Advanced Visual Medicine: Techniques, Applications and Software

Foundations of Rendering

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Overview

Rendering Modes: X-ray, MIP, shaded displays

Basic volumetric rendering: using raycasting

Transfer functions: mapping raw data to visuals

Rendering quality: post- vs. pre-shaded rendering

Controlling rendering effort: occlusions, importance

Rendering acceleration: rendering on GPUs

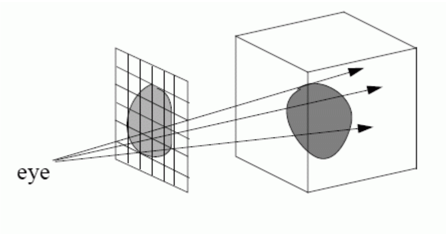
Navigation techniques: e.g., virtual colonoscopy

more info in [Kaufman 05]

Raycasting: Concept

Most intuitive rendering technique

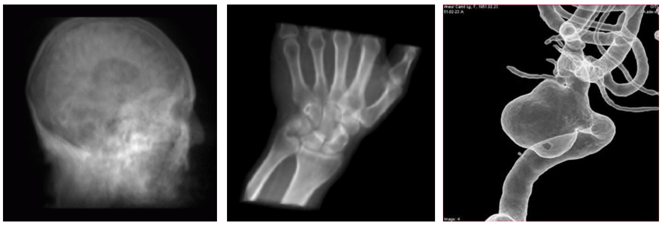
- shoot rays into the scene starting from the eye
- the “gold standard” of volume rendering
- use it to derive the fidelity of other paradigms



Volume Rendering Modes: X-Ray

Rays simply sum everything up that falls into their path

- good for first overview, since no data is culled away
- but overdraw and clutter can be a problem



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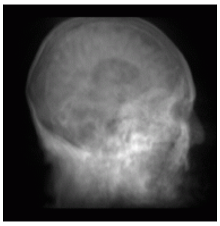
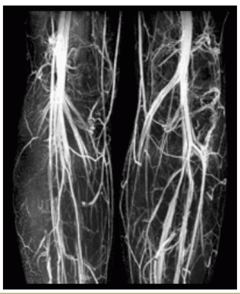



Volume Rendering Modes: MIP (1)

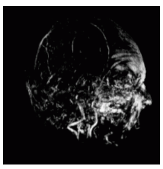
MIP = Maximum Intensity Projection

- a little bit more restrictive than X-ray
- keeps only the maximum value along the ray
- assumes that the maximum value is also the most important
- often used by doctors to get a first look at the data
- great for angiography visualization

legs



head



Volume Rendering Modes: MIP (2)

Various types of MIP [Yen 97] [Shareef 02]

- original MIP (OM)

  $$I(p) = \max_{0 \le z \le D}(f(z))$$

- thin slab MIP (TM)

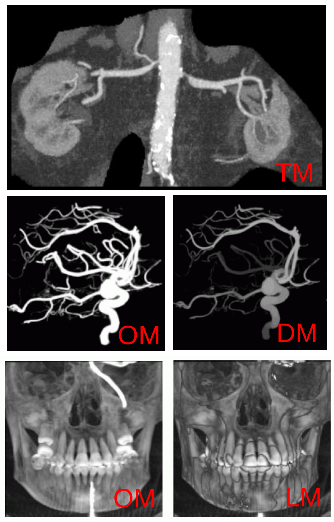
  $$I(p) = \max_{d1 \le z \le d2}(f(z))$$

- depth-shaded MIP (DM)

  $$I(p) = \max_{0 \le z \le D}(d(z) \cdot f(z))$$

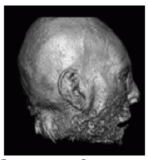
- local maximum MIP (LM)

  $$I(p) = \min_{0 \le z \le D}(z \mid f(z) \ge t \wedge LMAX(z))$$



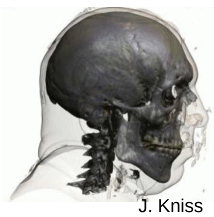
Shaded Volume Rendering

Identify actual surfaces and accentuate them by modeling the reflection of light



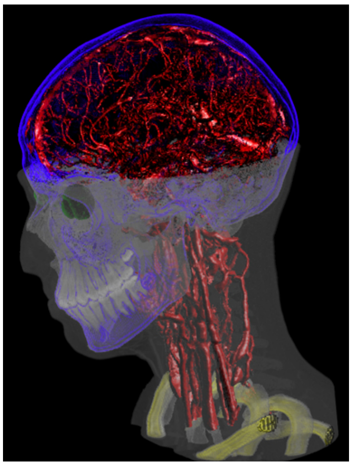
- require surface gradients
- need to map densities to color
- this mapping is done via *transfer functions*

There can be multiple nested surfaces



- to see all one needs to make front surfaces *semi-transparent* and *composite colors*
- achieve this mapping with a transfer function

All Combined: Two-Level Volume Rendering



Skin and teeth: MIP with different intensity ramps

Blood vessels: shaded volume rendering

Skull: contour rendering

Vertebrae: gradient magnitude-weighted transfer function with shaded volume rendering

A clipping plane has been applied to the skin object

[Hauser 01]

Shaded Volume Rendering: Overview

There are two approaches for this:

- polygonal rendering
- direct volume rendering

Shaded Volume Rendering: Overview

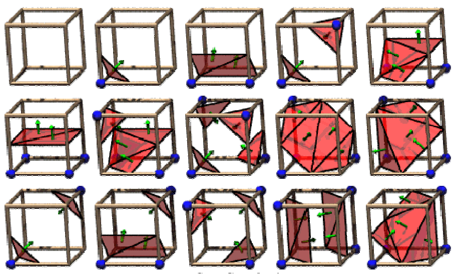
There are two approaches for this:

- polygonal rendering (somewhat dated)
- direct volume rendering (preferred)

Rendering With Polygons: Mesh Generation

Extraction of polygon mesh with *Marching Cubes*

- Set iso-value *iso* to boundary
- Label all voxels below *iso* as “*out*”, else as ”*in*”
- Then each voxel 8-cell fits one of 15 base cases:



The 15 Cube Combinations

[Lorensen 87]

Rendering With Polygons: Mesh Generation

Assemble mesh given the extracted polygons

Render with polygon graphics hardware

Rendering With Polygons: Mesh Generation

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Problem:

- will likely get very large meshes
- graphics pipeline will be overwhelmed
- rendering will not be interactive

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- simplify mesh - undesirable since loss of detail

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- do Direct Volume Rendering (DVR)

Rendering With Polygons: Mesh Generation

Assemble mesh given the extracted polygons

Render with polygon graphics hardware

Problem:

- will likely get very large meshes
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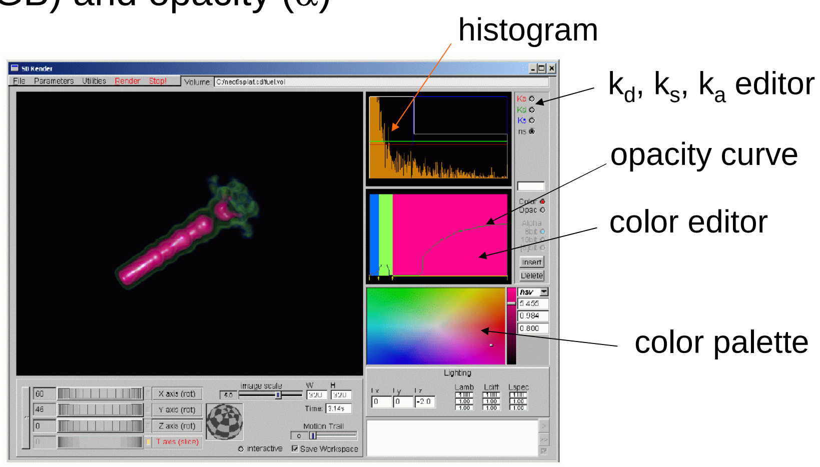
Solution:

- simplify mesh - undesirable since loss of detail
- do Direct Volume Rendering (this tutorial!)

