Visualization, Lecture

Volume Visualization

Part 2

Direct Volume Visualization

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Overview: Current Lecture

Contents of Current Lecture:

- introduction to direct volume visualization
- ray functions
- ray casting
- compositing

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Direct Volume Visualization

Overview:

- No intermediate representation
- “Real 3D”
- Integration of so much information: difficult
- Object-order vs. image-order rendering
- Various techniques (ray casting, shear-warp, texture mapping, etc.)
- Various rendering techniques (compositing, MIP, first-hit, average, etc.)

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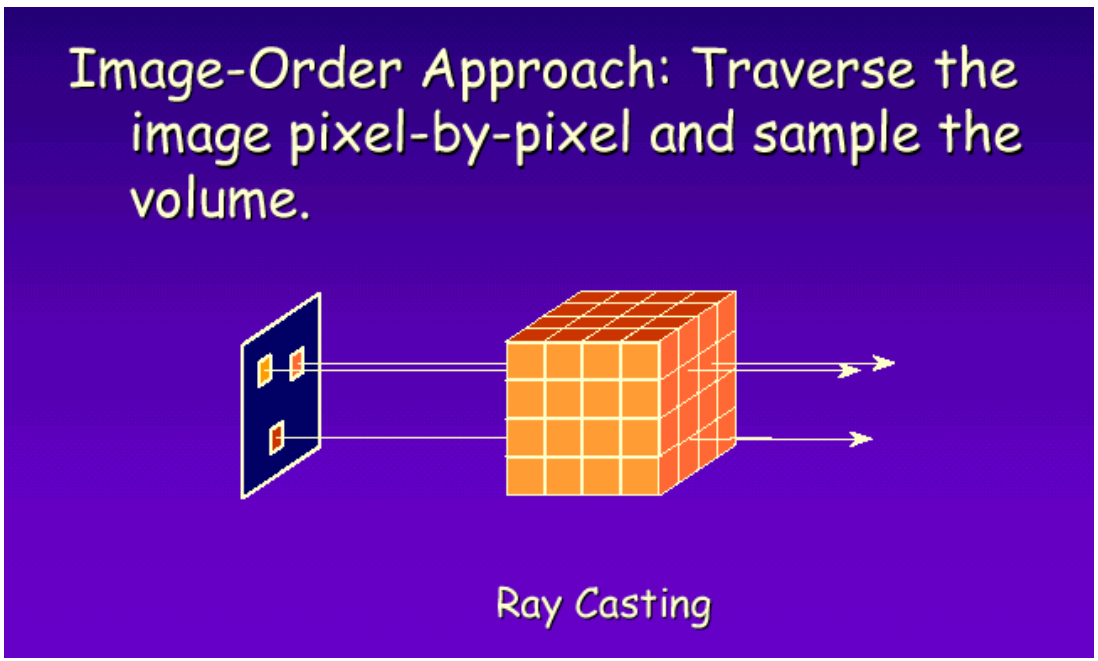
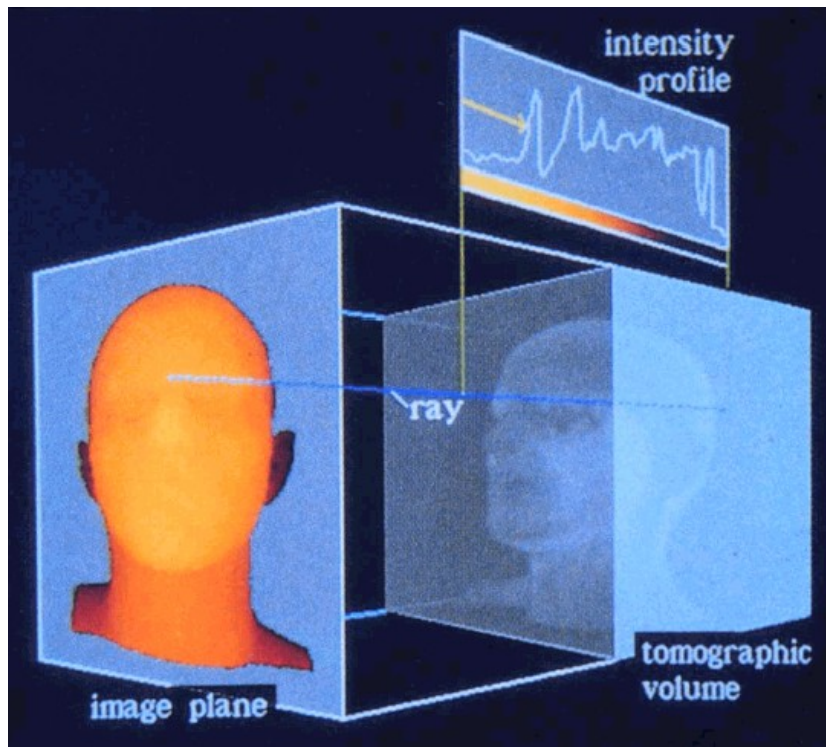
Direct Volume Visualization

Terminology:

- **Ray Casting**: the value of each pixel in the image is determined by sending a ray through the pixel into the scene (image order volume rendering)





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Rendering Techniques: Ray Functions

Ray Functions

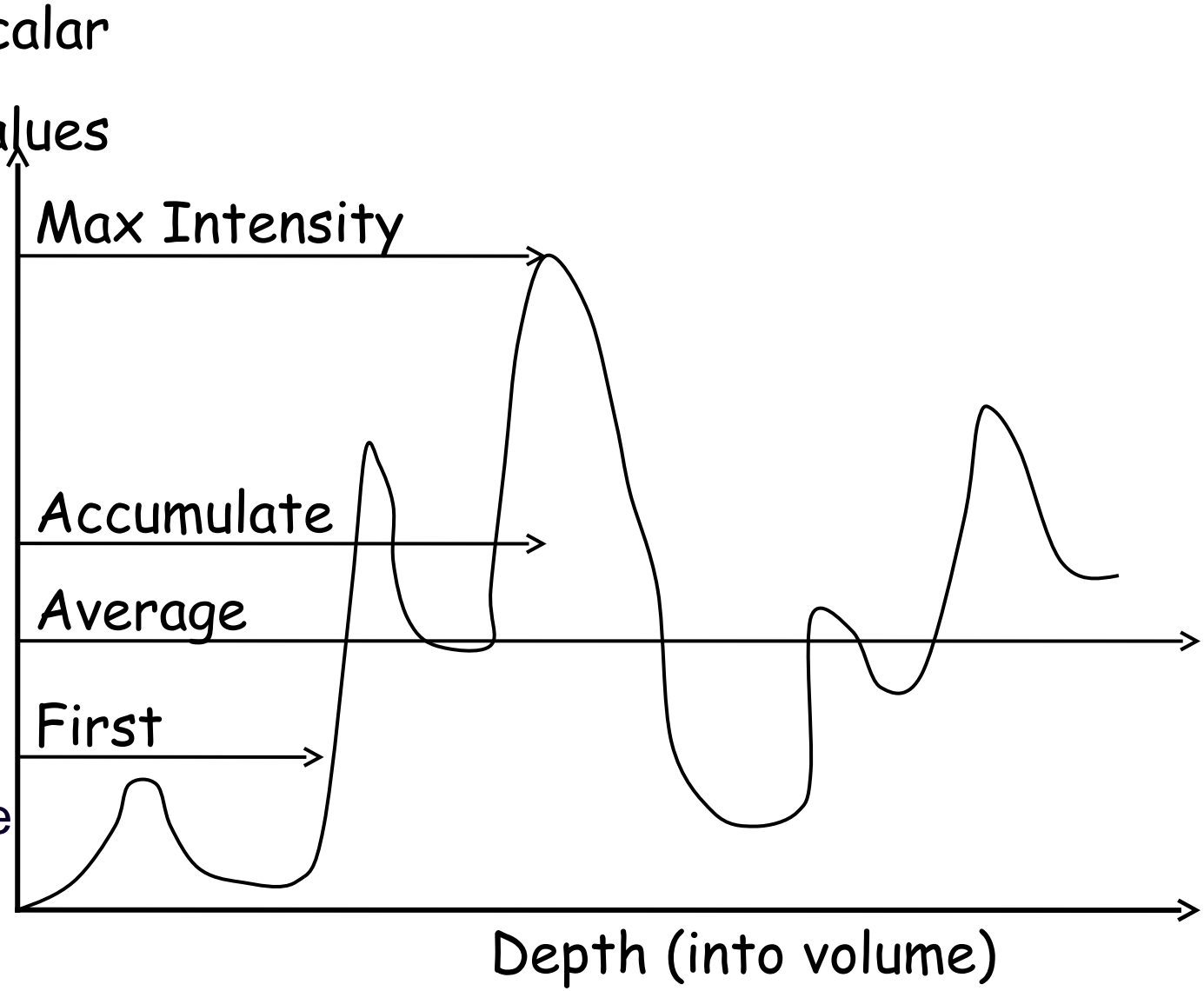
Overview:

- MIP

(**M**aximum **I**ntensity Projection)

