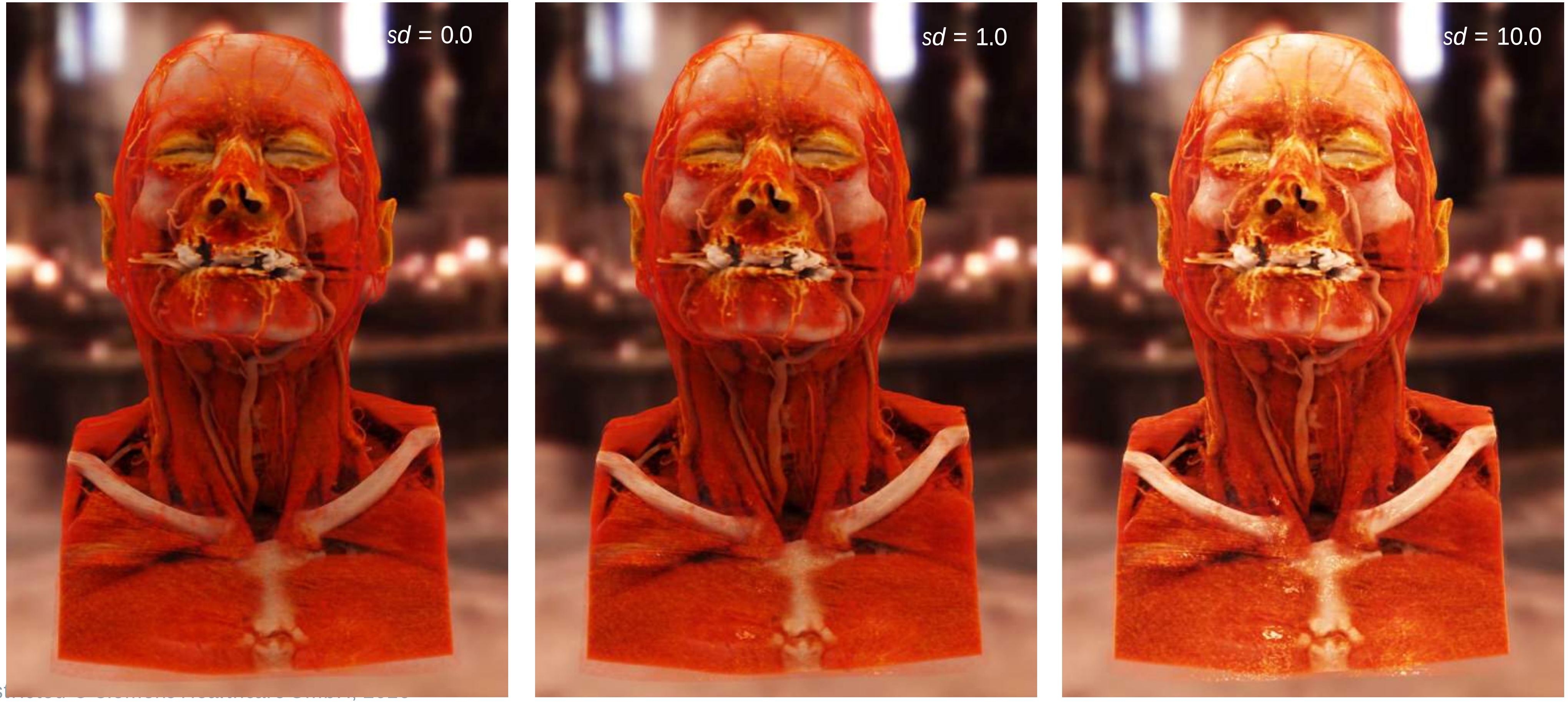


Hybrid Scattering

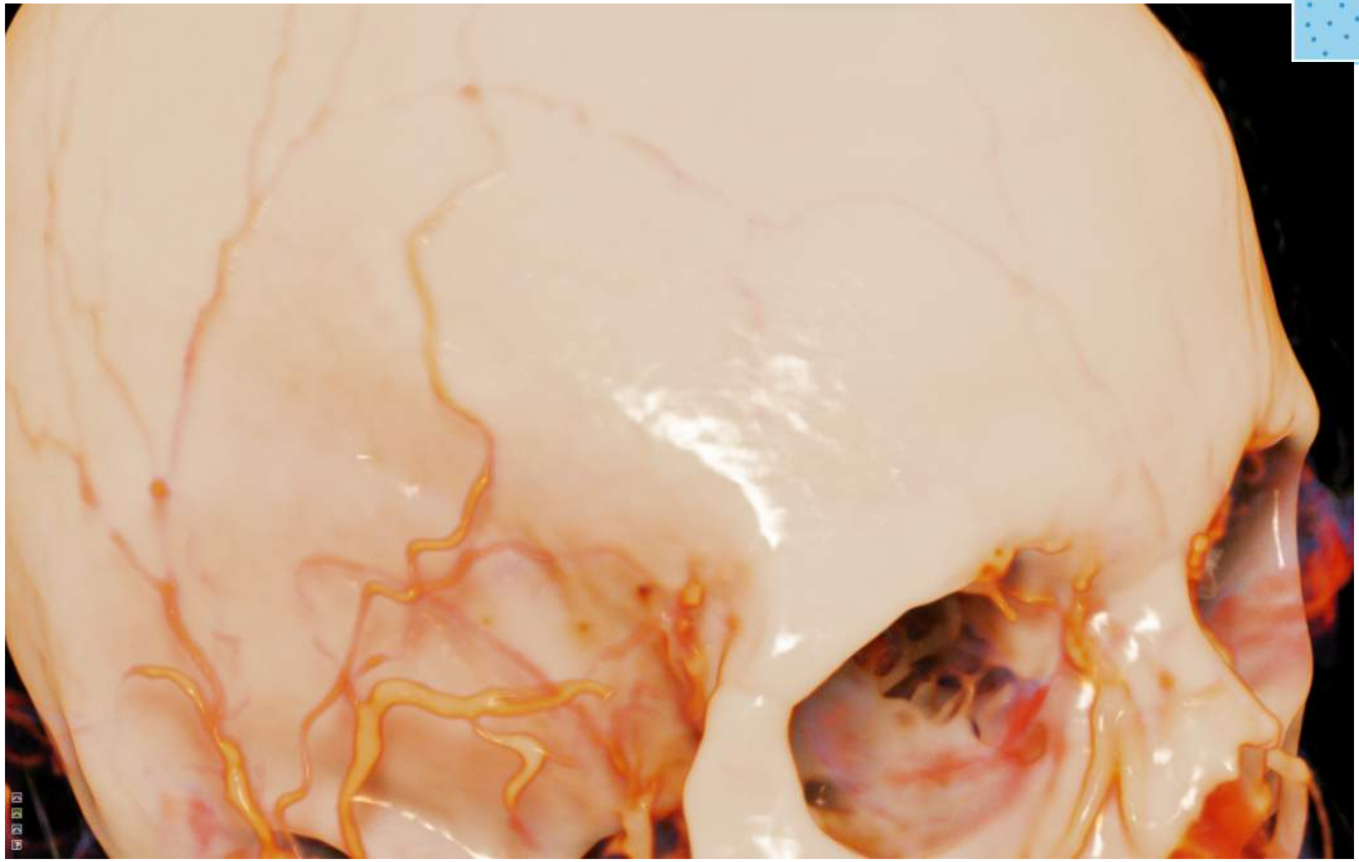
Switch stochastically between surface and volumetric scattering (Kroes 2012)