Transfer Functions: Basics

Map the volume scalar data (densities) into color (RGB) and opacity (α)



Back to Volume Rendering

Two modes of rendering

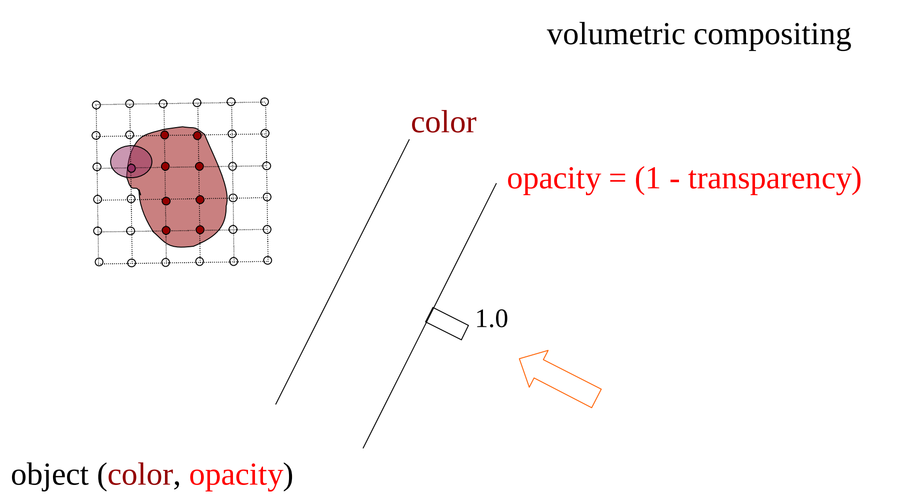
Pre-classified rendering: map first and render later

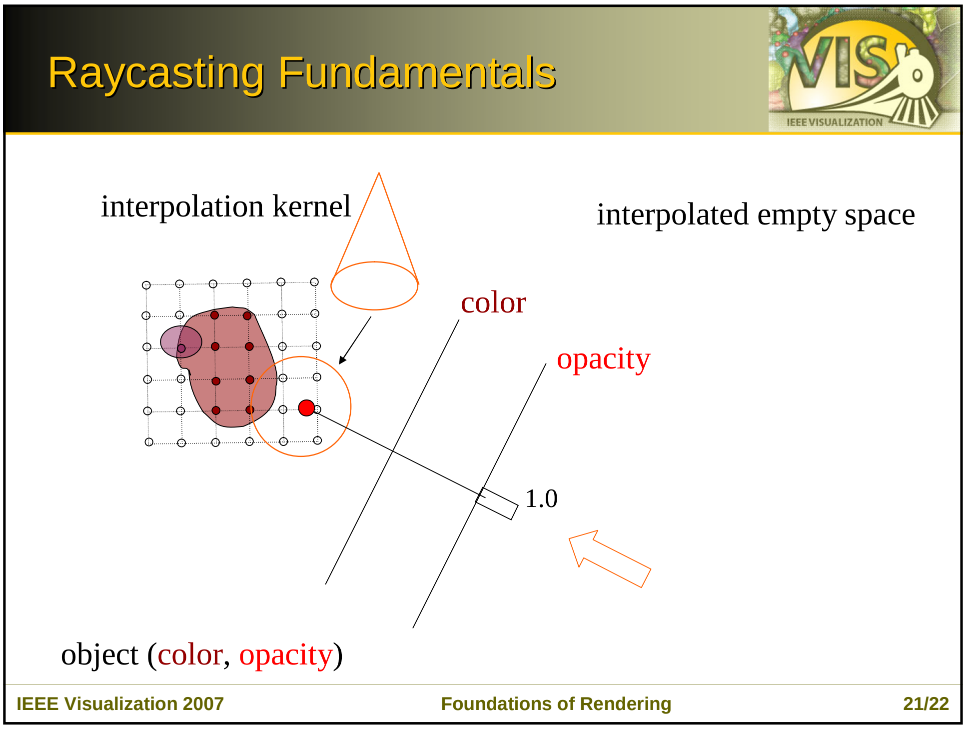
- now the voxels are 4-tuples: RGB color and opacity (=1-transparency)
- also known as *pre-shaded rendering*
- we shall look at this next

Post-classified rendering: render first and map later

- also known as *post-shaded rendering*
- we shall look at this later

Raycasting Fundamentals




Raycasting Fundamentals
IEEE VISUALIZATION
interpolation kernel
interpolated empty space
color
opacity
1.0
object (color, opacity)
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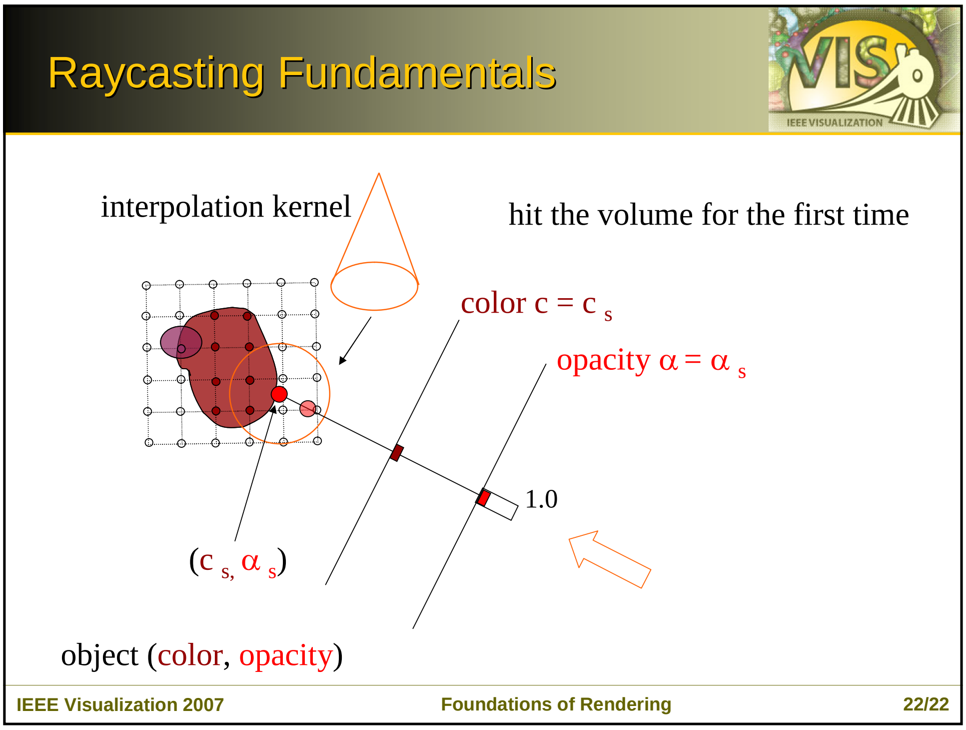
Raycasting Fundamentals
IEEE VISUALIZATION
interpolation kernel
hit the volume for the first time
color c = c s
opacity α = α s
1.0
(c s, α s)
object (color, opacity)
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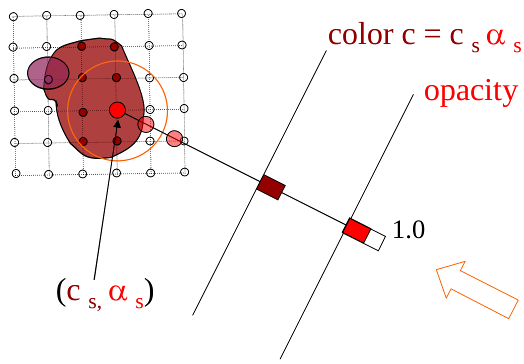
Raycasting Fundamentals

volumetric compositing



object (color, opacity)

Raycasting Fundamentals

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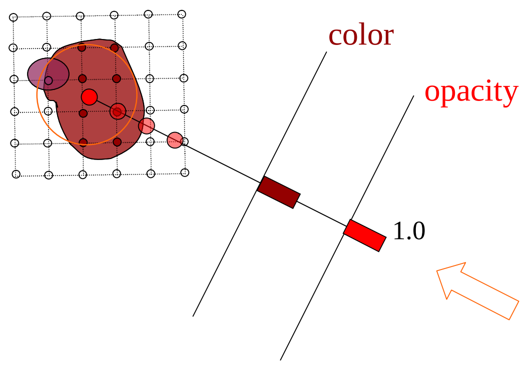

object (color, opacity)

Raycasting Fundamentals

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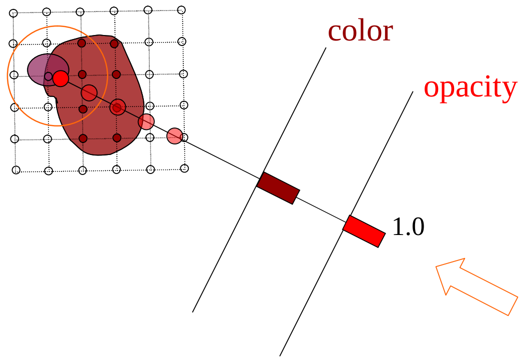

object (color, opacity)