- Compositing
- X-Ray
- First Hit

Ray functions produce an ***intensity profile*.**



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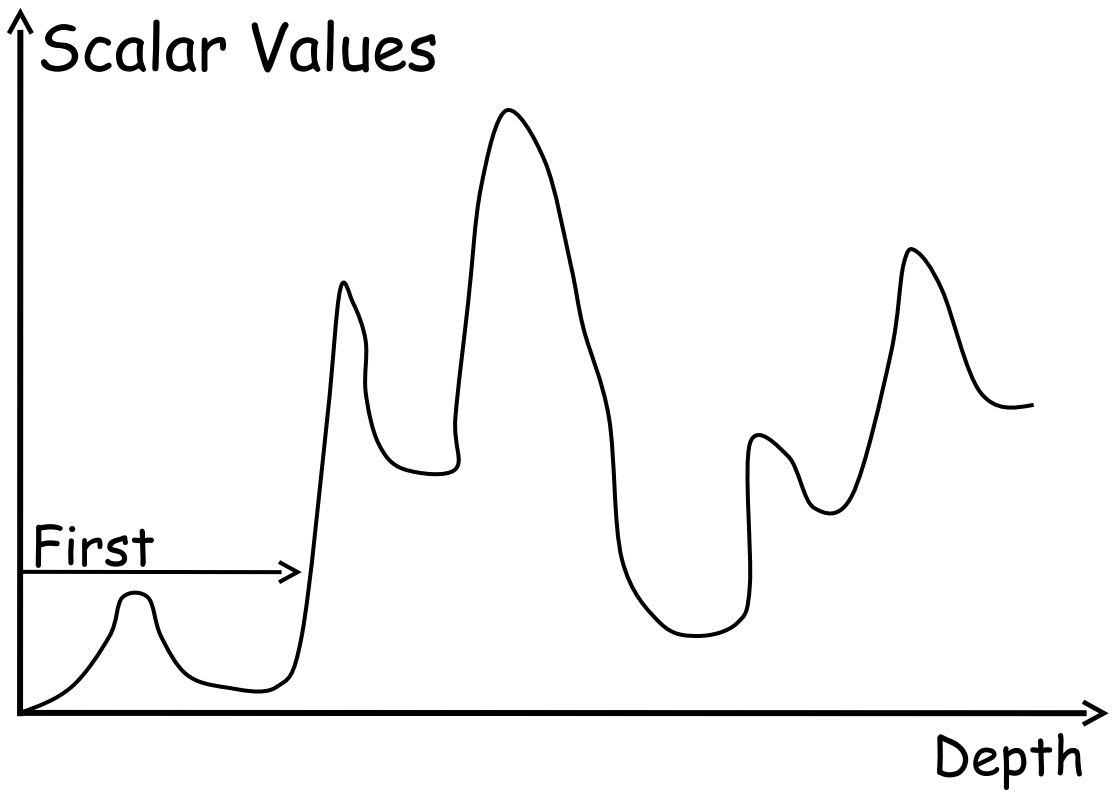
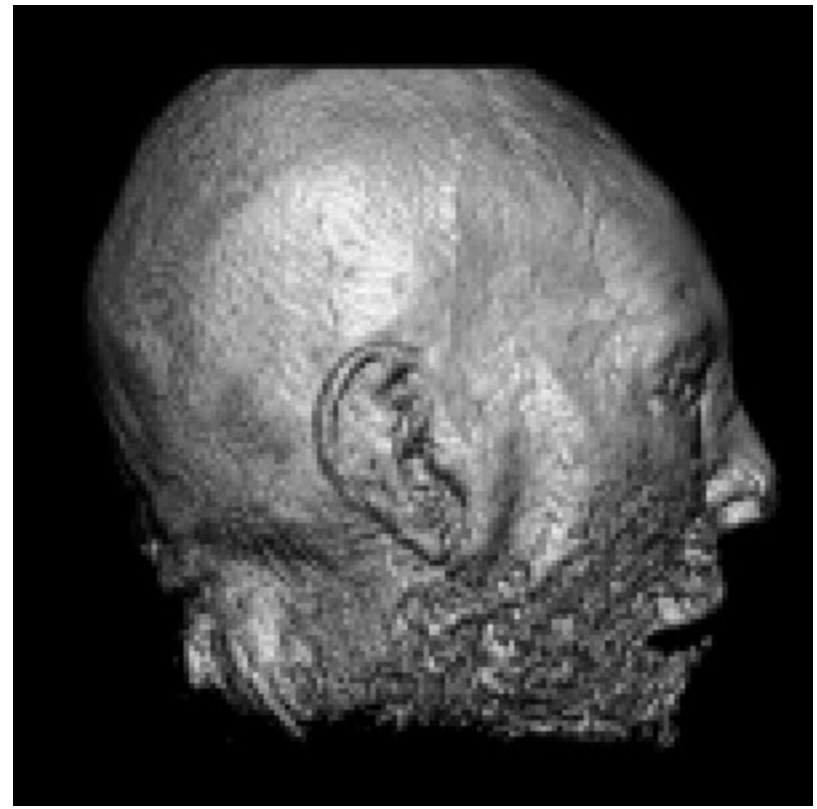
First Hit: Iso-surface Extraction





First Hit Ray Function: Extracts iso-surfaces (again), done by Tuy&Tuy ’84

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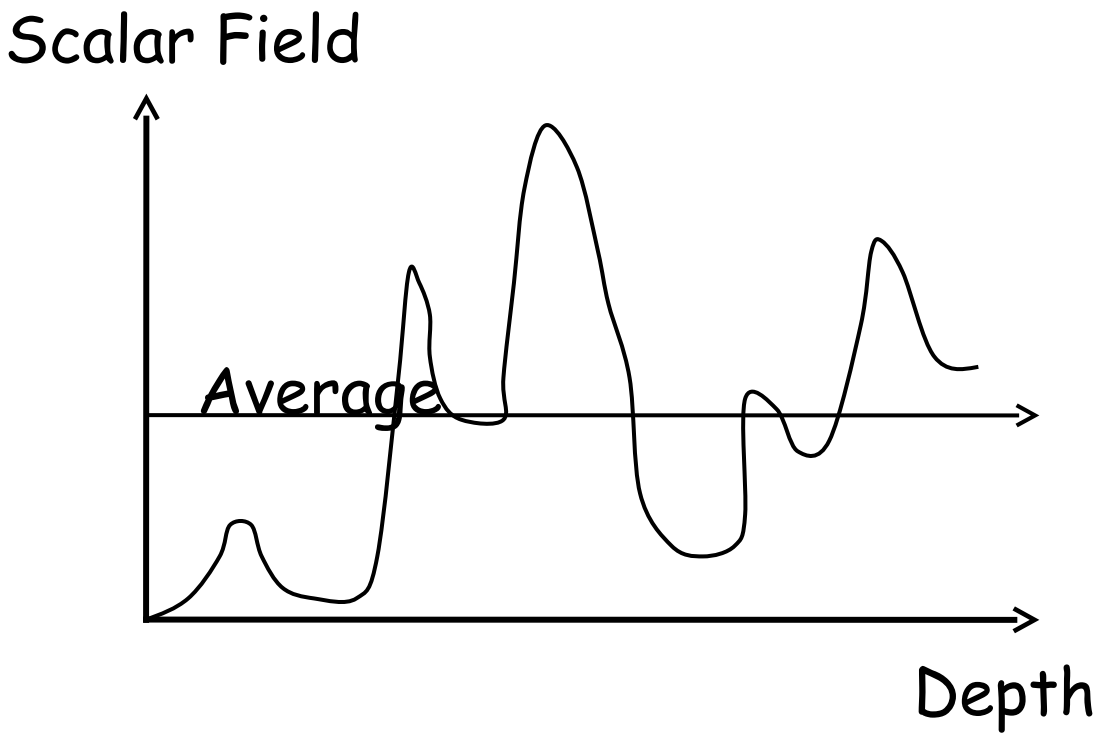
Average: Like X-Rays



Average Ray Function: Produces basically an X-ray picture

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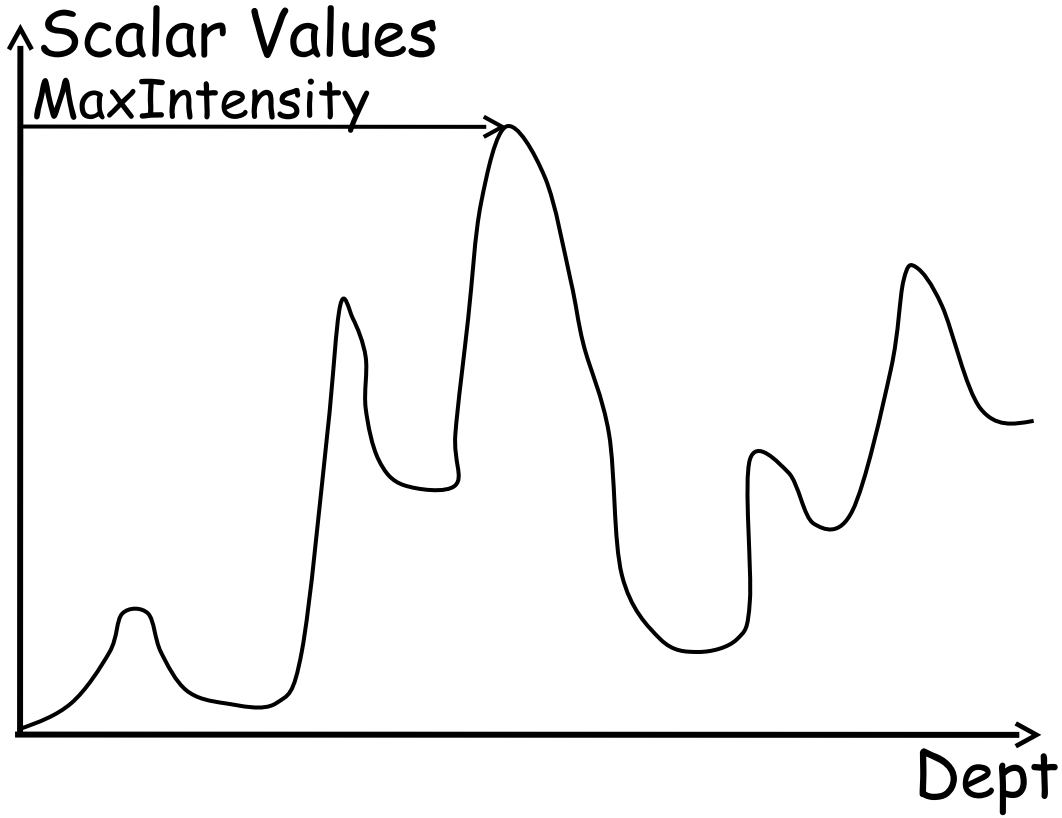
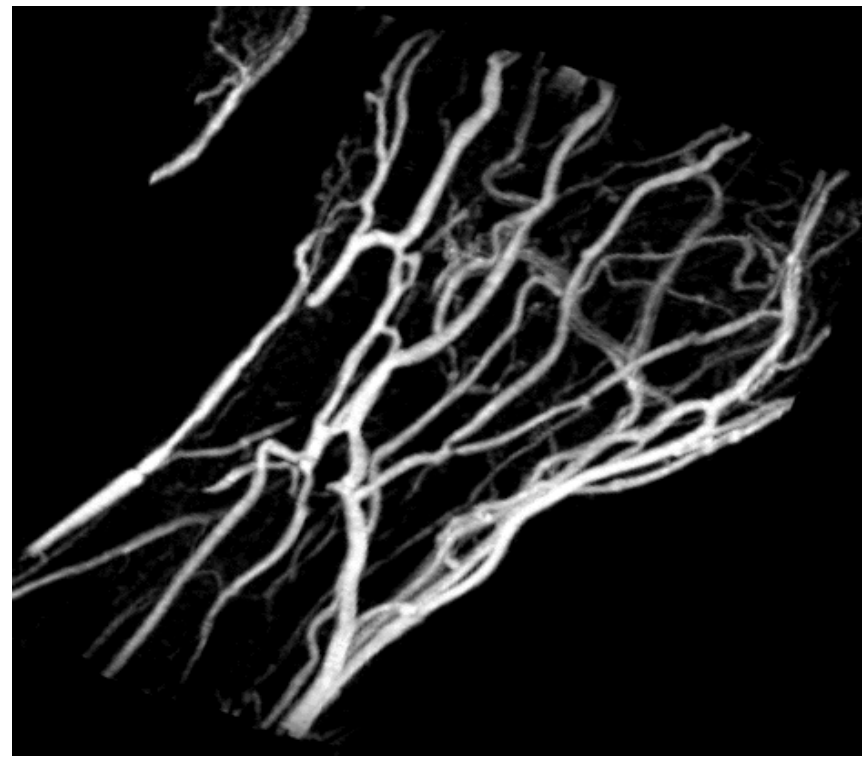
MIP: maximum-intensity projection