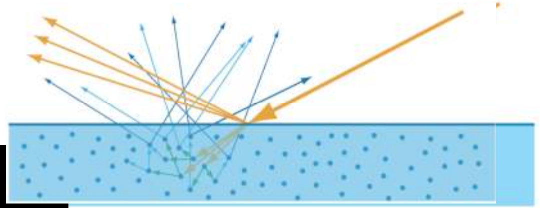
$$P_{BRDF} = \alpha_x \cdot (1 - e^{-sd \cdot |\nabla s(x)|})$$

$$h(x, \omega_i, w_o) = \begin{cases} h_{BRDF}(x, \omega_{i,} \omega_o), & if\ P_{brdf} > \psi \\ h_{HG}(x, \omega_{i,} \omega_o), & otherwise \end{cases}$$



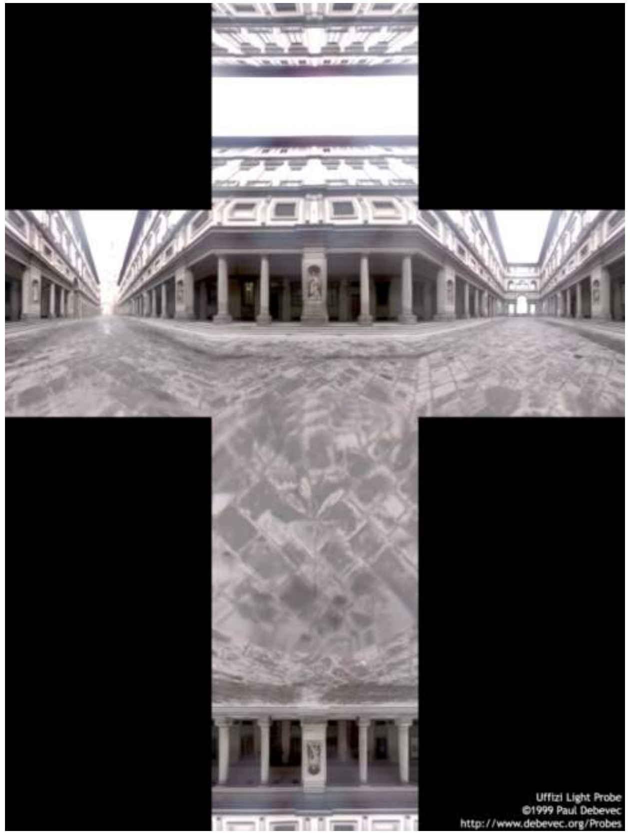
Subsurface scattering



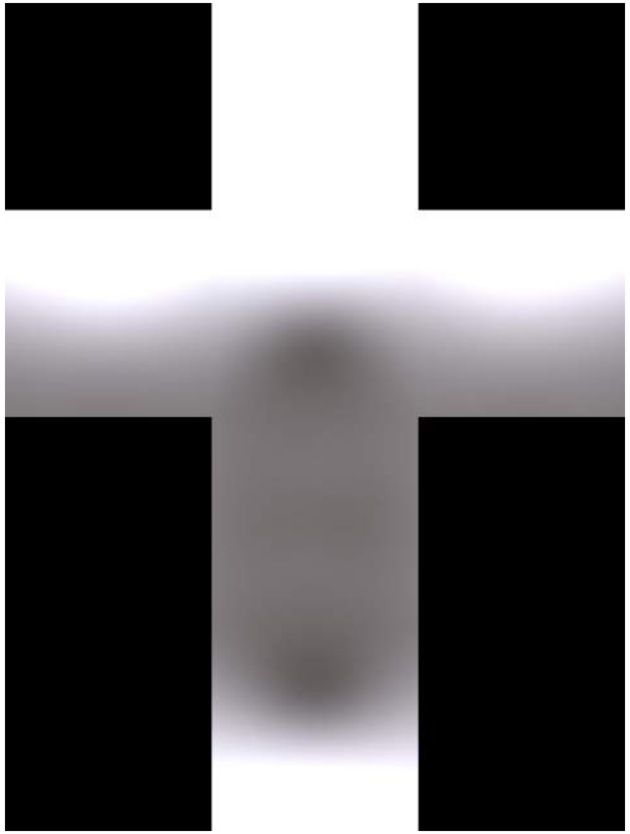


Real-Time Rendering, 3rd edition

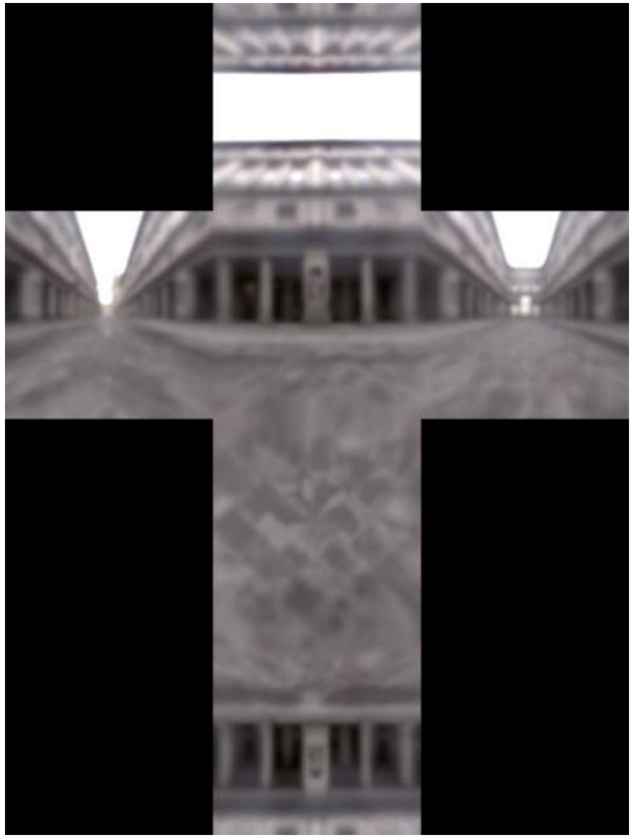
Image-based Lighting



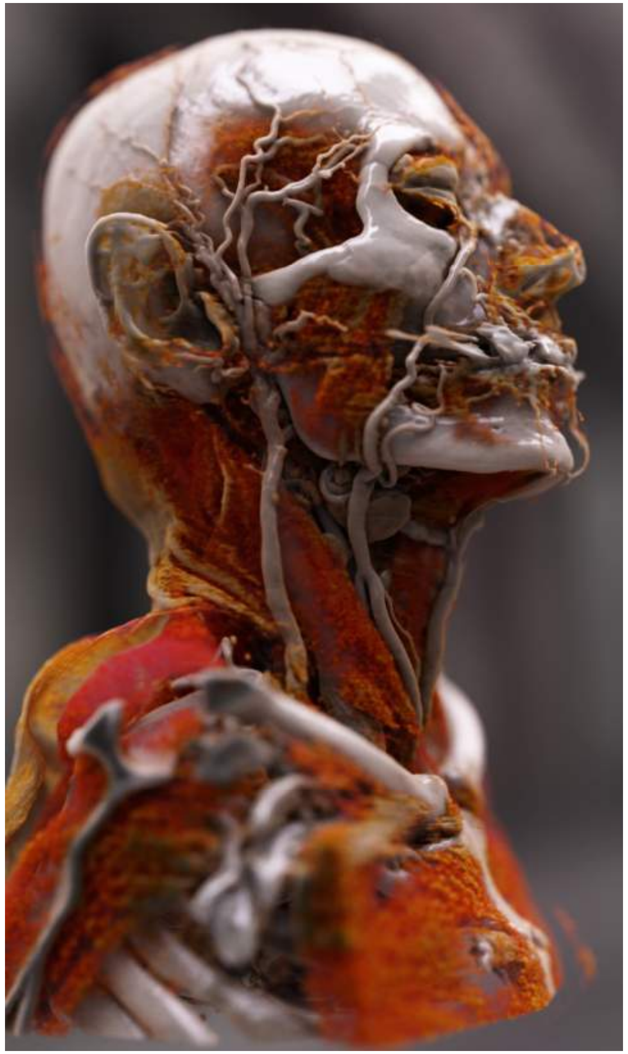
unfiltered



irradiance



reflective



Light Design: Internal Light Sources

functional imaging showing metabolic activity using a positron-emitting radionuclide (tracer)