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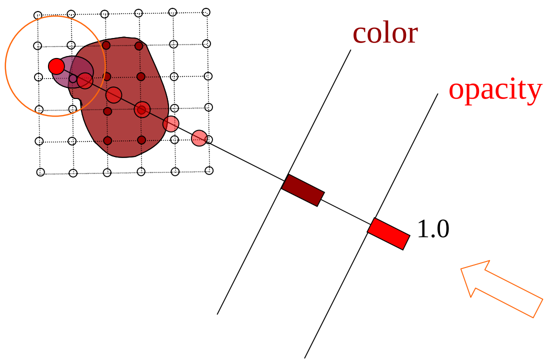
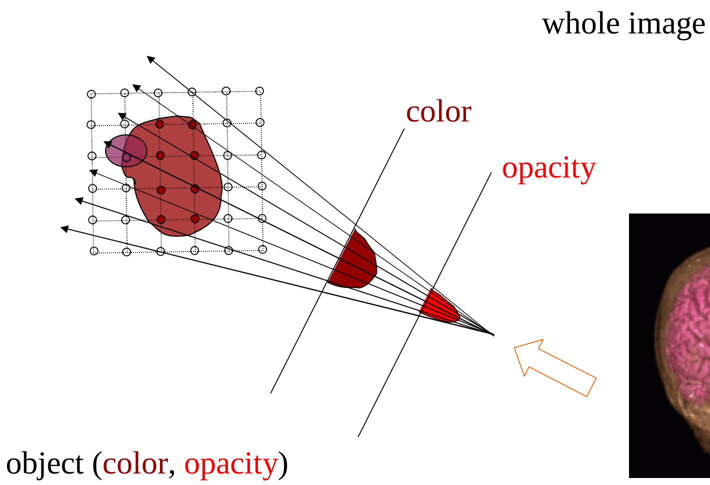
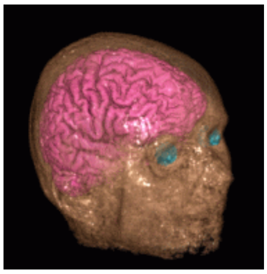


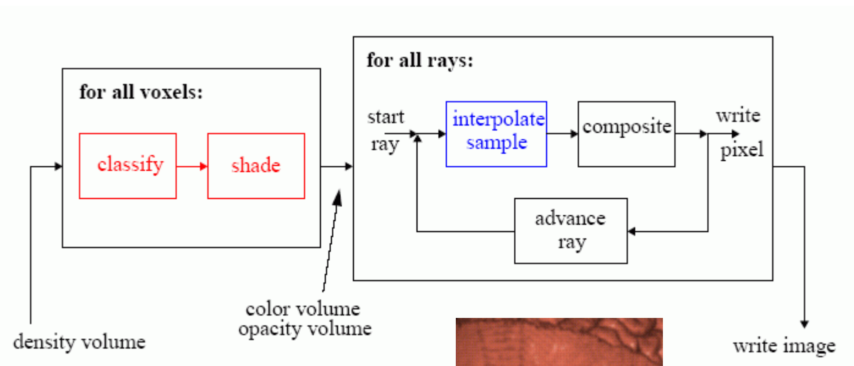
object (color, opacity)