Max Ray Function: **M**aximum **I**ntensity **P**rojection (MIP) used for Magnetic Resonance Angiogram (MRA)

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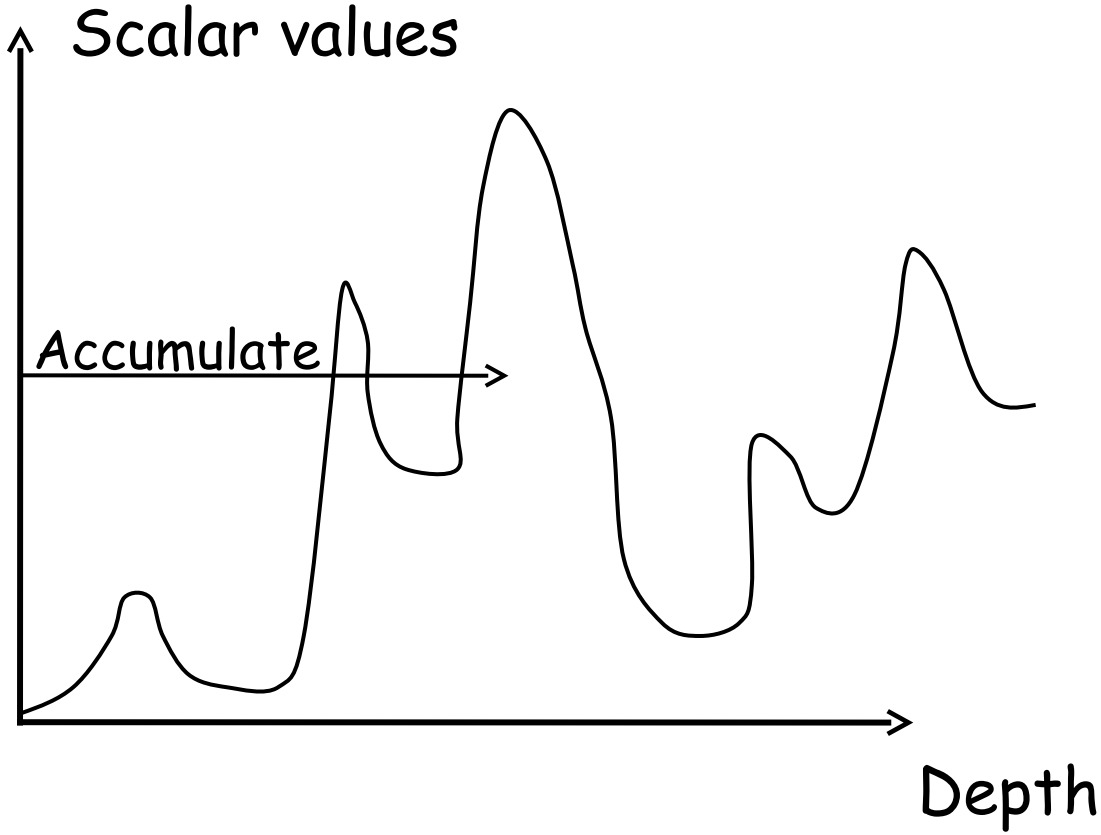
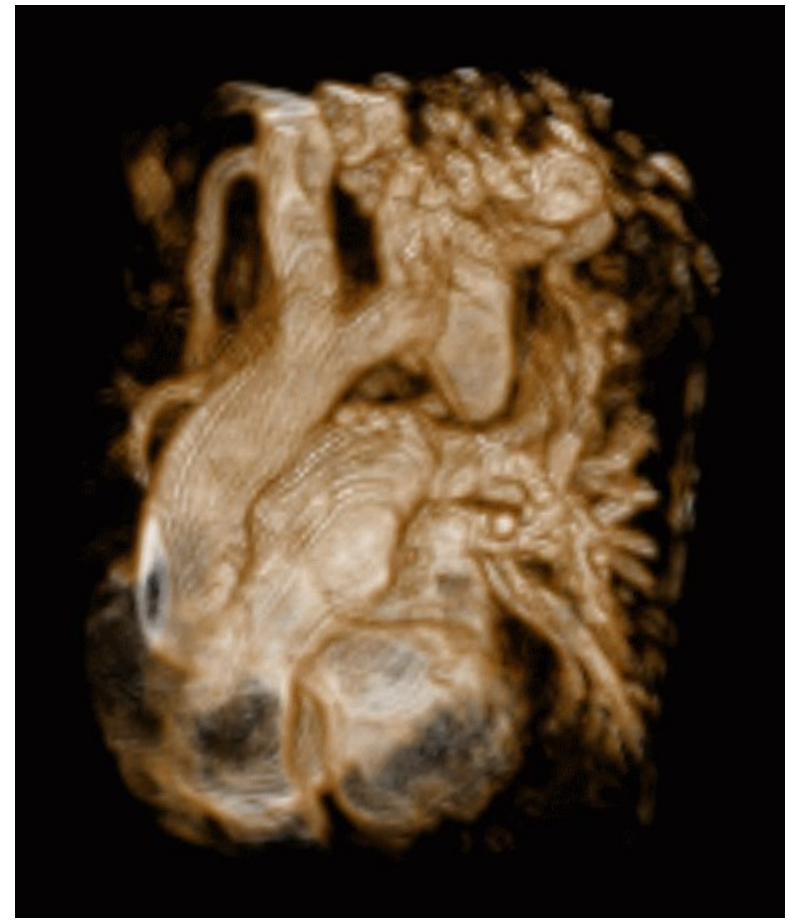
Compositing: Semi-transparency





Accumulate: Make transparent layers visible.

Levoy ‘88

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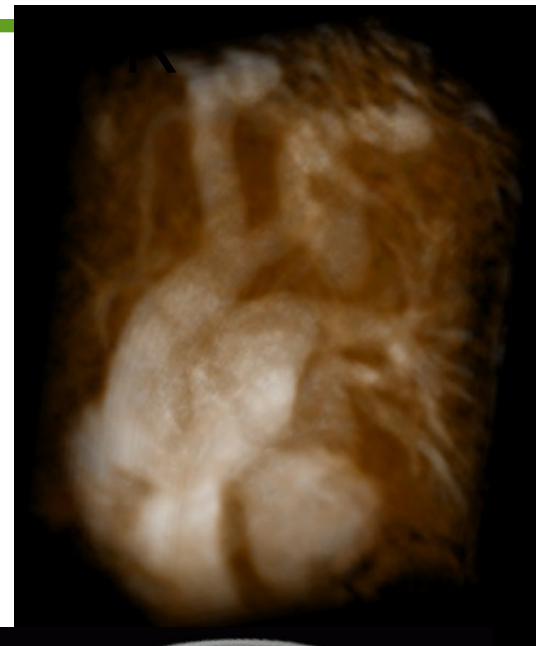
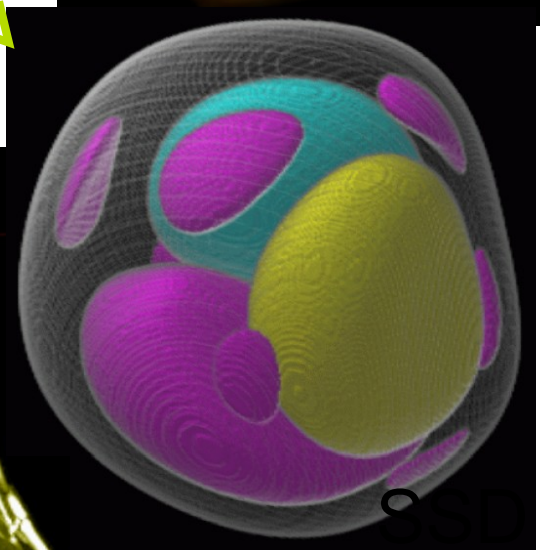
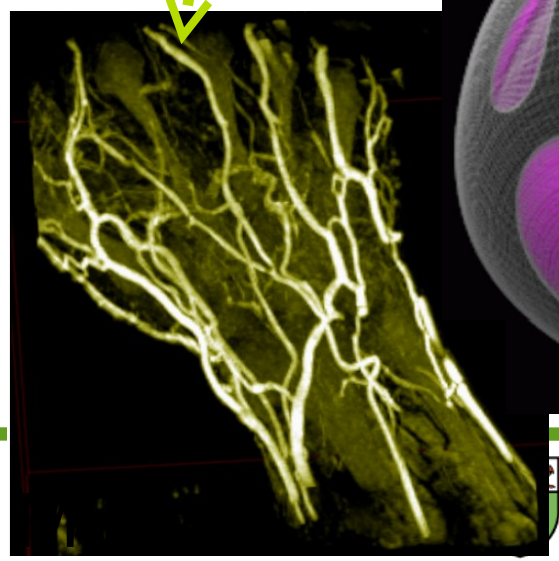
Combining Ray Functions

Some Possibilities:

- α-compositing
- shaded surface display
- maximum-intensity projection
- x-ray simulation
- contour rendering







The Ray Casting Pipeline

Classical
Image-Order Method

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Ray Tracing vs. Ray Casting

- Ray Tracing: image generation method
- In volume rendering: only primary light scattering --> thus Ray Casting
- Classical image-order method
- Ray tracing: radiate object surface or slices