Light Design: Back Lighting

MR data courtesy of:
Max Planck Institute, Leipzig, Germany

Tone Mapping

Global operators:

- Exposure function

$$L_{display}(x,y) := 1 - \exp(-L_{in}(x,y) * exposure)$$

- Reinhard's global operator

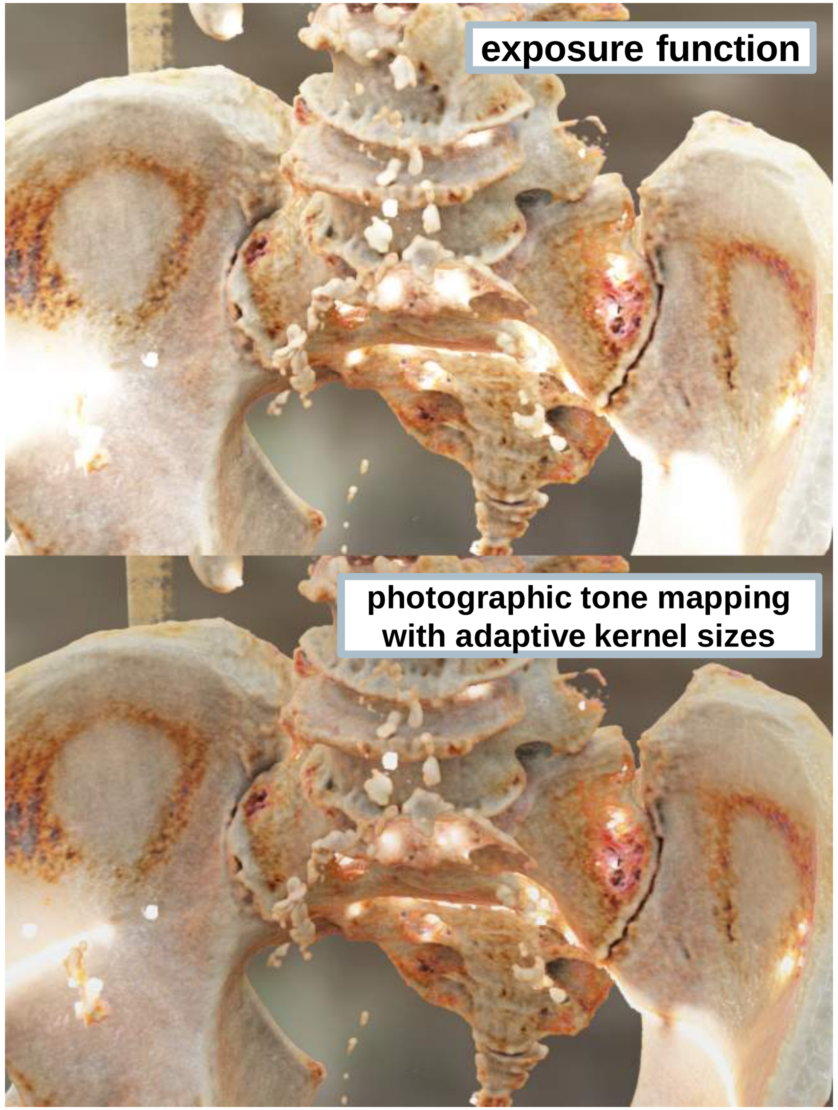
$$L_{display}(x,y) := \frac{L_{in}(x,y)}{1+L_{in}(x,y)}$$

- Filmic tone mapping: Uncharted 2 operator

$$L_{display}(x,y) := whitescale * \left(\frac{L(x,y)*(A*L(x,y)+C*B)+D*E}{L(x,y)*(A*L(x,y)+B)+D*F} - \frac{E}{F} \right)$$

Local operators:

For example: E. Reinhard, M. Stark, P. Shirley and J. Ferwerda, *Photographic Tone Reproduction for Digital Images, SIGGRAPH '02*