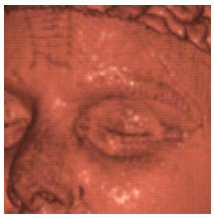
Raycasting Fundamentals



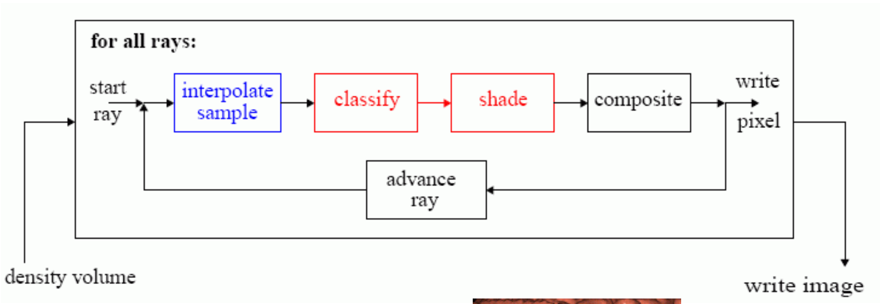


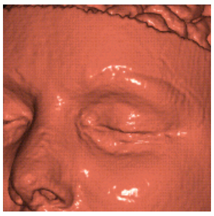
Pre-Shaded Rendering Pipeline



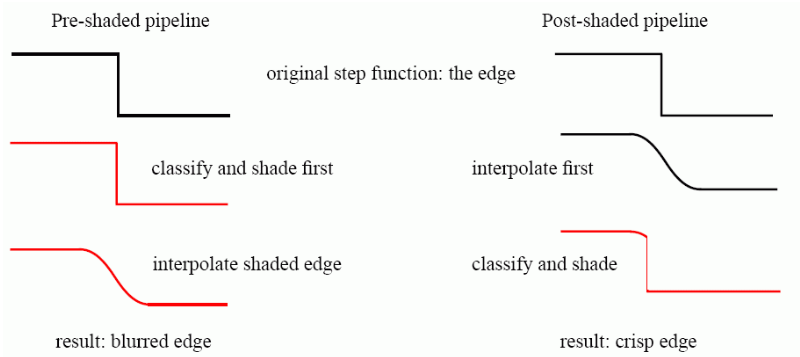


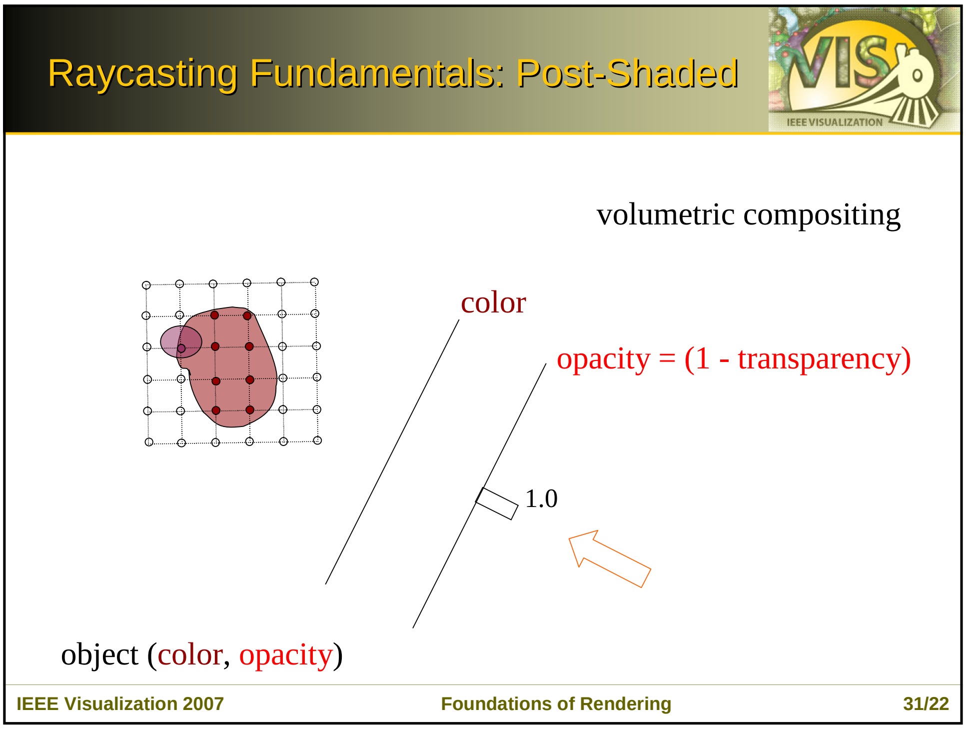
Post-Shaded Rendering Pipeline





Pre- vs. Post-Shaded Rendering




Raycasting Fundamentals: Post-Shaded
IEEE VISUALIZATION
volumetric compositing
color
opacity = (1 - transparency)
1.0
object (color, opacity)
IEEE Visualization 2007
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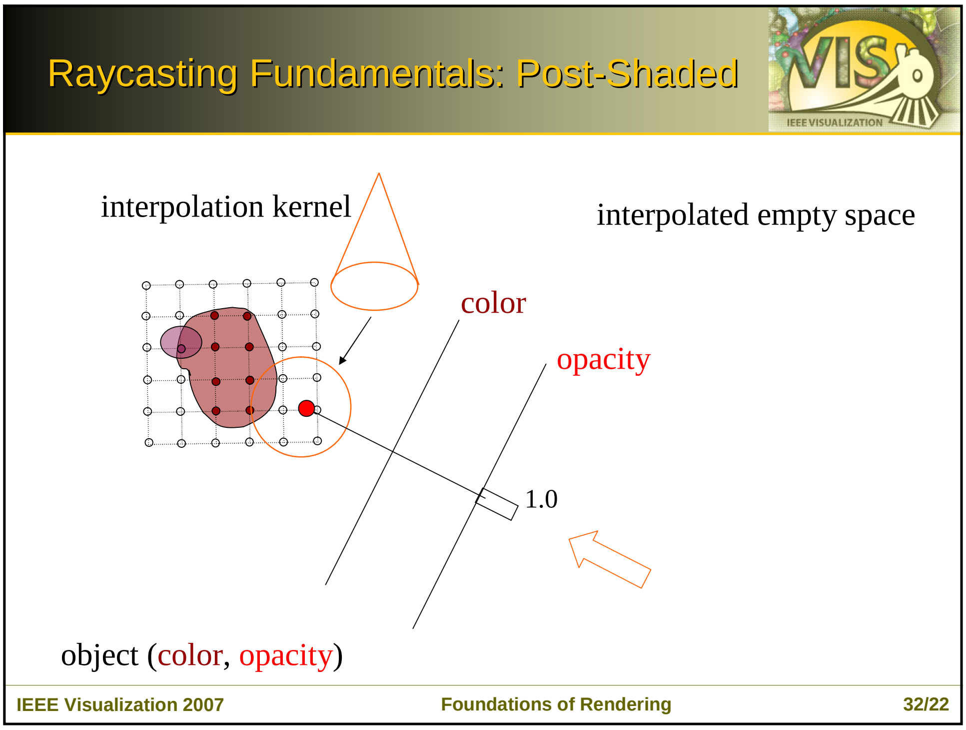
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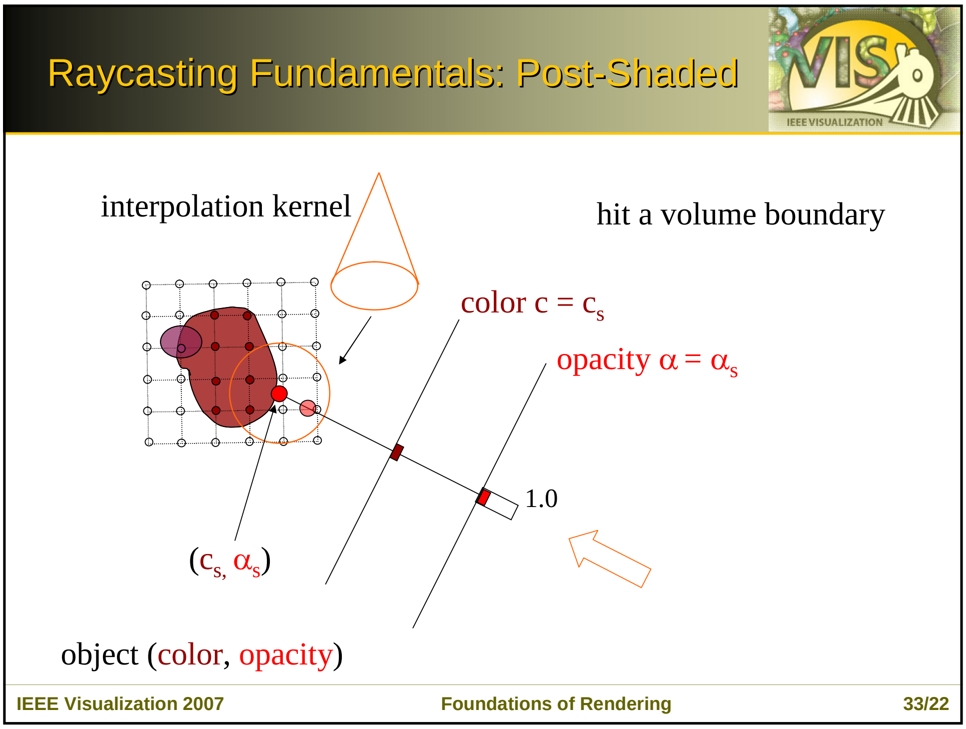
Raycasting Fundamentals: Post-Shaded
IEEE VISUALIZATION
interpolation kernel
hit a volume boundary
color c = c$_s$
opacity α = α$_s$
1.0
(c$_s$, α$_s$)
object (color, opacity)
IEEE Visualization 2007
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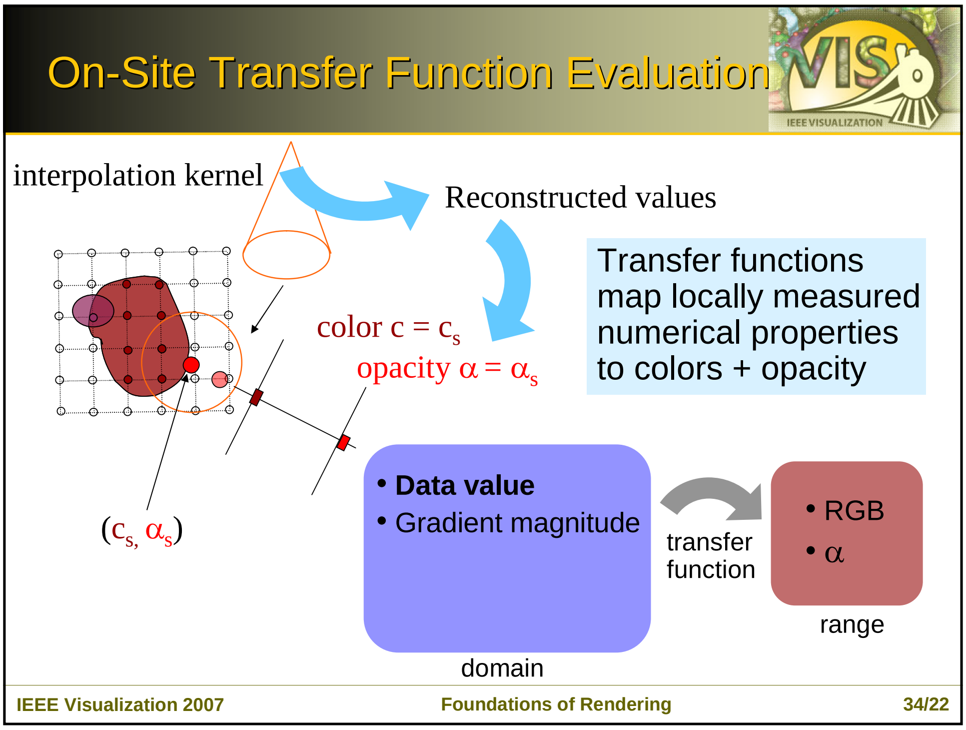
On-Site Transfer Function Evaluation
IEEE VISUALIZATION
interpolation kernel
Reconstructed values
Transfer functions map locally measured numerical properties to colors + opacity
color c = c$_s$
opacity α = α$_s$
(c$_s$, α$_s$)
• Data value
• Gradient magnitude
domain
transfer function
• RGB
• α
range
IEEE Visualization 2007
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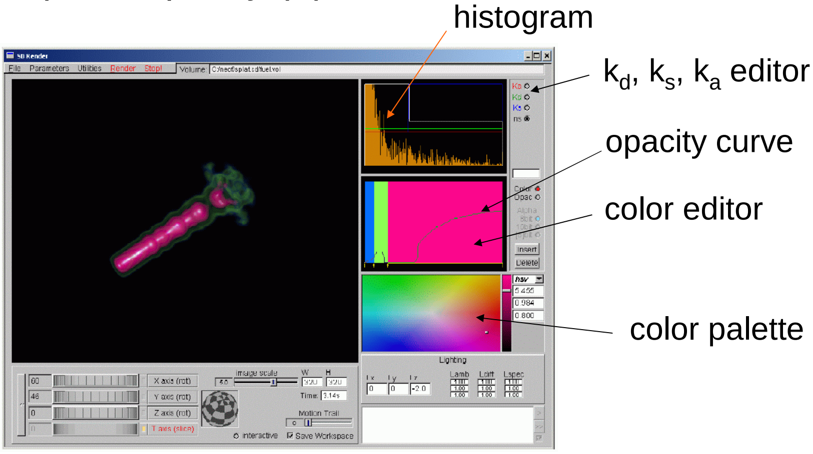
Transfer Functions: Basics

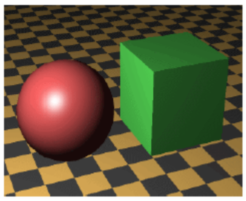
Map the volume scalar data (densities) into color (RGB) and opacity (α)