Ray casting: no objects, just scalar (e.g. density) values in 3D

- Theory: consider all density values

Practice: traverse volume slice by slice

- Interpolation necessary per slice

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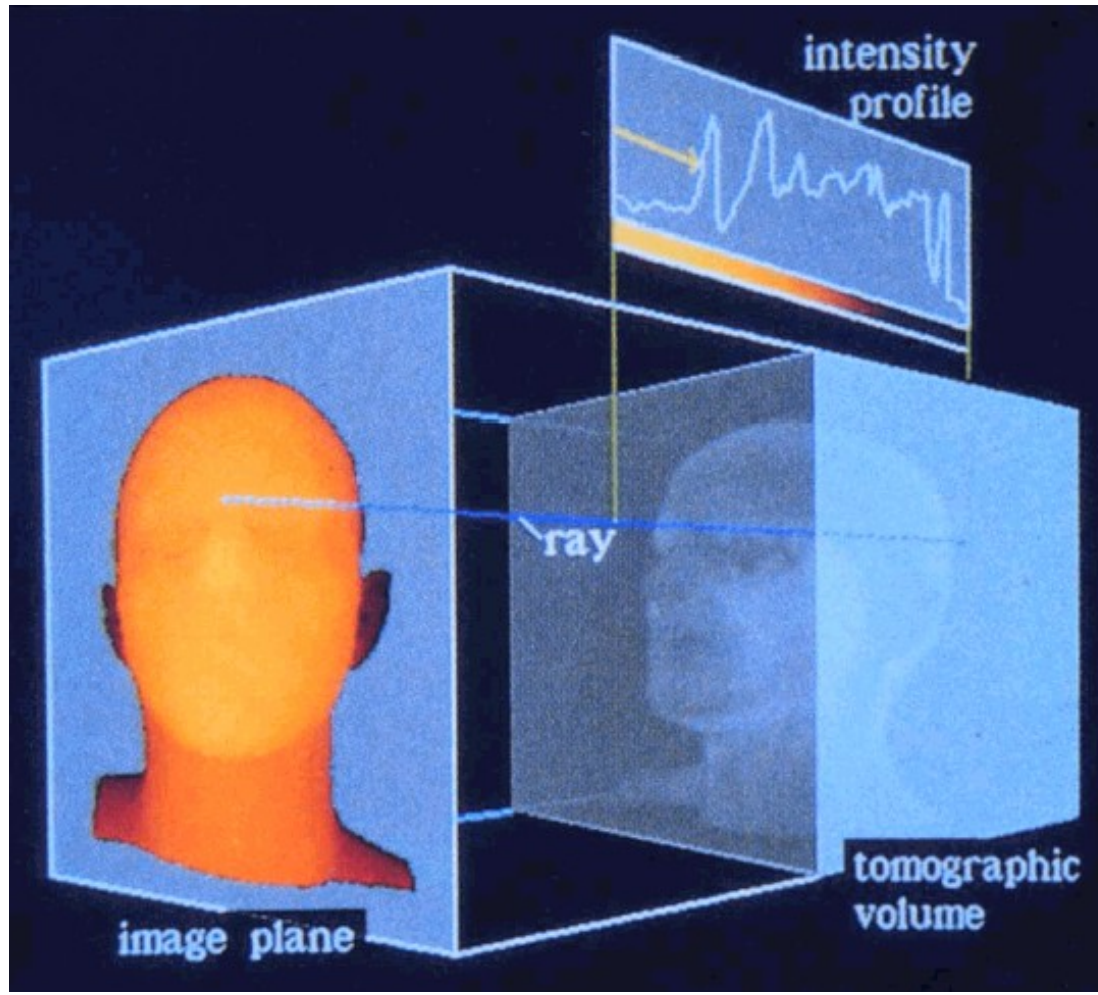
Ray Through Volume Data

Overview:

- Volume Data: 1D values defined in 3D, $f(\mathbf{x}) \in R^1$, $\mathbf{x} \in R^3$
- Ray defined as half of a line: $\mathbf{r}(t) \in R^3$, $t \in R^1>0$
- Values along Ray: $f(\mathbf{r}(t)) \in R^1$, $t \in R^1>0$ (intensity profile)



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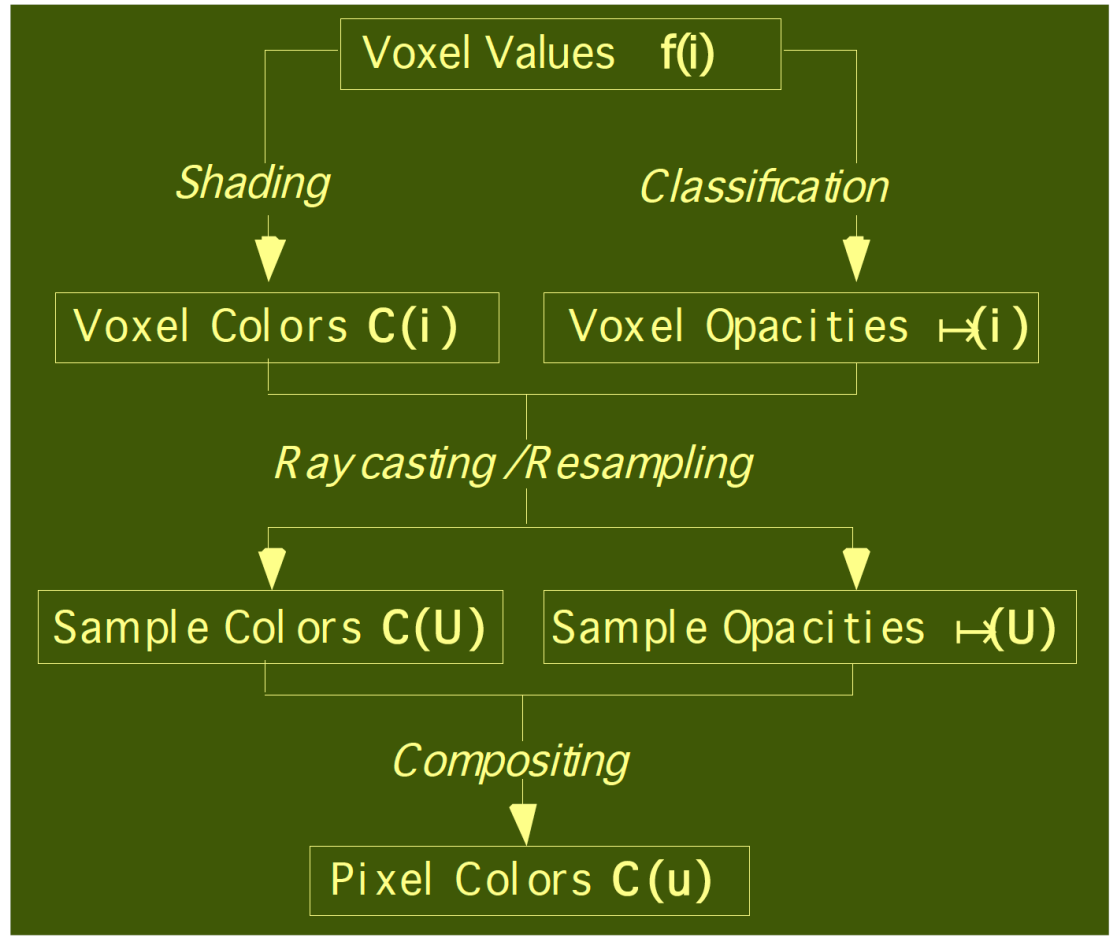
The Ray Casting Pipeline

Levoy ’88:

1. set color and alpha (using transfer function)
2. Ray casting, interpolation
3. Compositing



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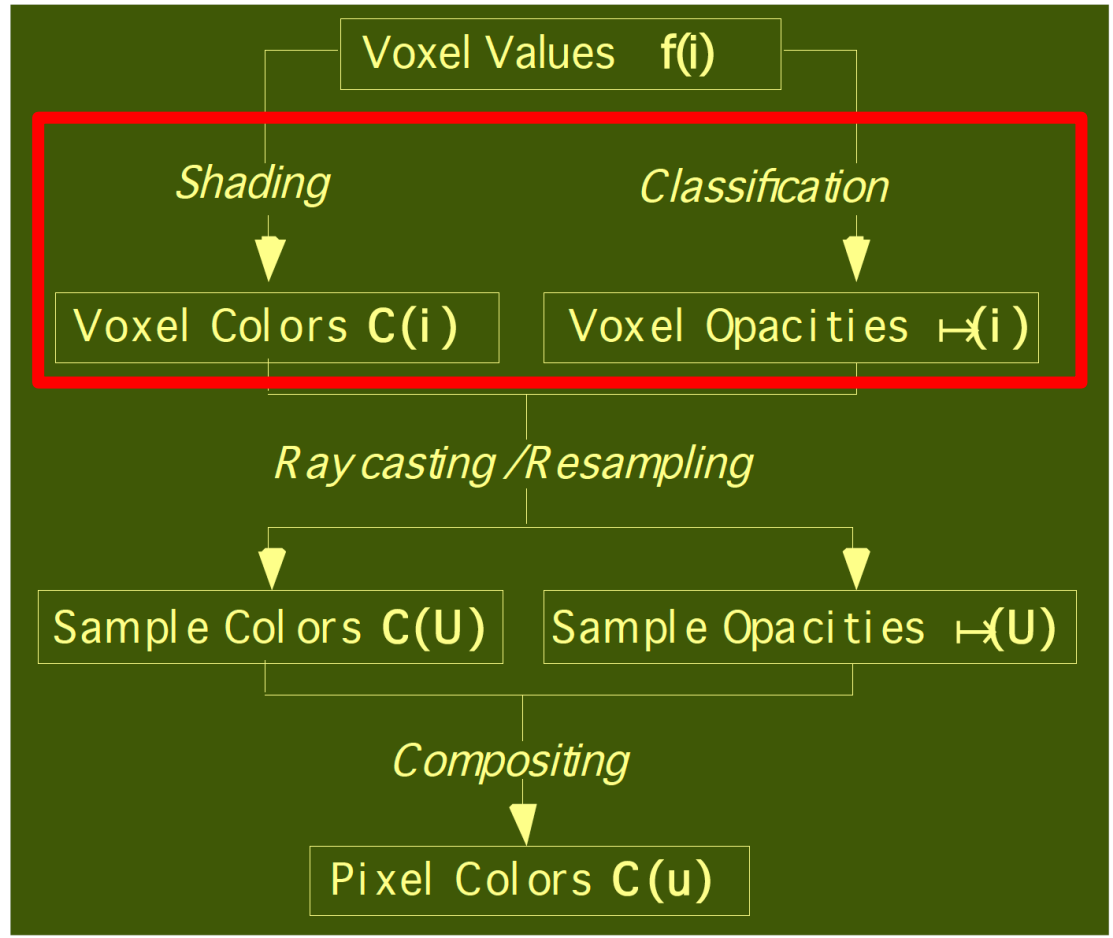