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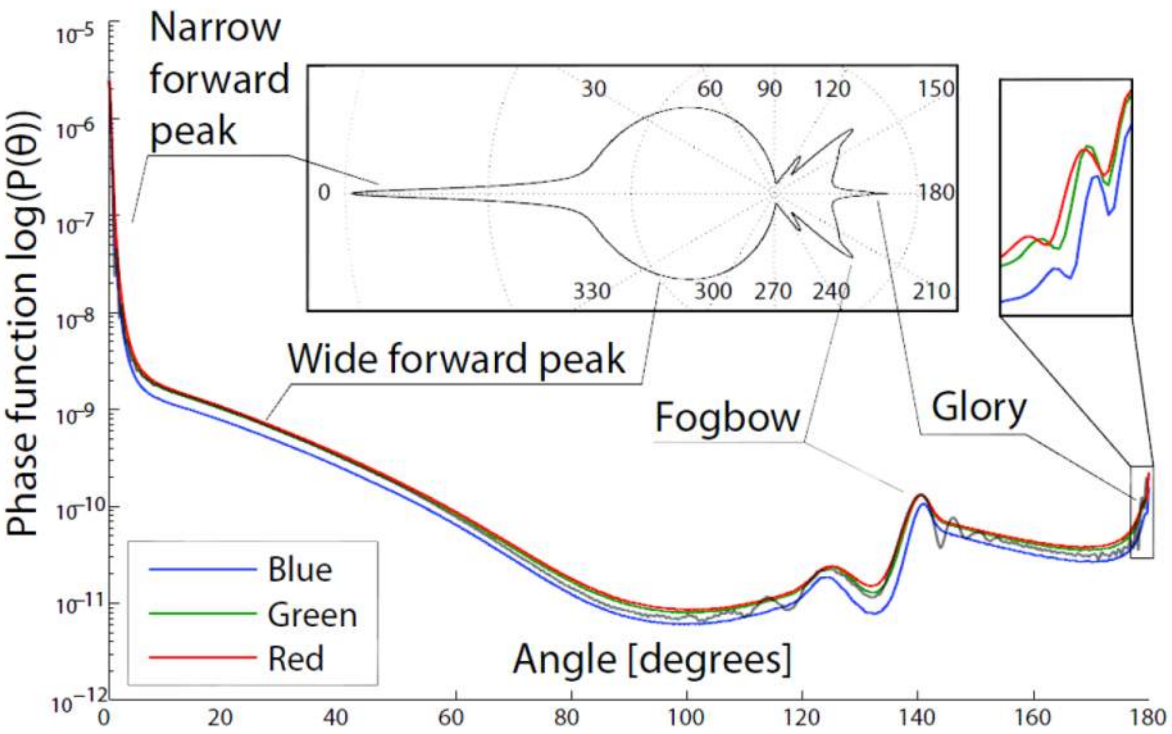
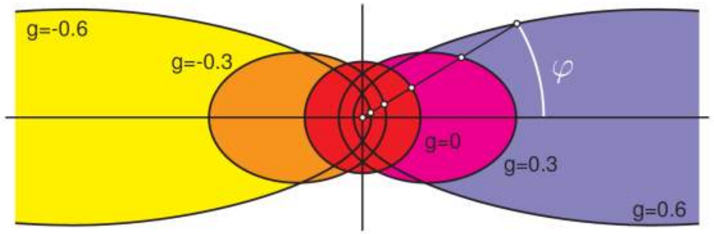
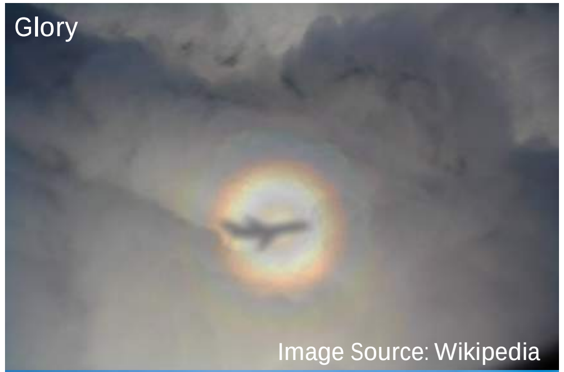
Phase Functions

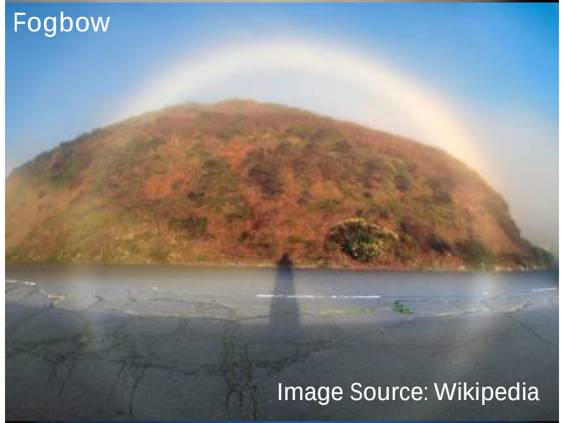


Henyey-Greenstein:

$$G(\varphi, g) = \frac{1 - g^2}{(1 + g^2 - 2g\cos\varphi)^{\frac{3}{2}}}$$

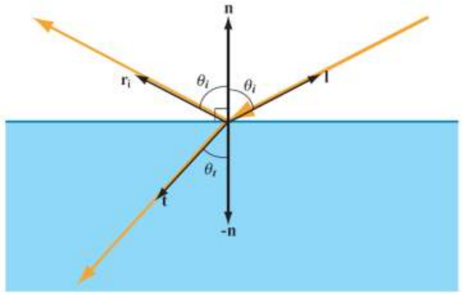






Transparent hulls

Foil	Ice	Water	Glass



Real-Time Rendering, 3rd edition

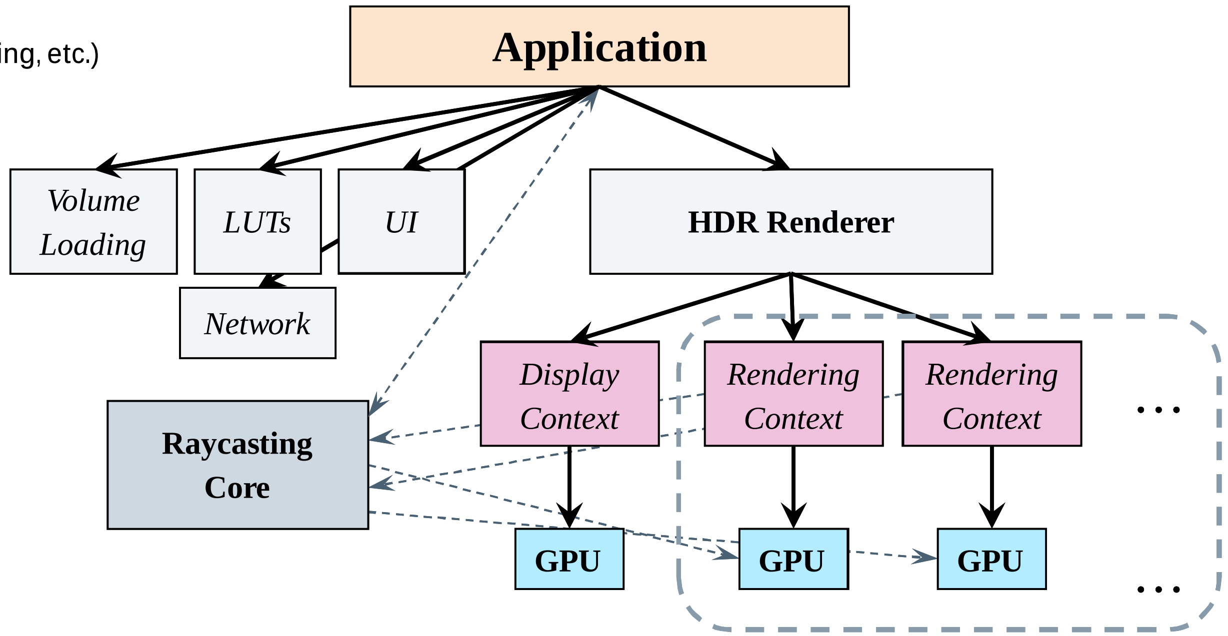
Schlick approximation

Scalable architecture leveraging distributed multi-GPU OpenGL rendering

- *Rendering Context*
  - Manages the resources and rendering algorithms for a single GPU in a rendering node