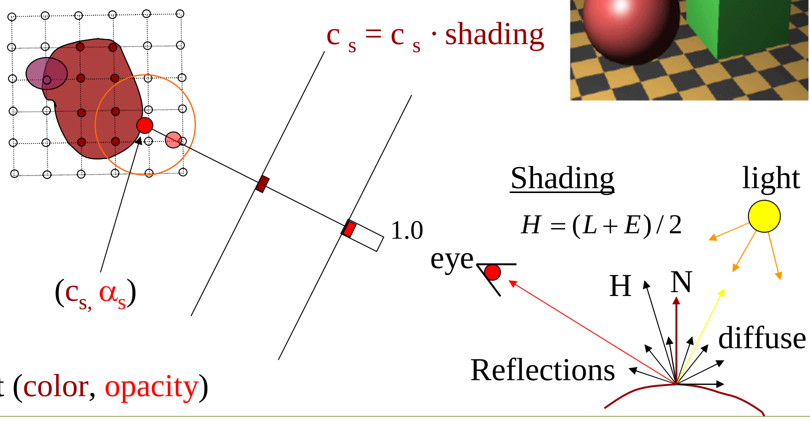


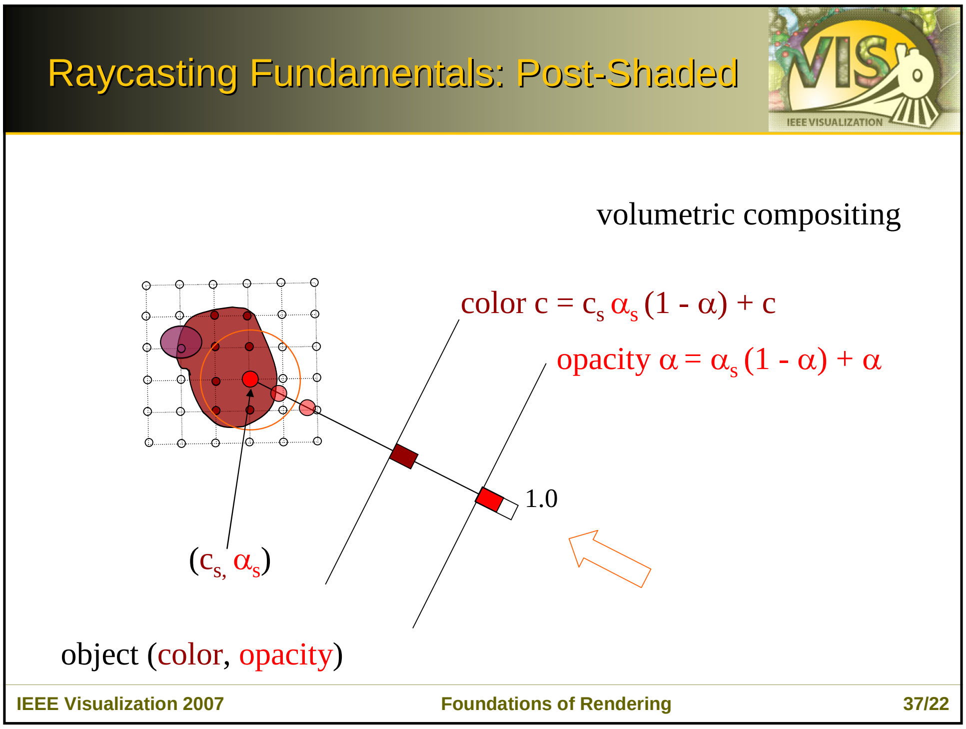
Raycasting Fundamentals: Post-Shaded

$$shading = c_s(k_a I_a + k_d I_L N \cdot L) + k_s I_L (H \cdot N)^{ns}$$

use unit vectors






Raycasting Fundamentals: Post-Shaded
IEEE VISUALIZATION
volumetric compositing
color c = c_s α_s (1 - α) + c
opacity α = α_s (1 - α) + α
1.0
(c_s, α_s)
object (color, opacity)
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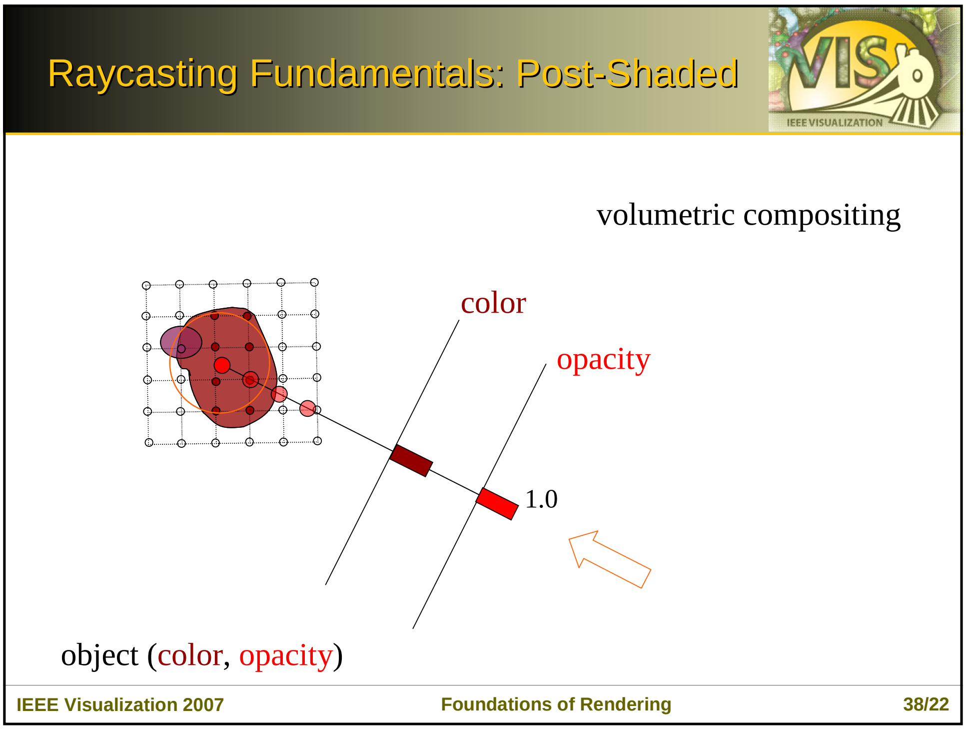
Raycasting Fundamentals: Post-Shaded
IEEE VISUALIZATION
volumetric compositing
color
opacity
1.0
object (color, opacity)
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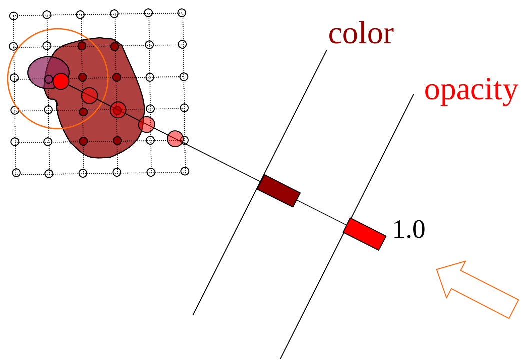
Raycasting Fundamentals: Post-Shaded

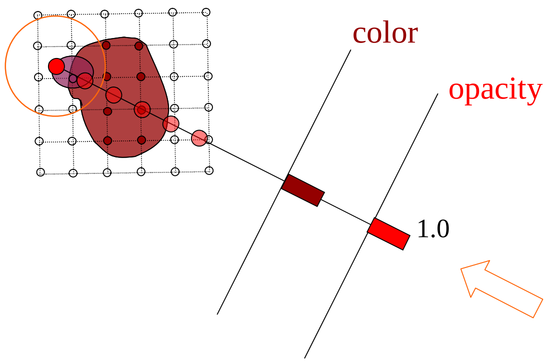
volumetric compositing



object (color, opacity)

Raycasting Fundamentals: Post-Shaded

volumetric compositing



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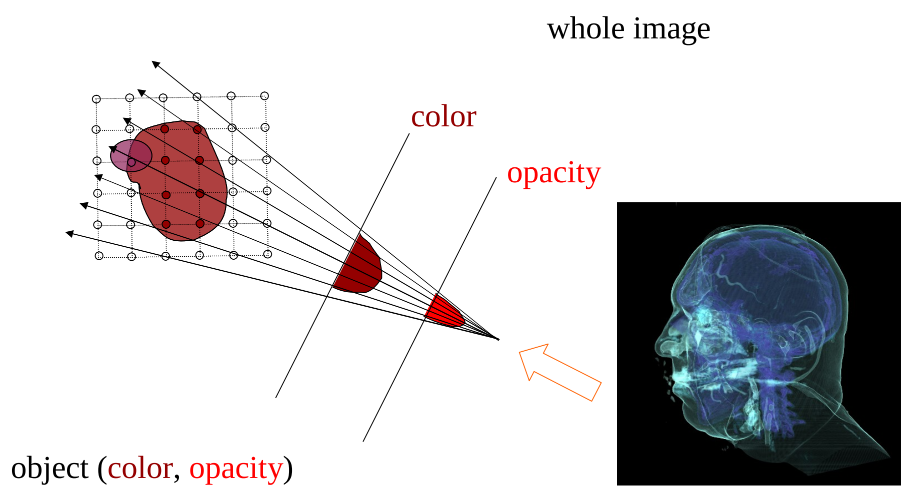
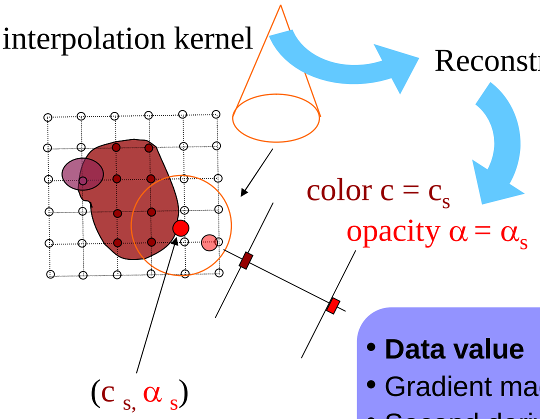