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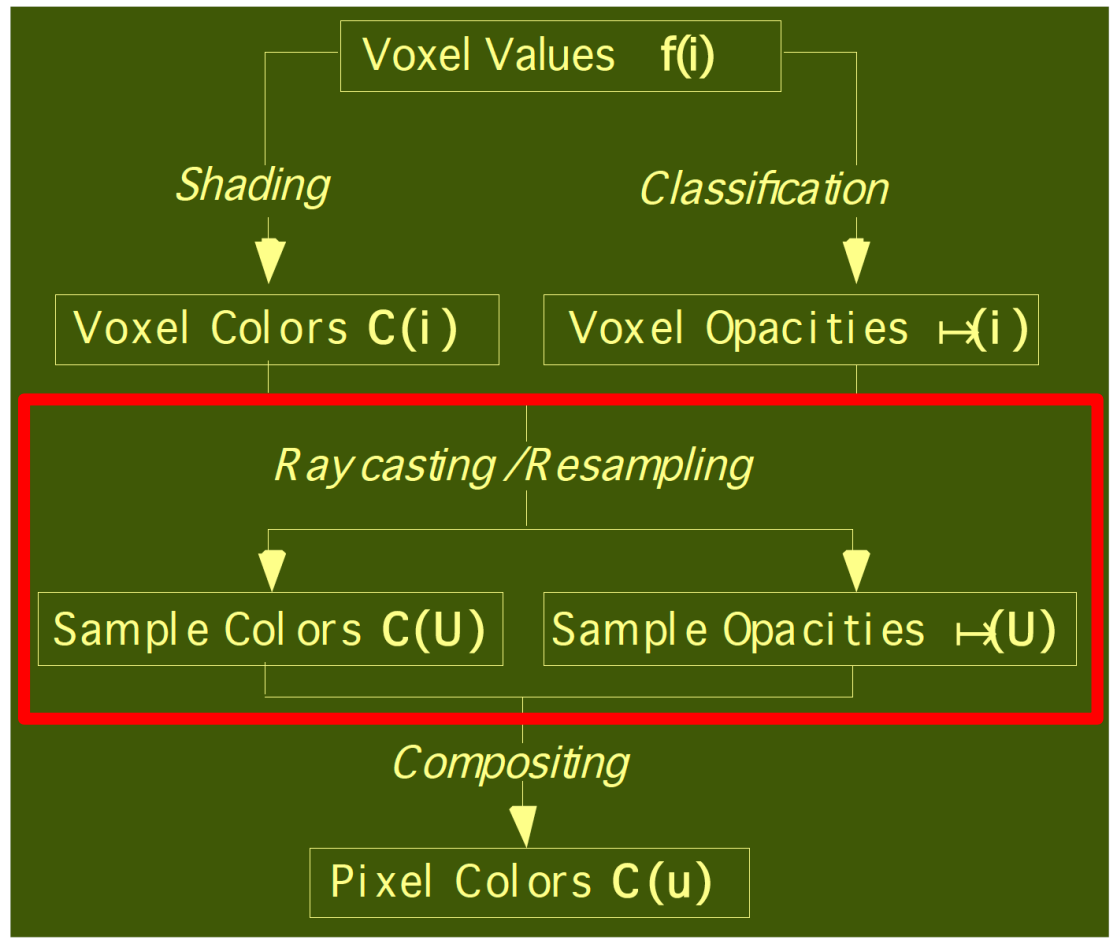

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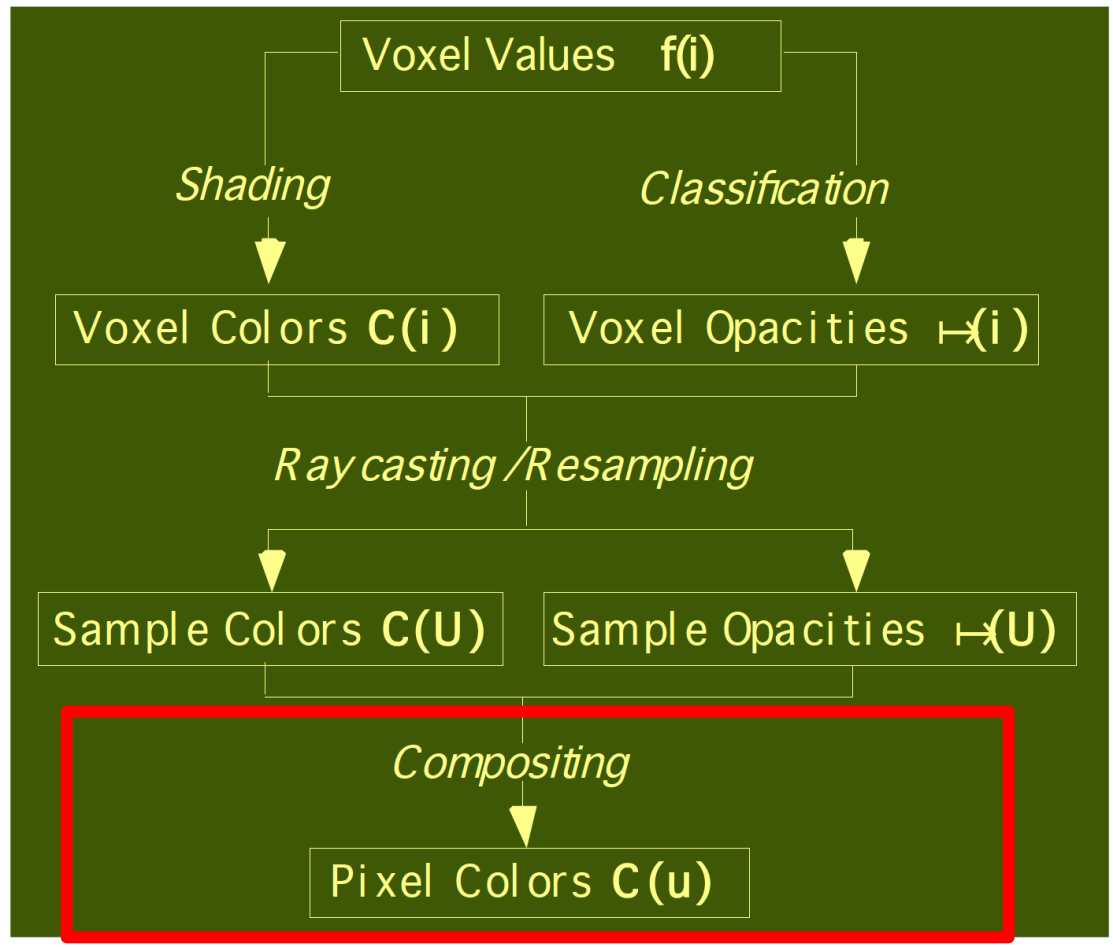

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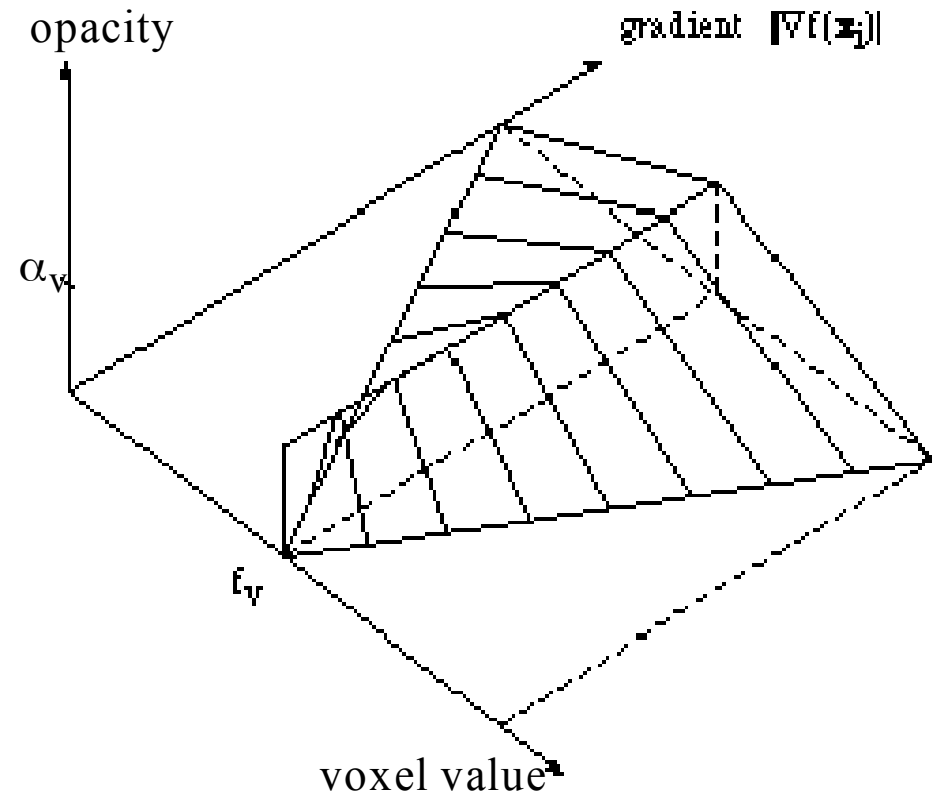
1. Shading and Classification of Voxel Values

voxel shading according to transfer function

- diffuse shading (Phong), gradient used to derive normals

voxel classification, f(i)→α(i):

- according to gradients
- emphasizes transitions/boundaries



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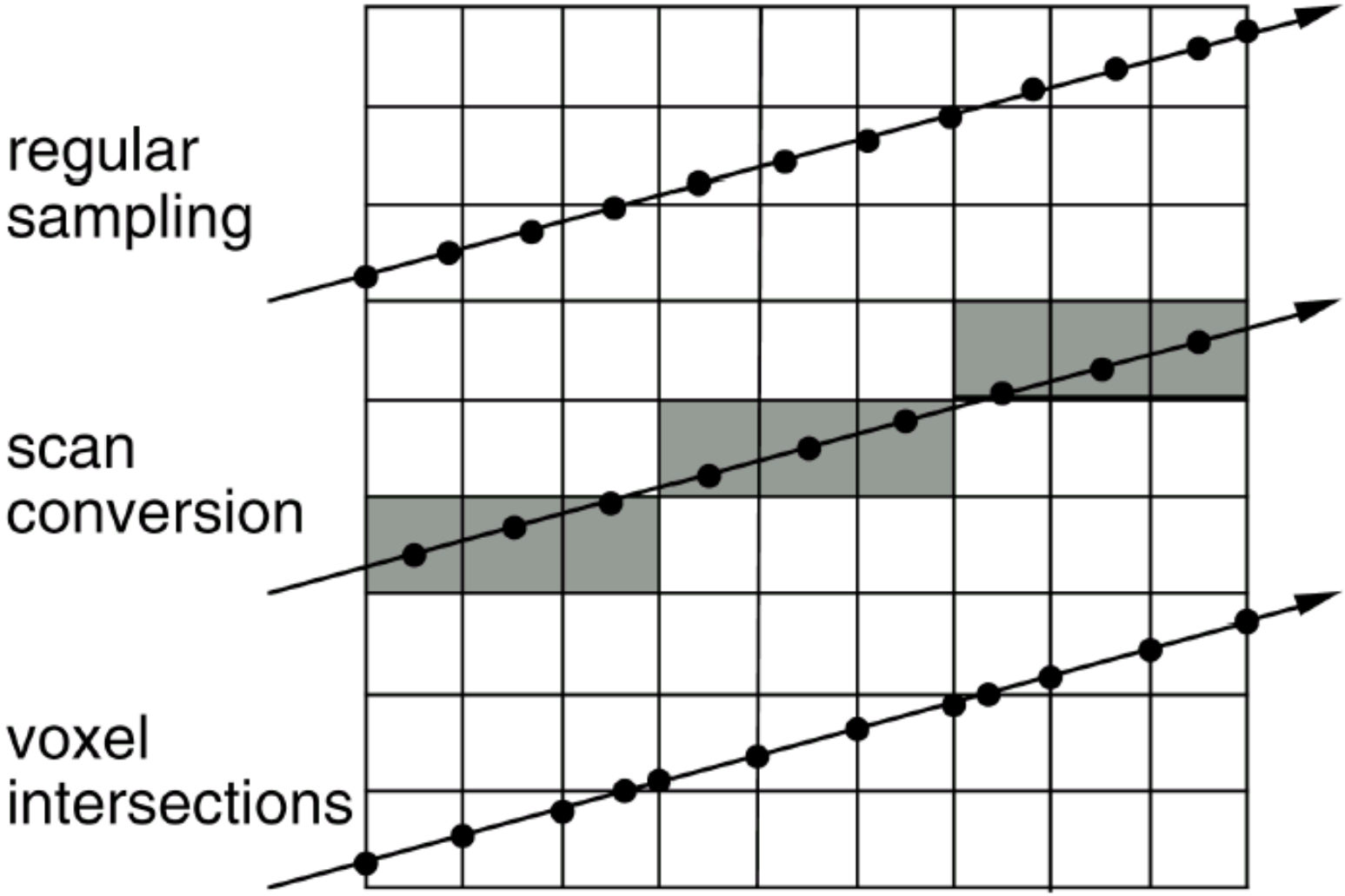
2. Ray traversal – Three Approaches