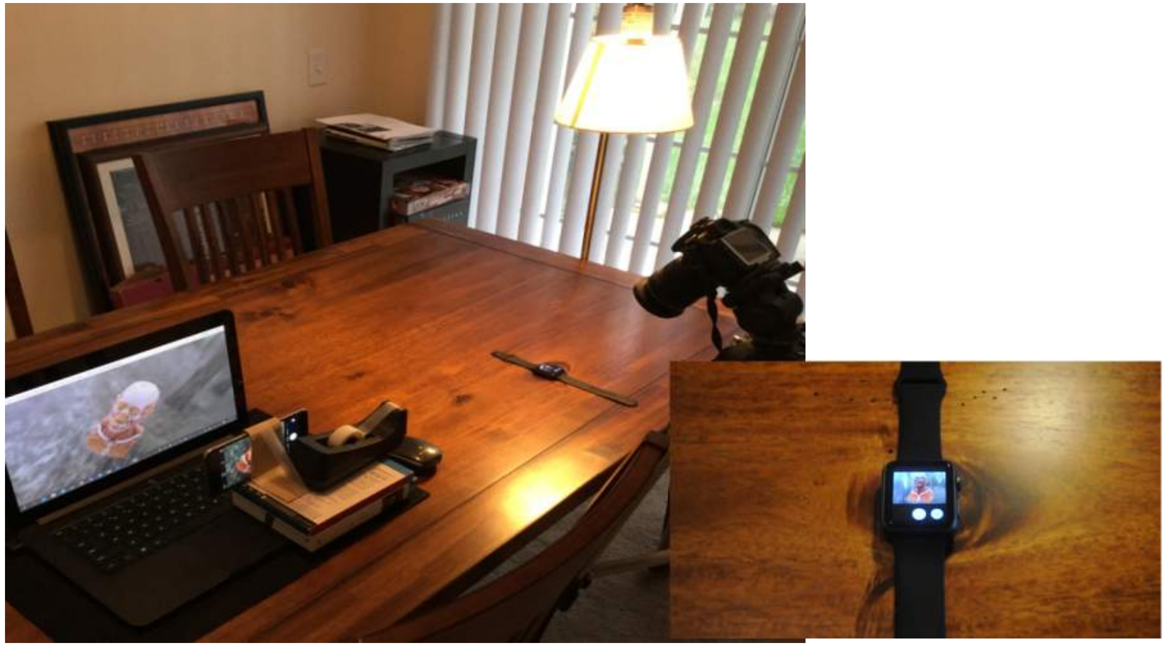
- *Raycasting Core*
  - Rendering core component, GLSL shader

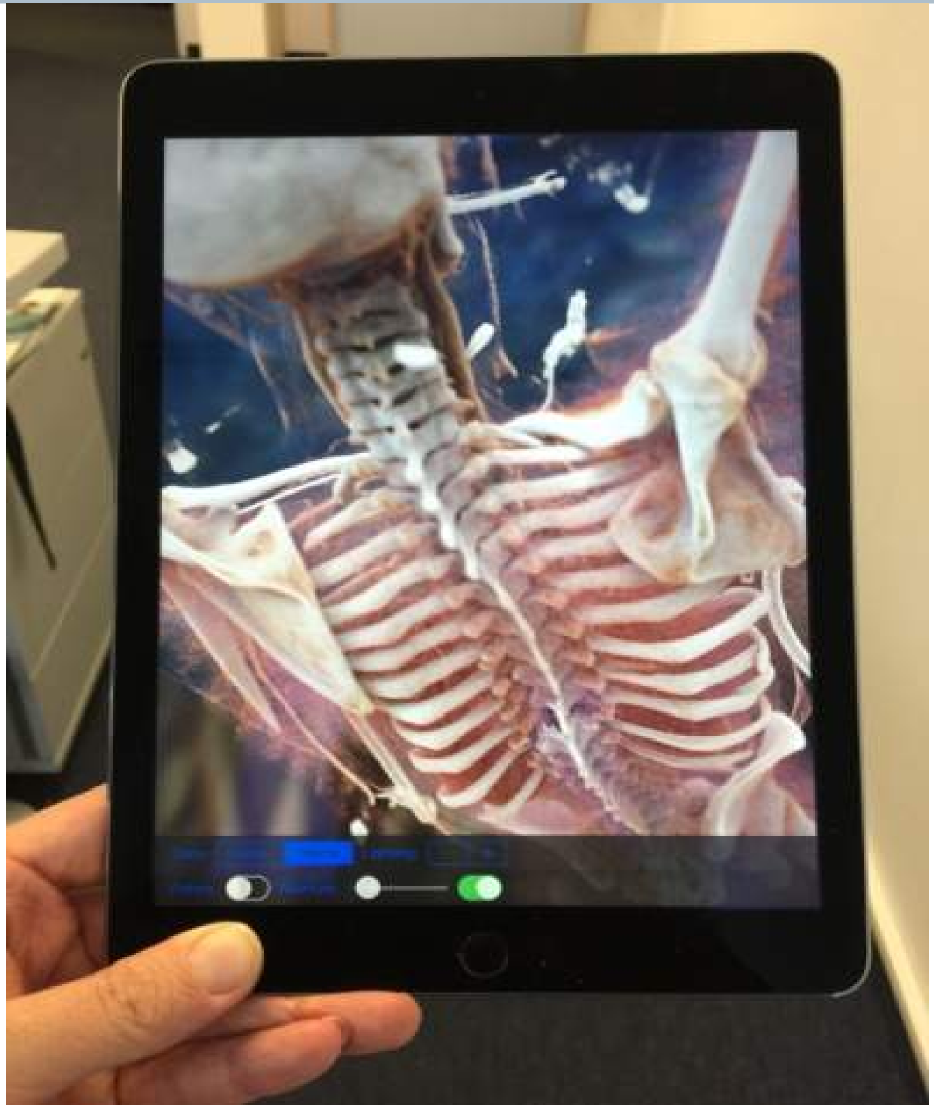
- *Display Context*
  - Manages the rendering results of local Rendering Contexts (GPU-to-GPU memory transfer (NV_copy_image), compositing, rescaling, tone-mapping, etc.)
  - May share a GPU with a *Rendering Context* or run on dedicated low-power GPU
  - Image capture and video streaming for remote viewing applications
  - GPU-based compositing and tone-mapping, fast image capture using NVIDIA Inband Frame Readback (IFR) with 4:2:0 chroma subsampling
  - Very low latency/bandwidth streaming for remote interaction applications