Back To Transfer Functions…



Transfer functions map locally measured numerical properties to colors + opacity

- **Data value**
- Gradient magnitude
- Second derivative
- Surface curvature

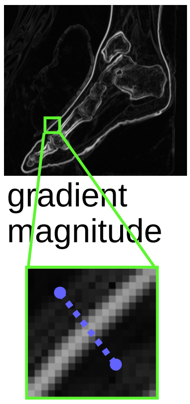
domain

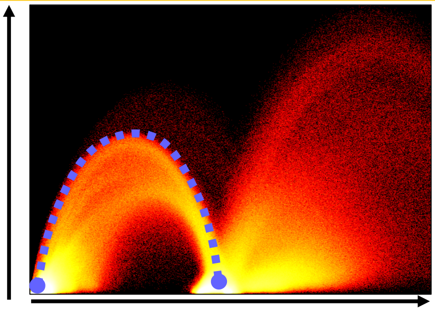
transfer function

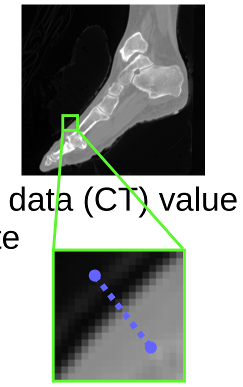
- RGB
- α

range

Transfer Functions: Multi-Dimensional

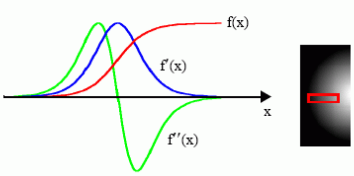




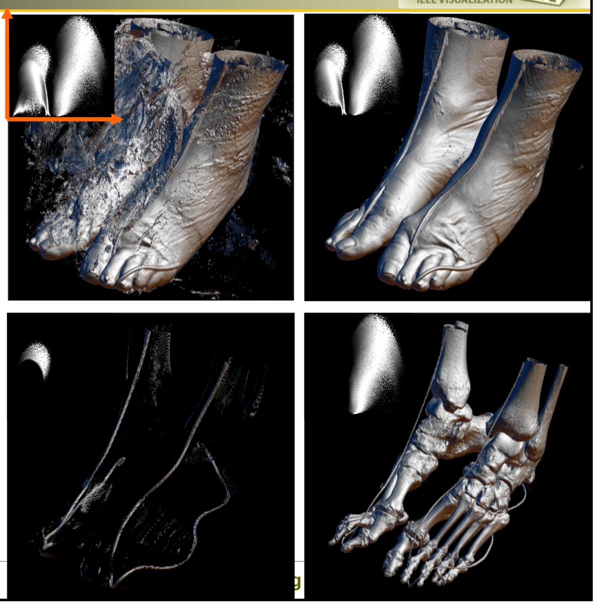


- **Boundaries** in volume create **arches** in (value,gradient) domain [Kindlmann 98]
- Arches guide placement of opacity to emphasize material interfaces [Kniss 01]

Transfer Functions: Multi-Dimensional



- Boundaries can be described in terms of:
  - – maximum in 1st derivative
  - – zero-crossing in 2nd derivative
- Semi-automatic classification possible in clean data



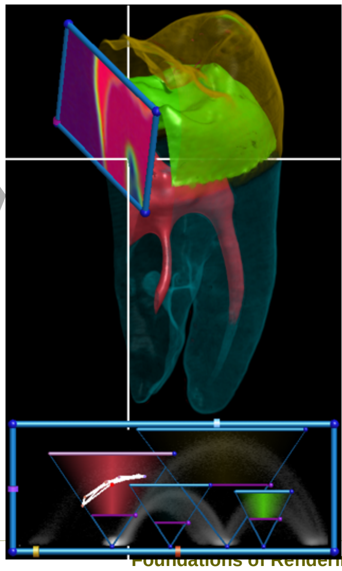
Transfer Functions: Multi-Dimensional

Dual-domain interaction:

[Kniss 01]

Make features opaque by pointing at them

New Rendering

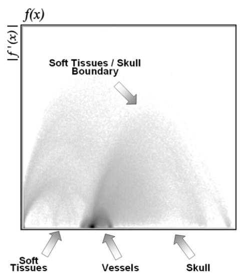


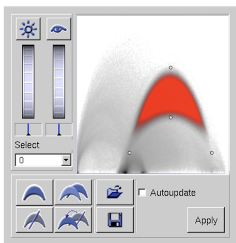
Actions in spatial domain

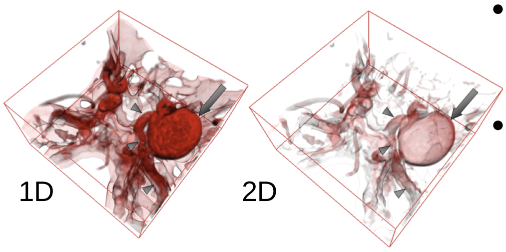
Changes to transfer function

New transfer function

Multi-D TFs: Refined and Applied







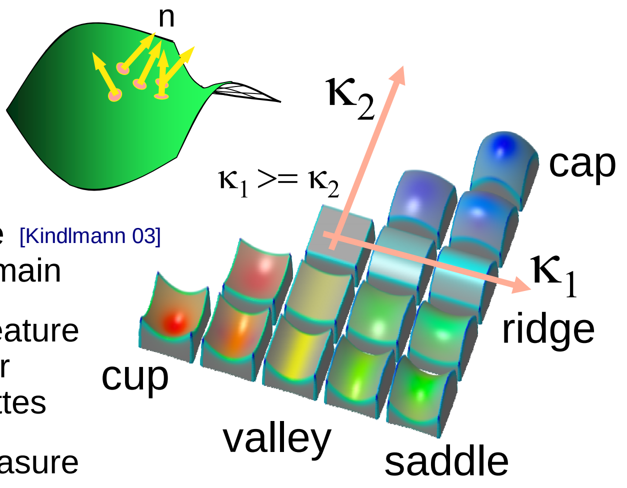
- Higeura et al. 04: Automatic Adjustment of Bidimensional Transfer Functions for Direct Volume Visualization of Intracranial Aneurysms
- Similar scans have similar histograms
- Registration between histograms: map standard TF to new scan

Transfer Functions: Multi-Dimensional

Curvature: how change in surface position changes surface normal (**n**)

Principal curvatures (κ_1,κ_2) form possible transfer function domain [Kindlmann 03]

- Enables surface feature enhancement, better control over silhouettes
- Convolution to measure 1st and 2nd derivatives



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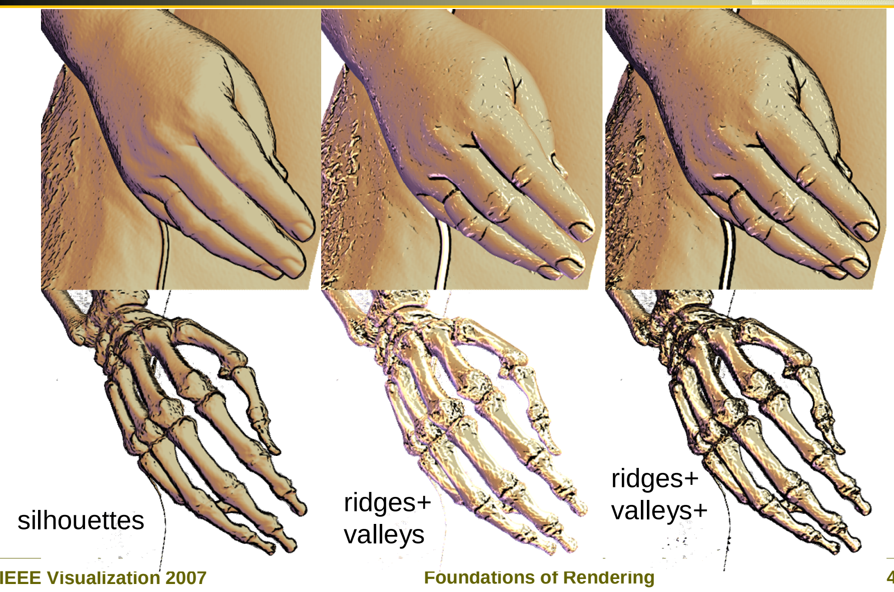
Transfer Functions: Multi-Dimensional