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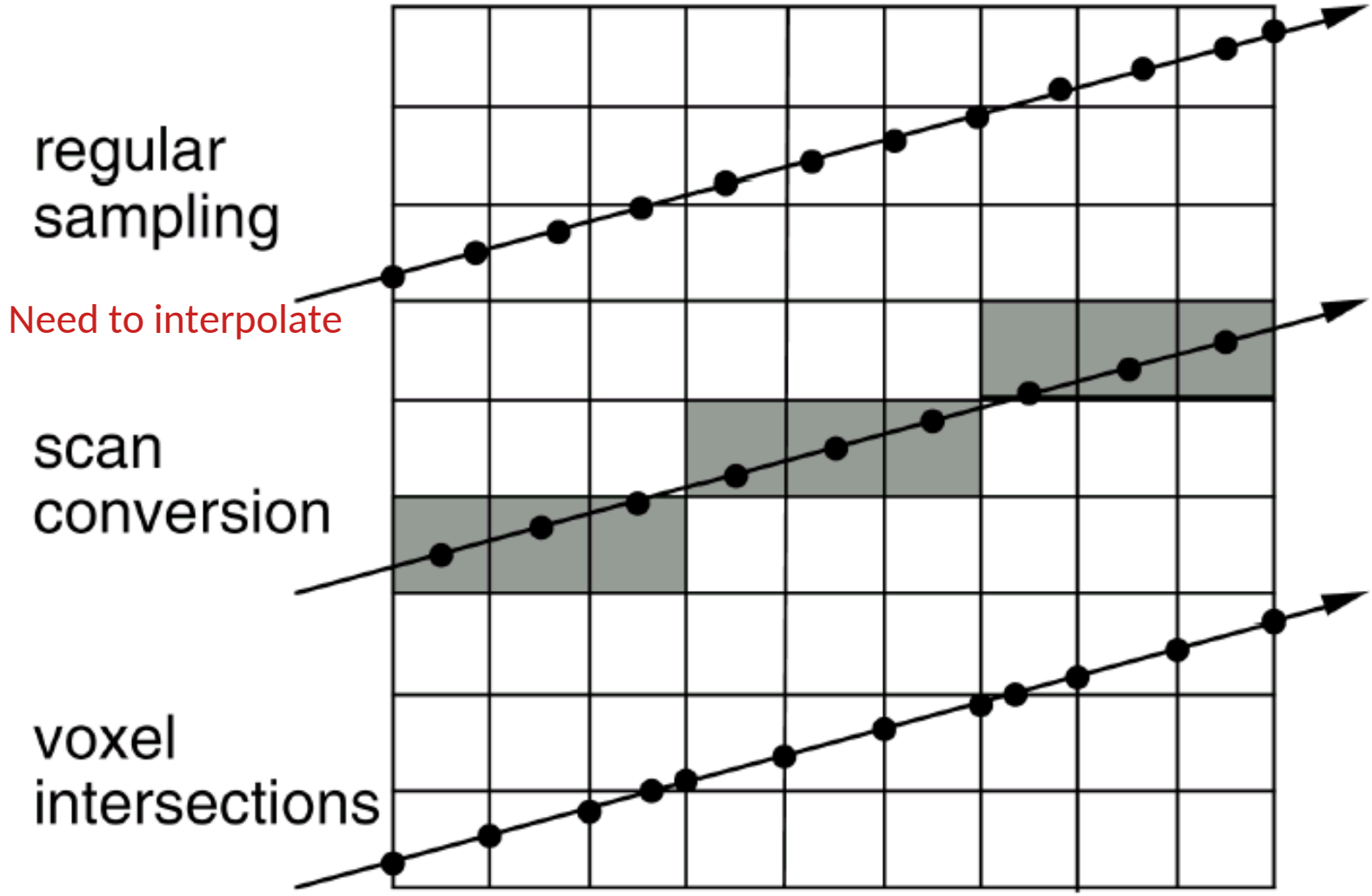

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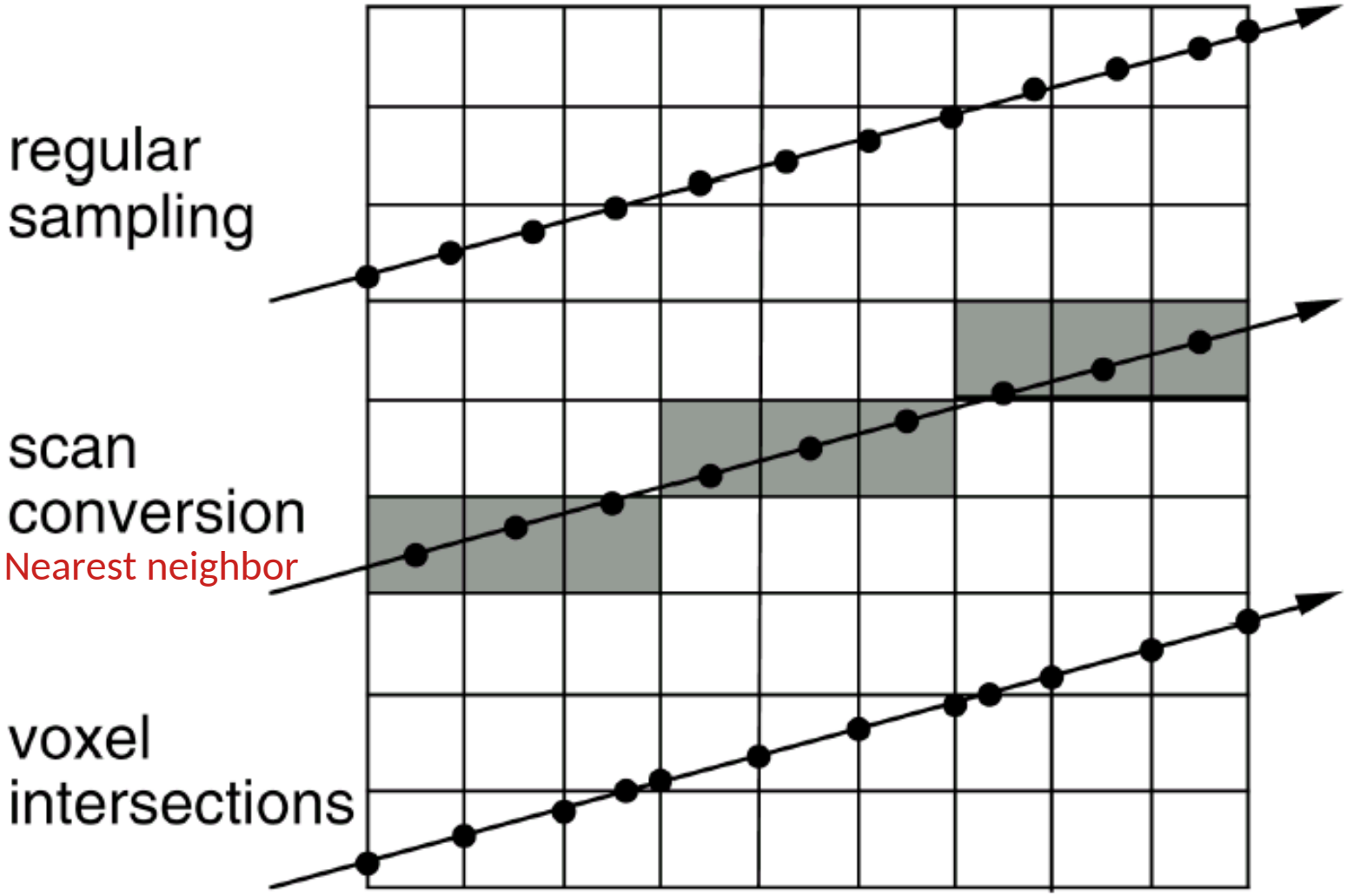

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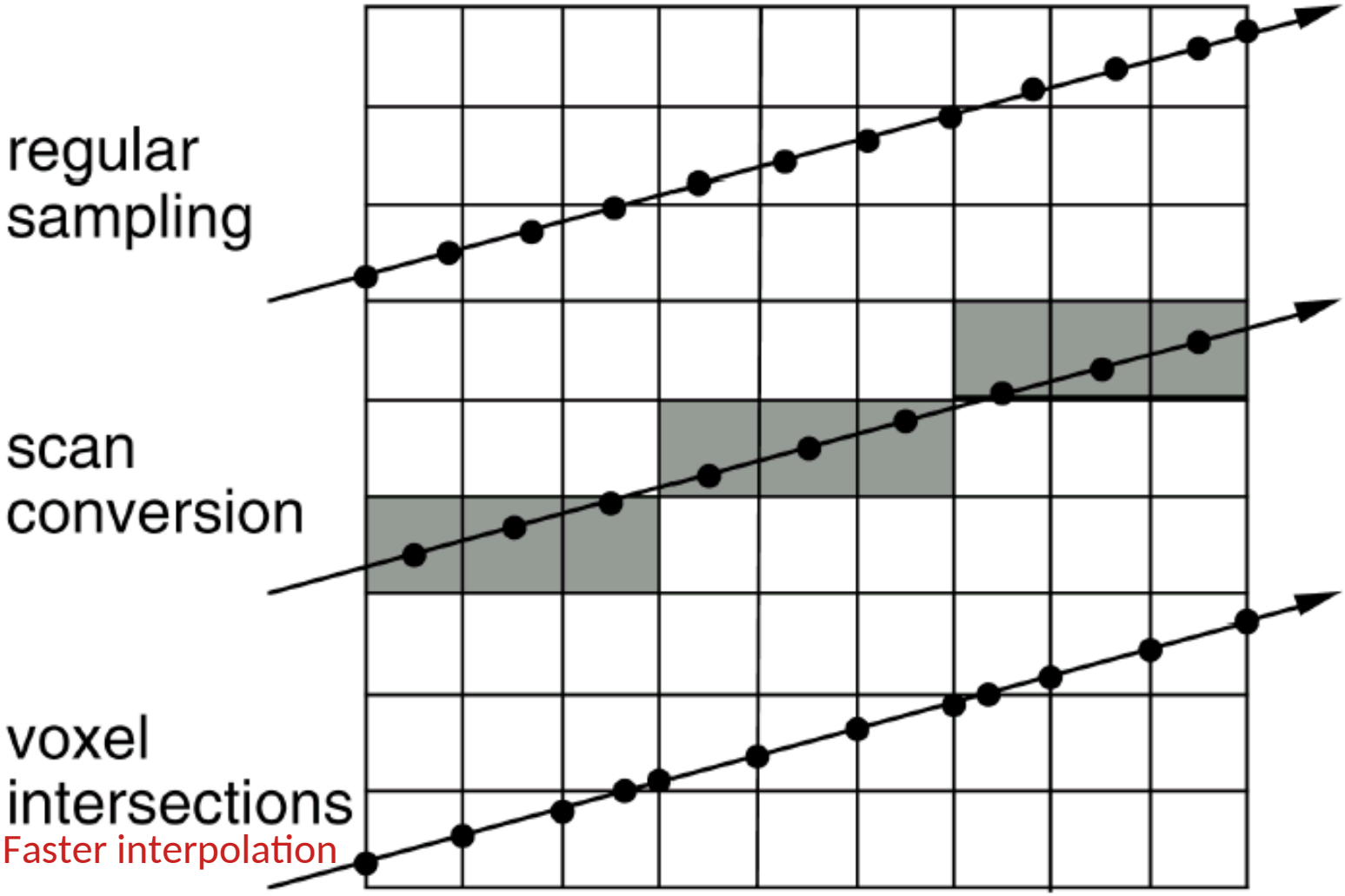