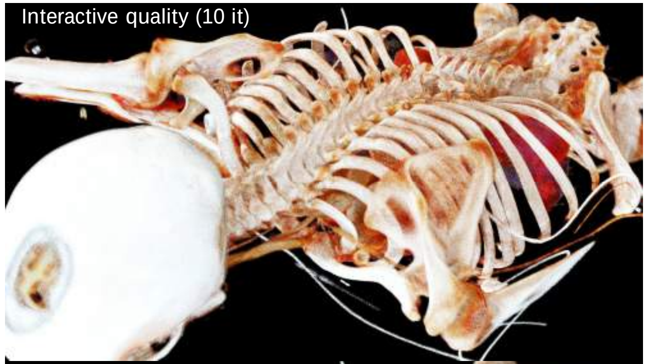
Mobile Cinematic Rendering

- Cloud-based Rendering Server, iOS client
- iOS native renderer (iPad Air 2/iPhone6)
- Android native renderer (Tegra K1)
- iWatch from cloud or iPhone (30 fps)

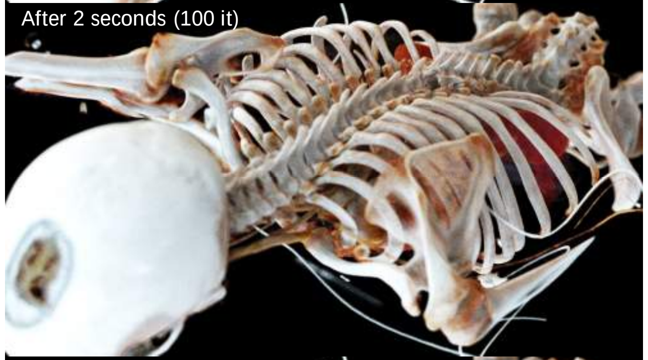




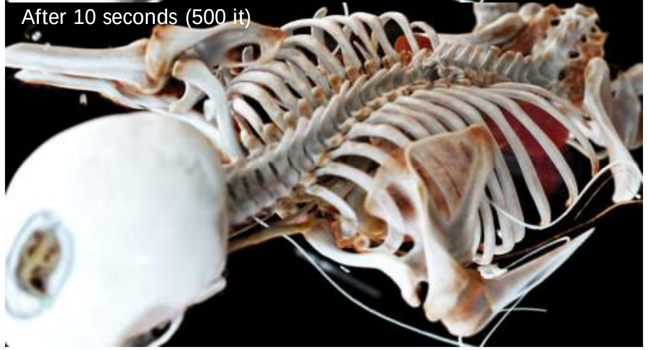
Computational Load (GTX 980, data: 512x512x1699@16bit, 1920x1080)



total rays:	20.736.000
total paths:	14.024.580
total scatter events:	41.064.594
total absorption events:	6.278.458
total light lookups:	34.397.030
total gradients:	27.230.231
total sample events:	1.687.624.300
total classification events:	1.503.524.423



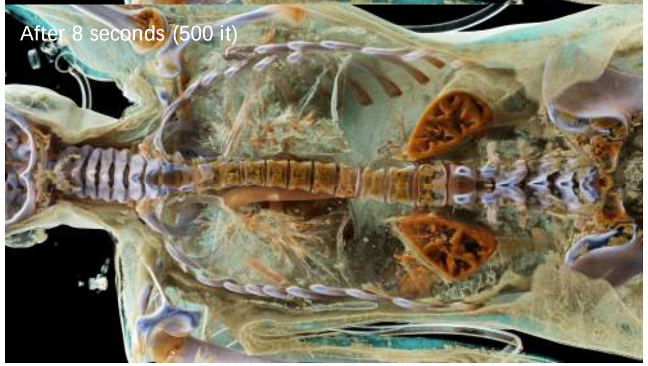
total rays:	207.360.000
total paths:	138.562.408
total scatter events:	442.808.953
total absorption events:	85.142.516
total light lookups:	365.000.004
total gradients:	224.830.809
total sample events:	16.769.200.328
total classification events:	15.213.027.095



total rays:	1.036.800.000
total paths:	689.463.816
total scatter events:	2.189.449.922
total absorption events:	419.597.242
total light lookups:	1.805.740.978
total gradients:	1.130.386.976
total sample events:	84.105.247.524
total classification events:	76.286.984.974

total rays:	20.736.000
total paths:	17.975.530
total scatter events:	54.965.441
total absorption events:	10.318.989
total light lookups:	24.426.885
total gradients:	44.807.988
total sample events:	943.121.939
total classification events:	653.538.011

total rays:	207.360.000
total paths:	173.973.381
total scatter events:	563.696.623
total absorption events:	111.945.658
total light lookups:	313.506.260
total gradients:	384.046.705
total sample events:	10.798.965.836
total classification events:	8.287.325.606