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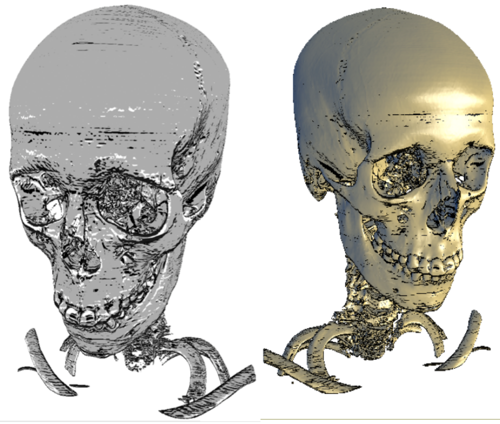
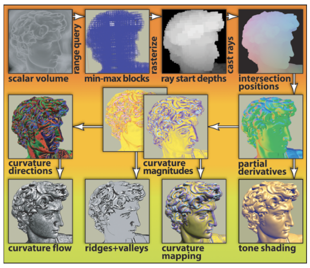
Curvature Based TFs: Interactive

- Hadwiger et al. 05: Real-Time Ray-Casting and Advanced Shading of Discrete Isosurfaces
- Cubic-spline Convolution-based Curvature on the GPU



- Interactive exploration with NPR effects



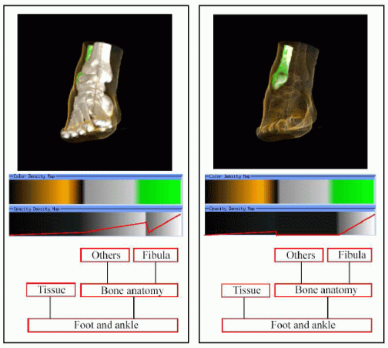
Transfer Functions: Clinical Practice

For medical visualization it is advisable to keep the interaction with transfer functions at a minimum

Doctors (unlike scientists) do not have the time (nor desire) to play with complex transfer function editors

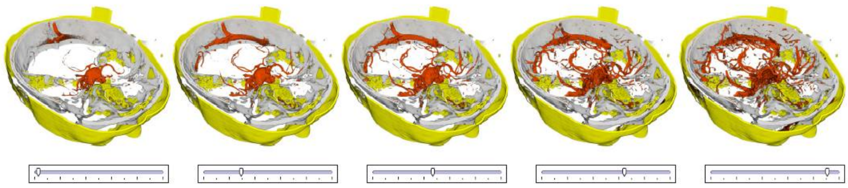
Better approach: [Mueller 05]

- simplify
- make task-oriented
- automate
- include semantics



Transfer Functions: Clinical Practice

A single slider bar is most appreciated [Rezk-Salama Vis06]

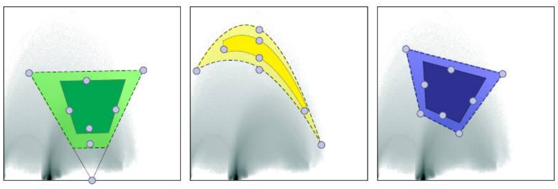


Enables doctors to quickly fine-tune the transfer function for specific objects

- works since in CT usually only small deviations exist
- but these require complex interactions in the transfer function domain

Parameter Mapping Approach (1)

Typical transfer function parameterization:



Datasets typically only deviate modestly from this

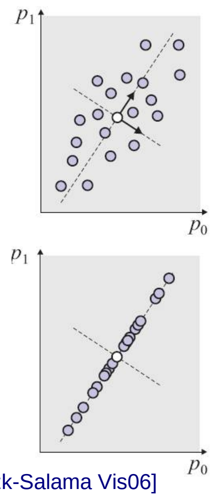
- but in complex ways
- meaning, lots of tweaking is required

[Rezk-Salama Vis06]

Parameter Mapping Approach (2)

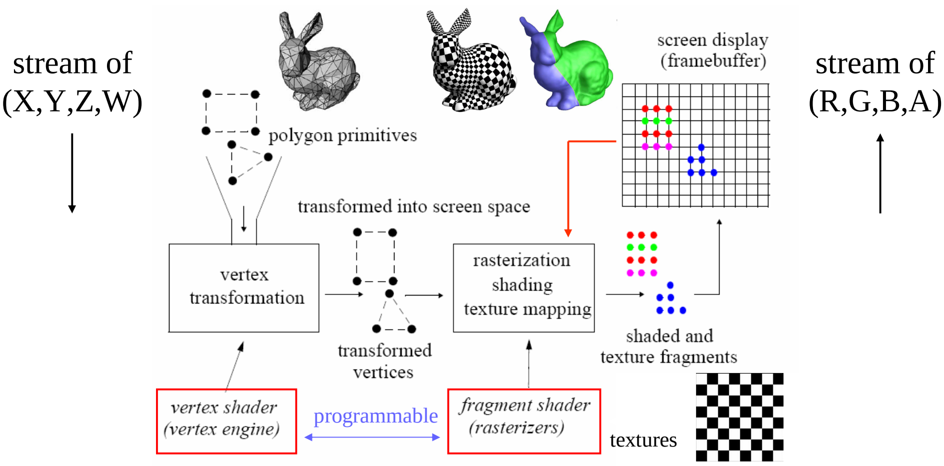
We can learn these deviations by observing a few datasets

- encode the parameters into an N-D vector
- find the principal component of the vectors (the main Eigenvector)
- project all other vectors onto this Eigenvector
- the min and max then represent the min and max of the slider



[Rezk-Salama Vis06]

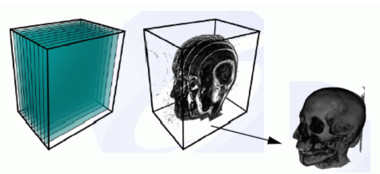
Accelerated Rendering on GPUs



Accelerated Rendering on GPUs: Concept

Simplest approach [Rezk-Salama 01]

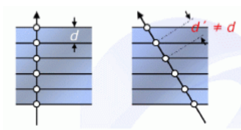
- represent the volume as a stack of axis-aligned “proxy polygons”
- texture-map volume slices onto corresponding proxy polygons
- render polys to screen, properly shifted according to viewing direction, front-to-back
- shade and composite slice by slice



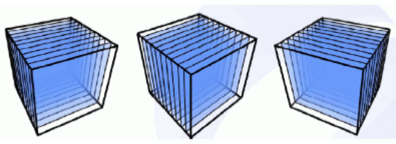
Accelerated Rendering on GPUs: Main Issues

There are two main disadvantages with this approach:

- sampling distance *d* is larger than 1.0 for off-axis viewing directions



- need three stacks of volumes, one for each major viewing direction

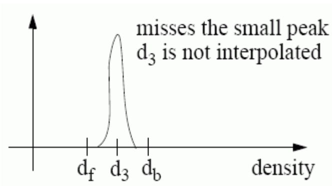


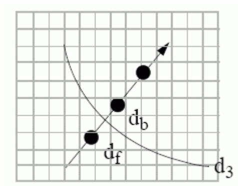
from: Engel, Kraus, Ertl, Graphics Hardware Workshop 2001

Pre-Integrated Volume Rendering (1)

Designed to overcome artifacts due to:

- too large sampling intervals (rays, 2D textures)
- transfer functions with high frequency features, which may not be captured by two consecutively interpolated densities





Pre-Integrated Volume Rendering (2)