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2. Ray Traversal, Interpolation

- Voxel-based vs. cell-based ray traversal
- Tri-linear (interpolotion within the cell) vs. Bi-linear (interpolation along cell edges)
- Tri-linear:
- first 4* in z-Direction (Quadratic interpolation),
- then 2* in y-Direction (Linear interpolation),
- then 1* in x-Direction (value interpolation)

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3. Compositing

Terminology

compositing: the sample-by-sample accumulation of color and opacity values along a ray as it traverses volume data. –bob

kernel: (a.k.a. convolution kernel a.k.a. convolution filter) “one or two dimensional images that are used for computing the weighted average of pixel images” –The OpenGL Programming Guide

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3. Compositing: F2B vs. B2F

Back-to-Front (B2F):

- $c = c(1- \alpha(i\Delta s)) + C(i\Delta s)$
- $\alpha = \alpha(1 - \alpha(i\Delta s)) + \alpha(i\Delta s)$

Front-to-Back (F2B):

- $c = C(i\Delta s)\ \alpha\ (i\Delta s)\ (1- \alpha) + c$
- $\alpha = \alpha(i\Delta s)(1 - \alpha) + \alpha$

c = current color

α = opacity (inverse of transparency)

i = sample index

s = sample

Δs = distance between samples

C = color at sample

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Compositing: F2B vs. B2F

F2B: a ray can be stopped once opacity approaches 1.0 -early ray termination.

B2F: a generalization of the Painter's algorithm –less frequently used.

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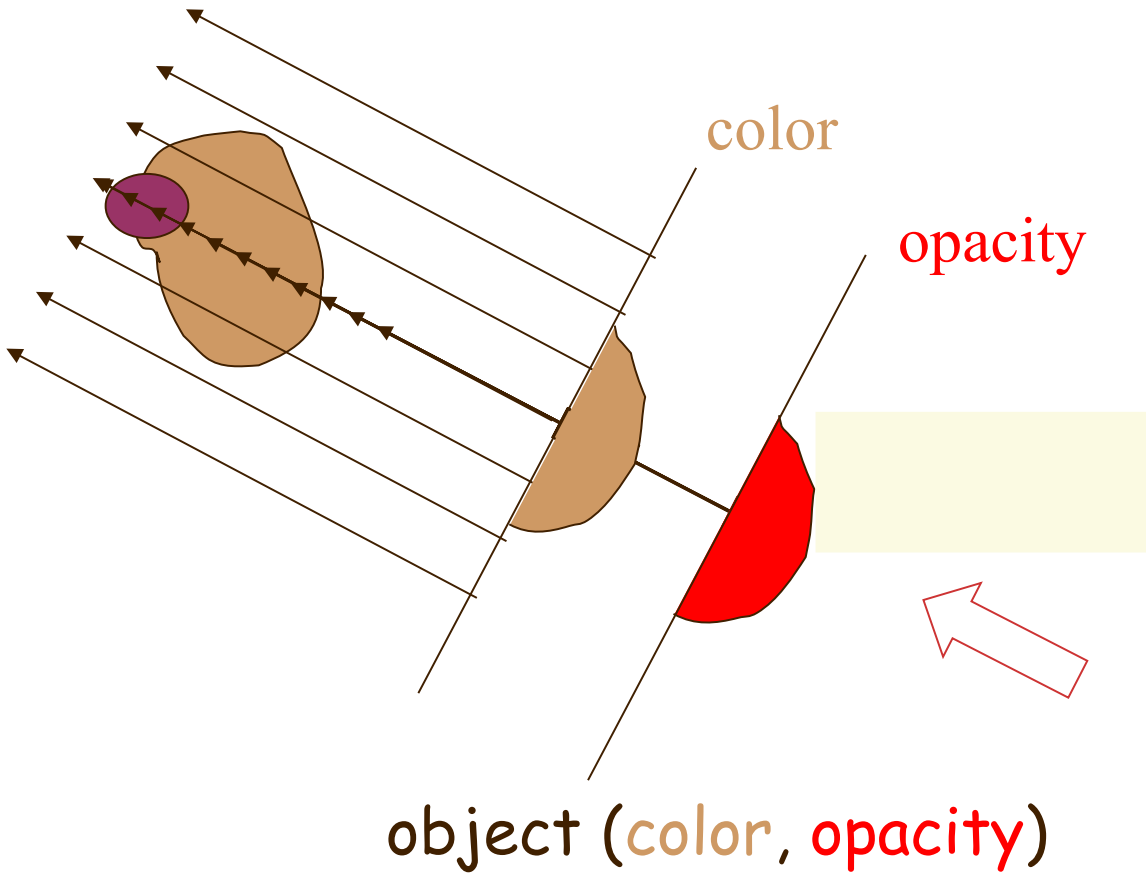
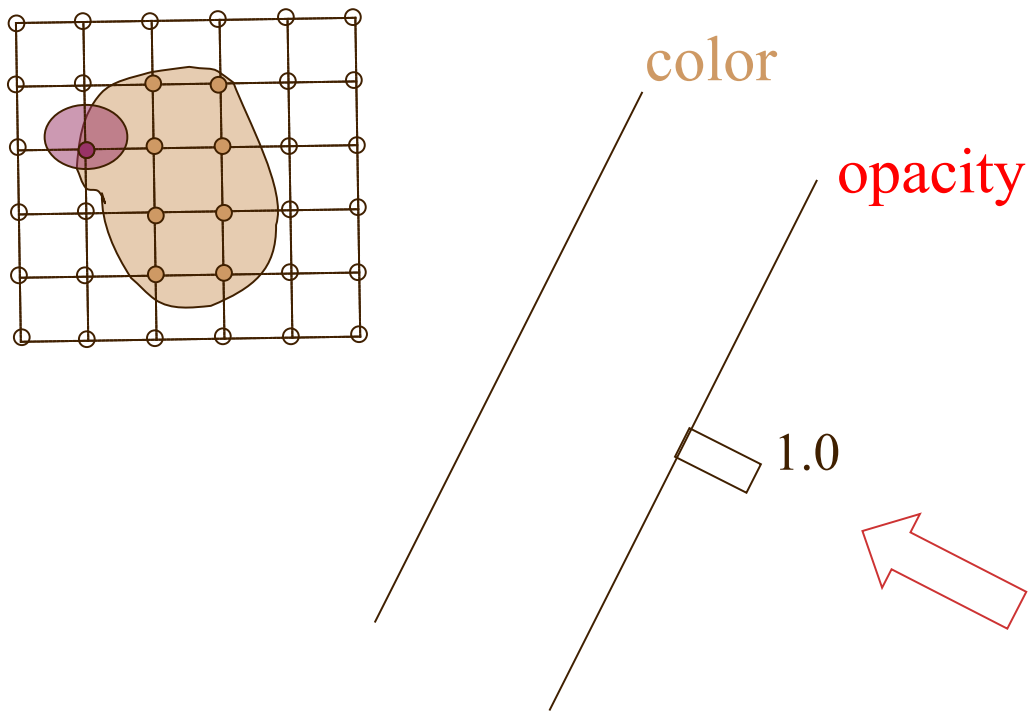
Volumetric Ray Integration