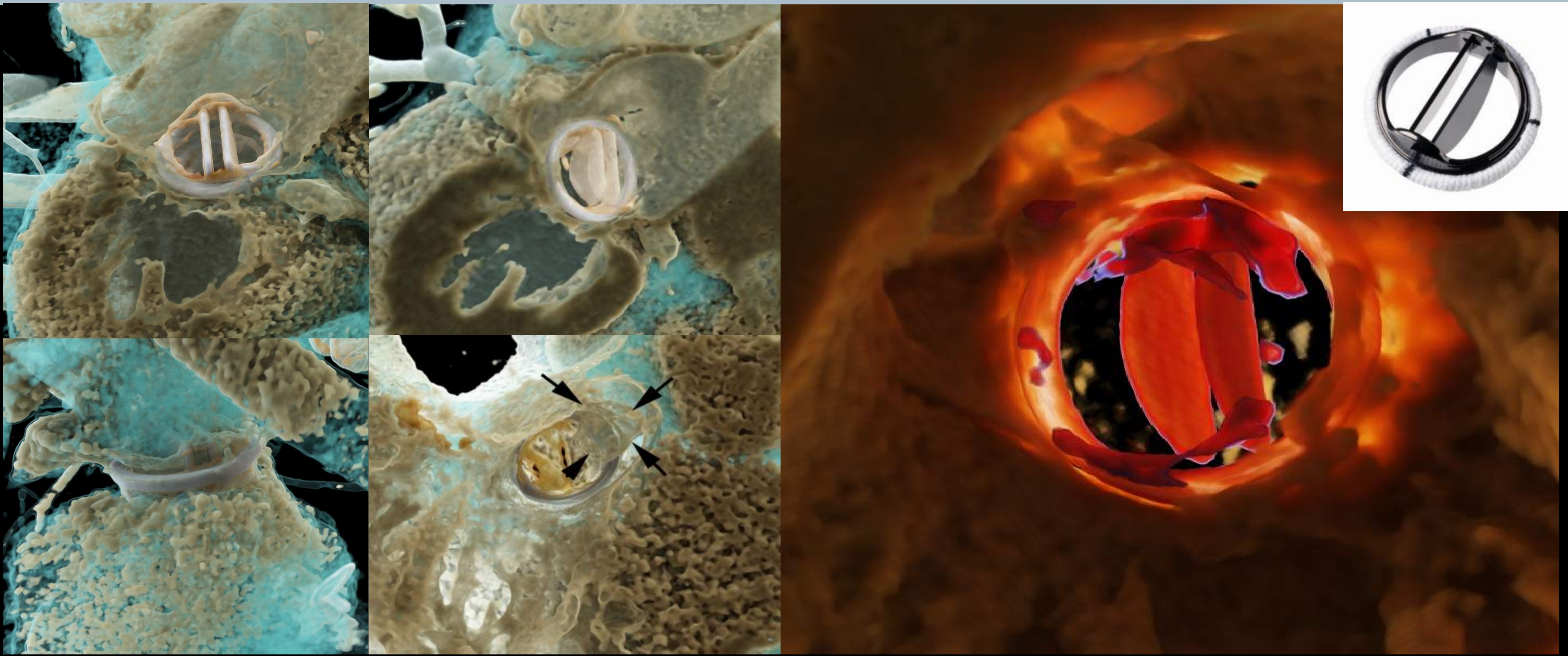


total rays:	1.036.800.000
total paths:	862.863.830
total scatter events:	2.786.035.042
total absorption events:	556.145.086
total light lookups:	1.549.583.536
total gradients:	1.896.305.376
total sample events:	53.563.338.027
total classification events:	41.148.705.771

Application: CT Heart

Data by courtesy of:
Hospital do Coração, São Paulo, Brazil

Application: Artificial Heart Valve



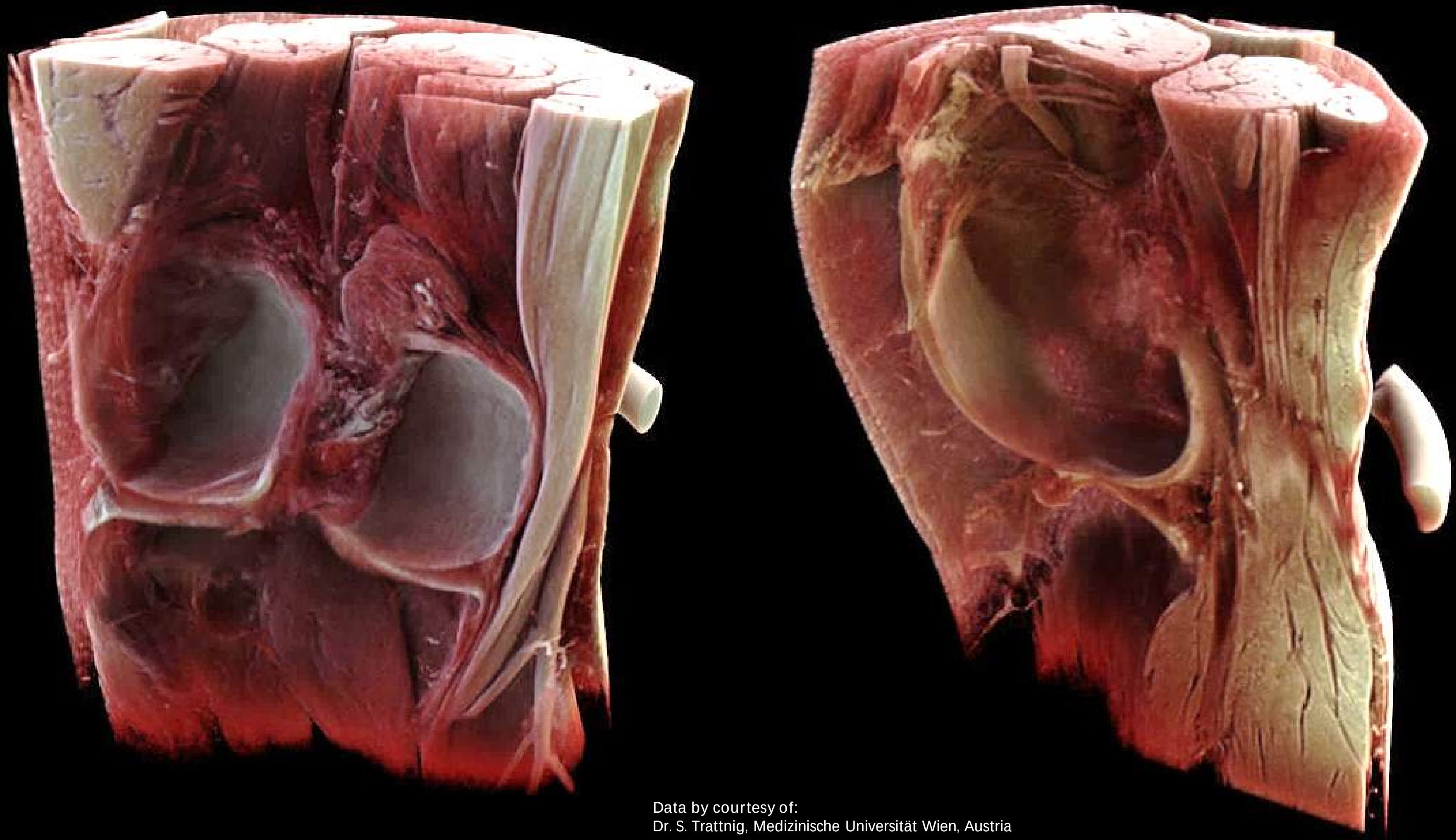
Data courtesy of Dr. Ricardo Budde – Erasmus Medical Center, Rotterdam