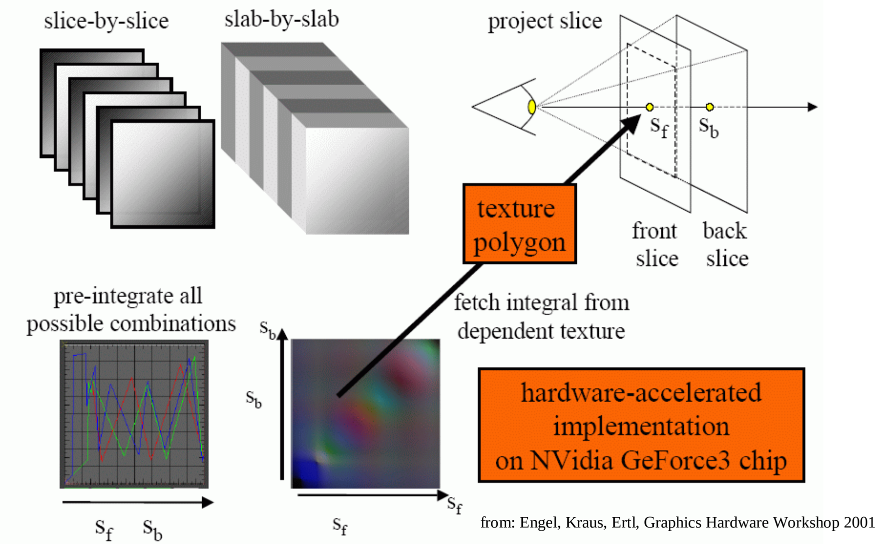
Solution:

- pre-compute color and opacity integrals for all possible front- and back density pairs, d_f and d_b
- gives rise to a 2D table, indexed by interpolated d_f and d_b, assuming piecewise linear densities:

$$c(d_f, d_b) = \int_0^1 \mu((1-s)d_f + sd_b) \cdot c((1-s)d_f + sd_b) e^{-\int_0^s \mu((1-s)d_f + sd_b) dt} ds$$

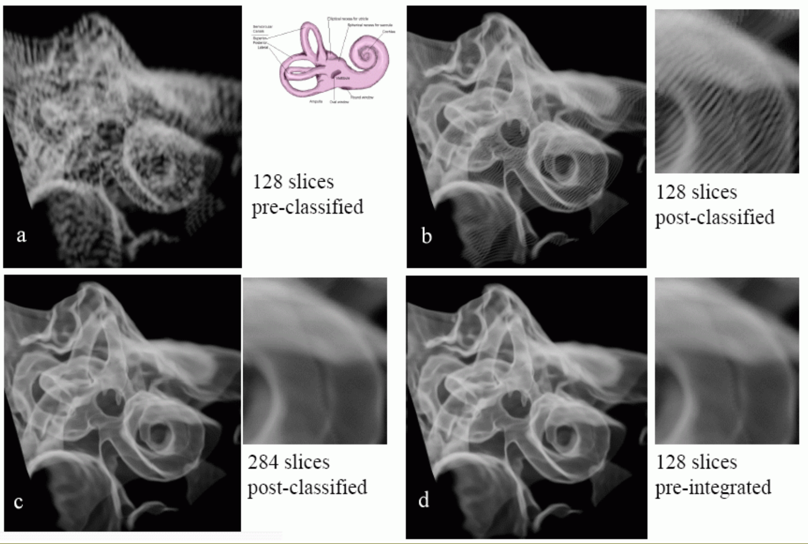
- pre-integrated opacities computed similar

Pre-Integrated Volume Rendering (3)



from: Engel, Kraus, Ertl, Graphics Hardware Workshop 2001

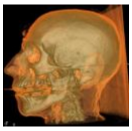
Pre-Integrated Volume Rendering (4)

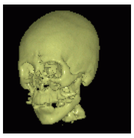


Accelerated Rendering on GPUs: Conclusions

Using the texture mapping hardware approach allows interactive frame rates with practical-sized datasets

More advanced GPU-based renderer offer:





- raycasting (more natural than textures)
- empty-space skipping [Stegmaier 05] [Leung 06]
- early ray termination, occlusion culling
- advanced rendering effects (shadows, translucencies, advanced lighting, etc.)

These offer advantages in speed, quality, flexibility

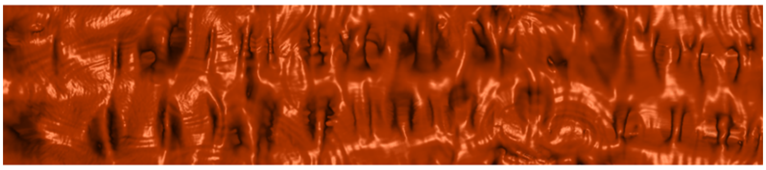
Alternative To 3D Viewing: Intro

Let's have a look at virtual colonoscopy

- complex structure requires fly-throughs

Alternative to 3D Viewing: Practice

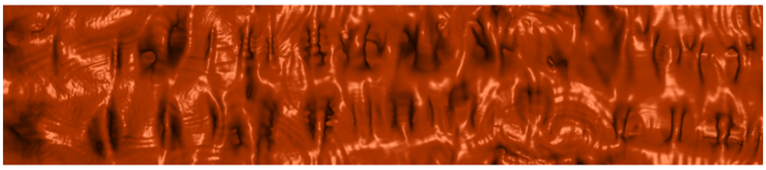
Surface flattening using conformal mapping [Hong Vis06]



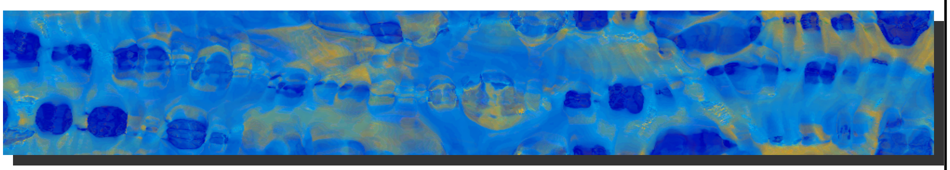
Now can visualize the entire colon as one image

Alternative to 3D Viewing: Practice

Surface flattening using conformal mapping:

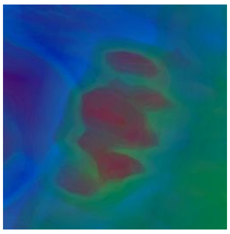


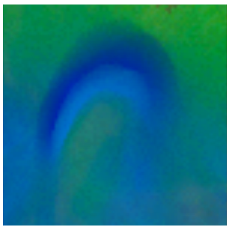
Rendered in translucent mode: [Hong Vis06]



Enables Quick Diagnosis

Only local inspection:

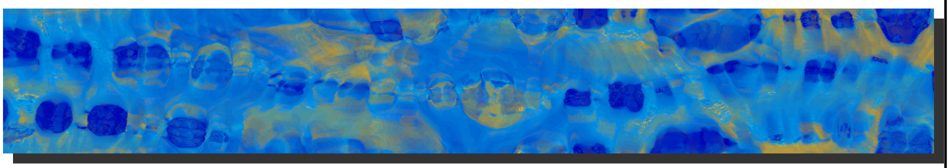




Hyperplastic polyp   Adenoma

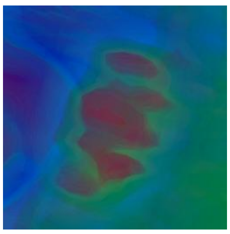
[Hong Vis06]

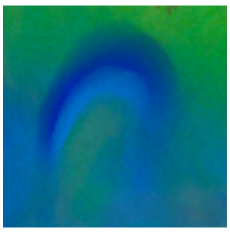
Flattening enables a *global* overview of pathology:



Enables Quick Diagnosis

Only local inspection:





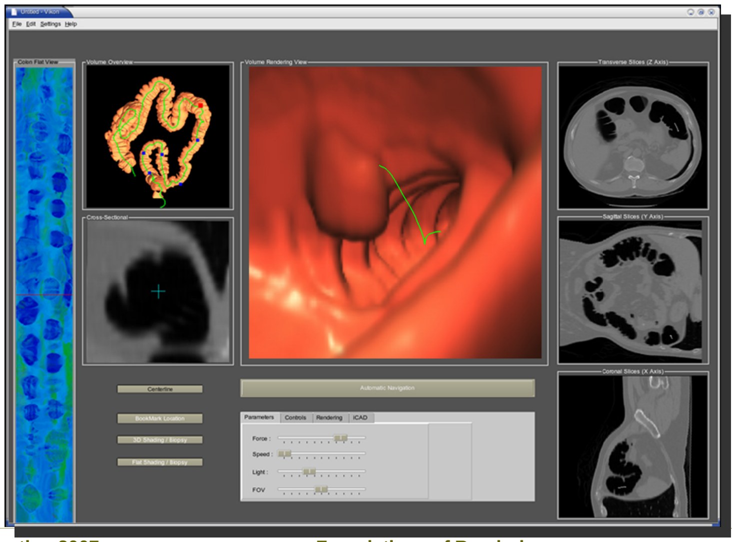
Hyperplastic polyp   Adenoma

[Hong Vis06]

CAD (Computer Aided Diagnosis):

Marked: suspected polyps

Actual Interface For Clinical Use



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Acknowledgments

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