Application: Gout visualization by urat detection using Dual-Source CT

Application: Cinematic Rendering of CT Vascular Head

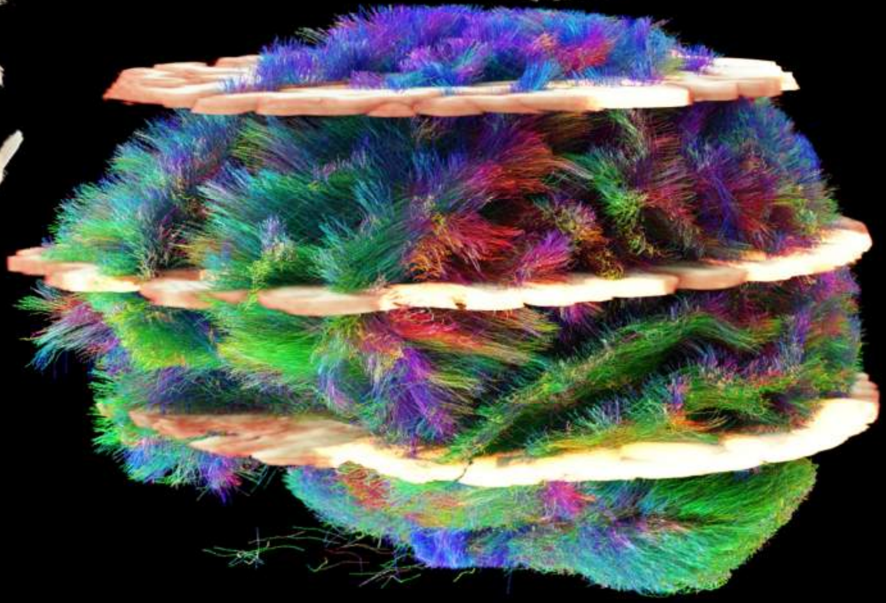
Courtesy of Israelitisches Krankenhaus, Hamburg, Germany

Application: Magnetom 7T Knee



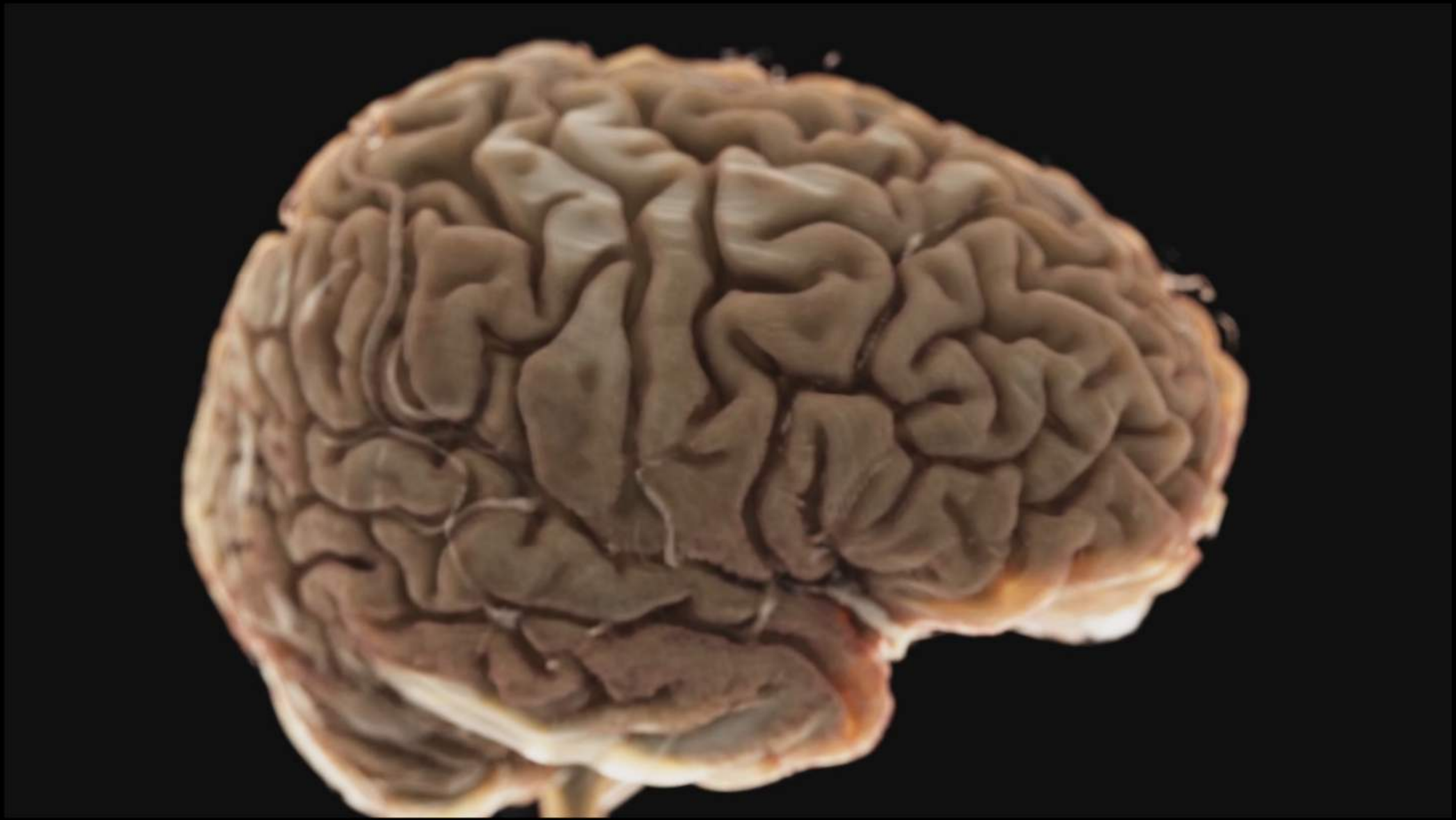
Data by courtesy of:
Dr. S. Trattnig, Medizinische Universität Wien, Austria

Application: MR brain with DTI Fibers



MR data courtesy of:
Max Planck Institute, Leipzig, Germany

Application: Cinematic Rendering of MR 7T Brain



MR data courtesy of:
Max Planck Institute, Leipzig, Germany

Data by courtesy of:
Dr. Philip Alexander Glemser,
Working group leader Forensic Imaging,
German Cancer Research Center, Heidelberg

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Deep Space 8k, Ars Electronica Center, Linz, Austria

- Museum of the future: Intersection of arts, technology, society
- 16x9 meters wall and floor projections, 8192x4320 pixels each, >70 MP active stereo, 120 Hz
- 8 Christie Boxer 4k30 Mirage: 30,000 lumen, 3DLP, 4K projector at 120Hz, 4096x2160 px, shutter glasses
- 2 XI-MACHINES, each with four NVIDIA Quadro M6000, NVIDIA Mosaic technology

2.691.367.920.768 tri-linearly interpolated samples


Credit: Magdalena Leitner


Credit: Florian Voggeneder

Credit: Florian Voggeneder

Conclusions

- Siemens is pioneering the use of NVIDIA GPUs to bring heavy computationally dependent ray/path tracing to medical visualization

- Applications in special diagnostics, surgery planning, communication and education

- Photorealistic/Hyperrealistic images lead to democratization of medical imaging

Thank you for your Attention! Questions?

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