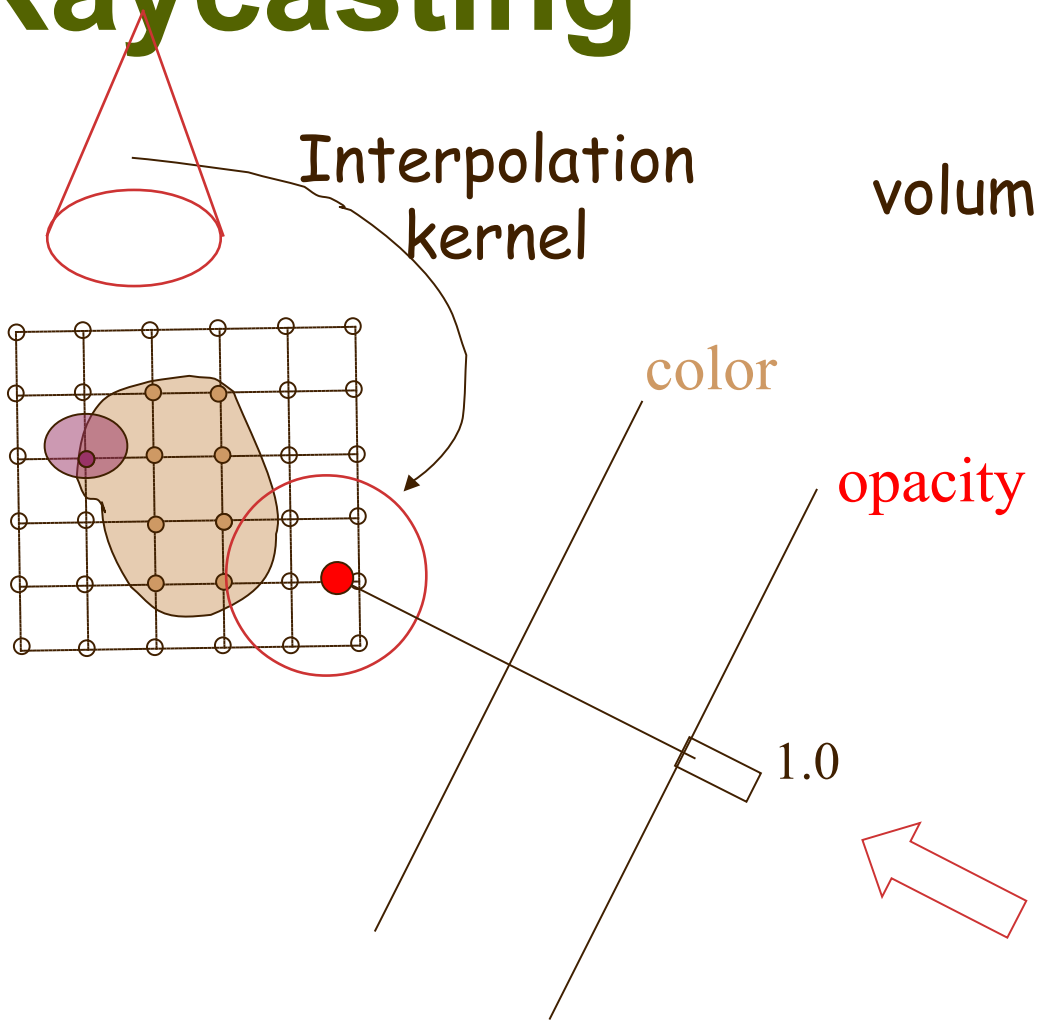


Raycasting

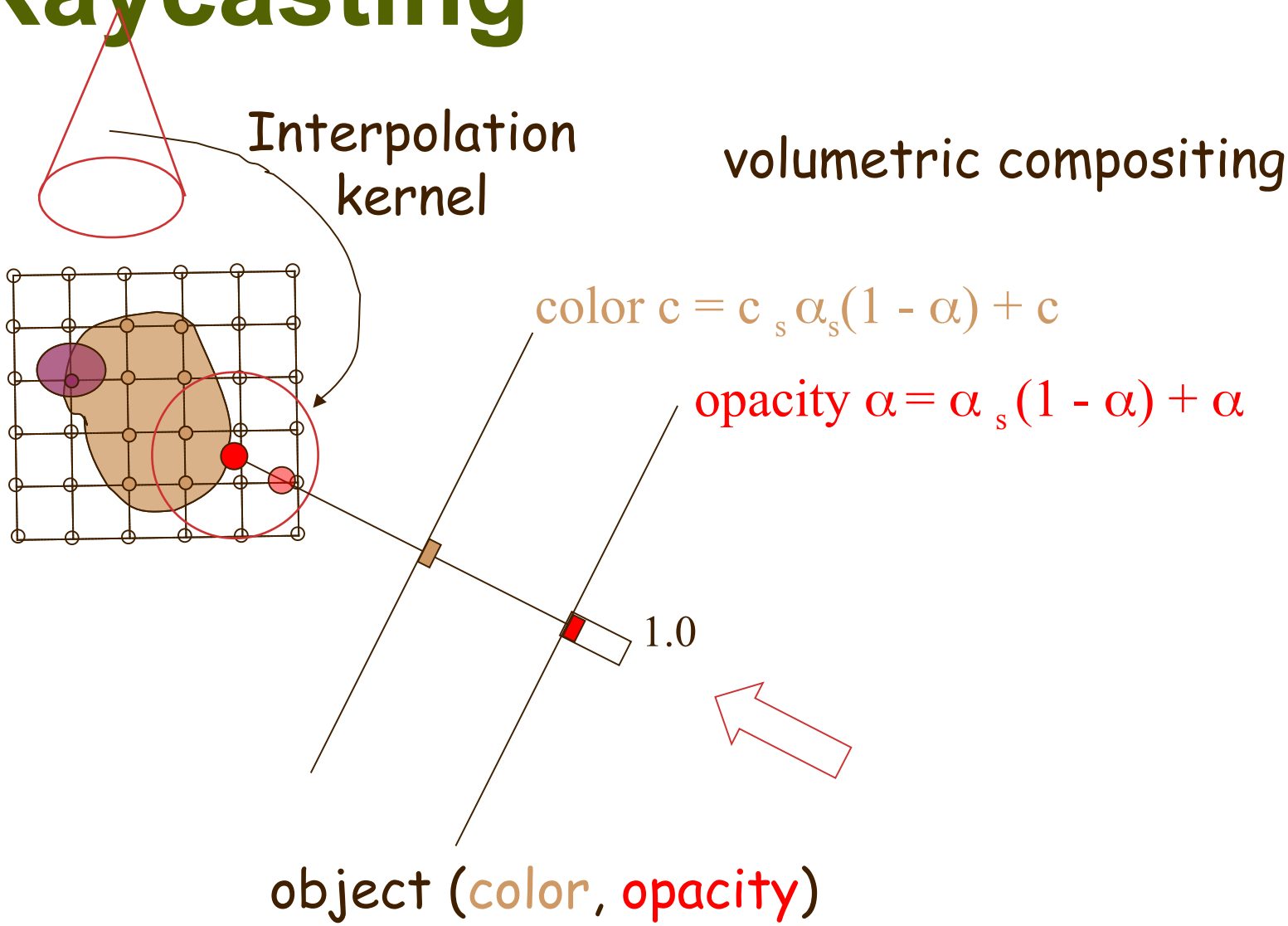
volumetric compositing



Raycasting

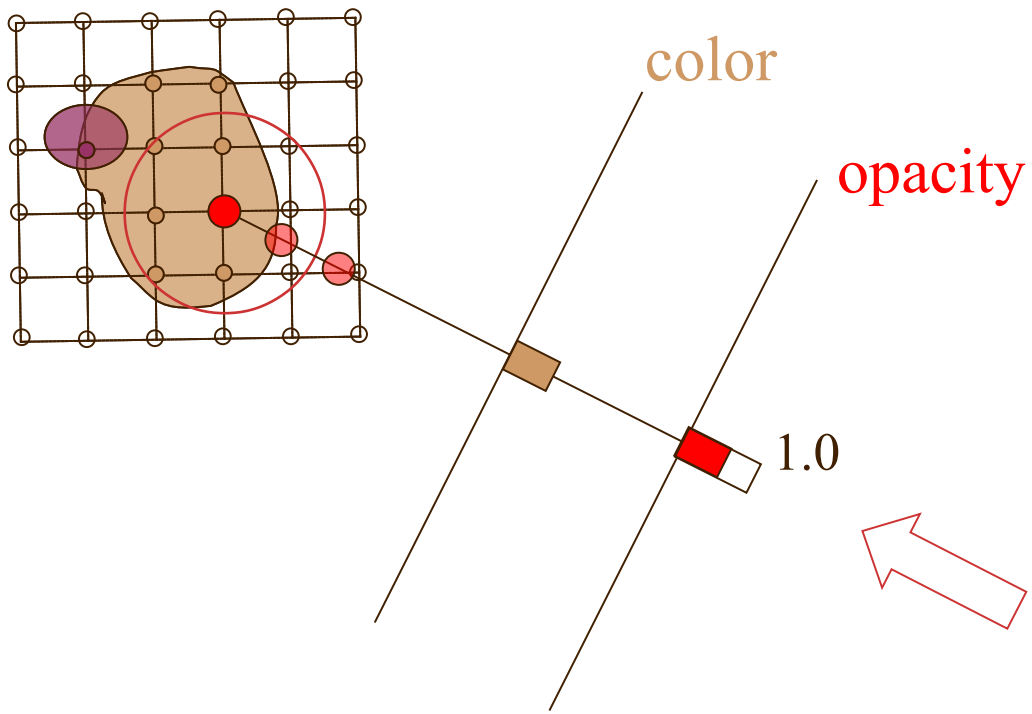

Interpolation kernel
volumetric compositing
color
opacity
1.0
object (color, opacity)

Raycasting


Interpolation kernel
volumetric compositing
color c = c s αs(1 - α) + c
opacity α = α s(1 - α) + α
1.0
object (color, opacity)

Raycasting

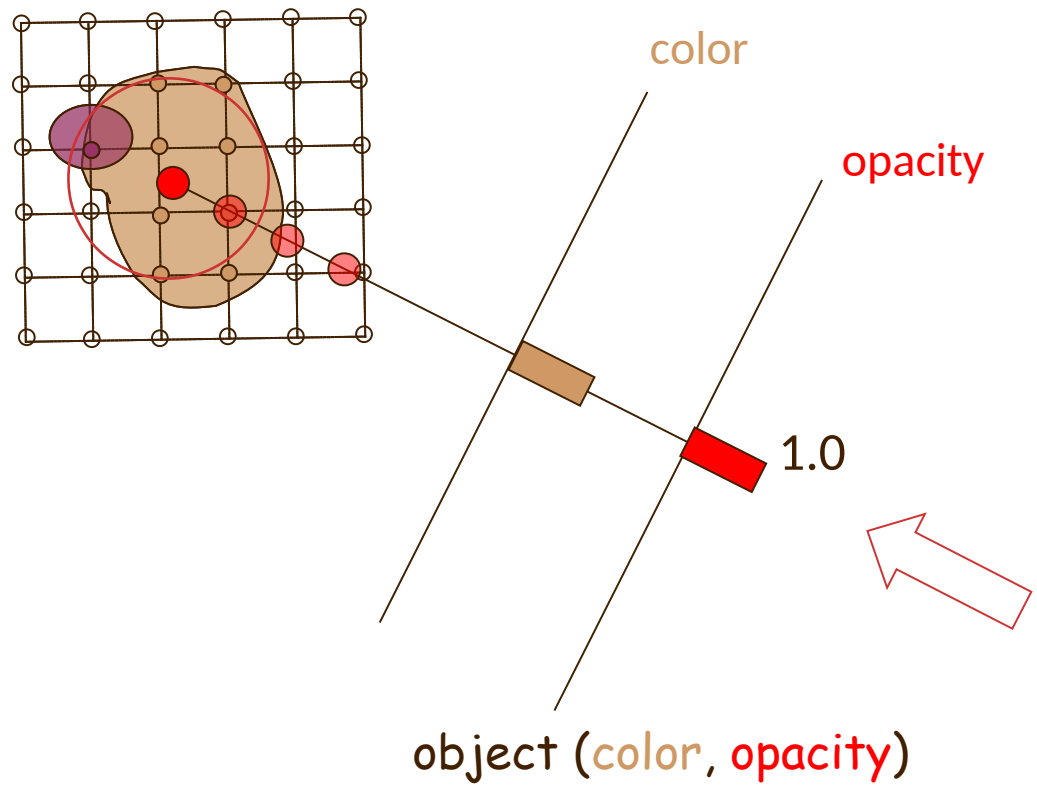
volumetric compositing



object (color, opacity)

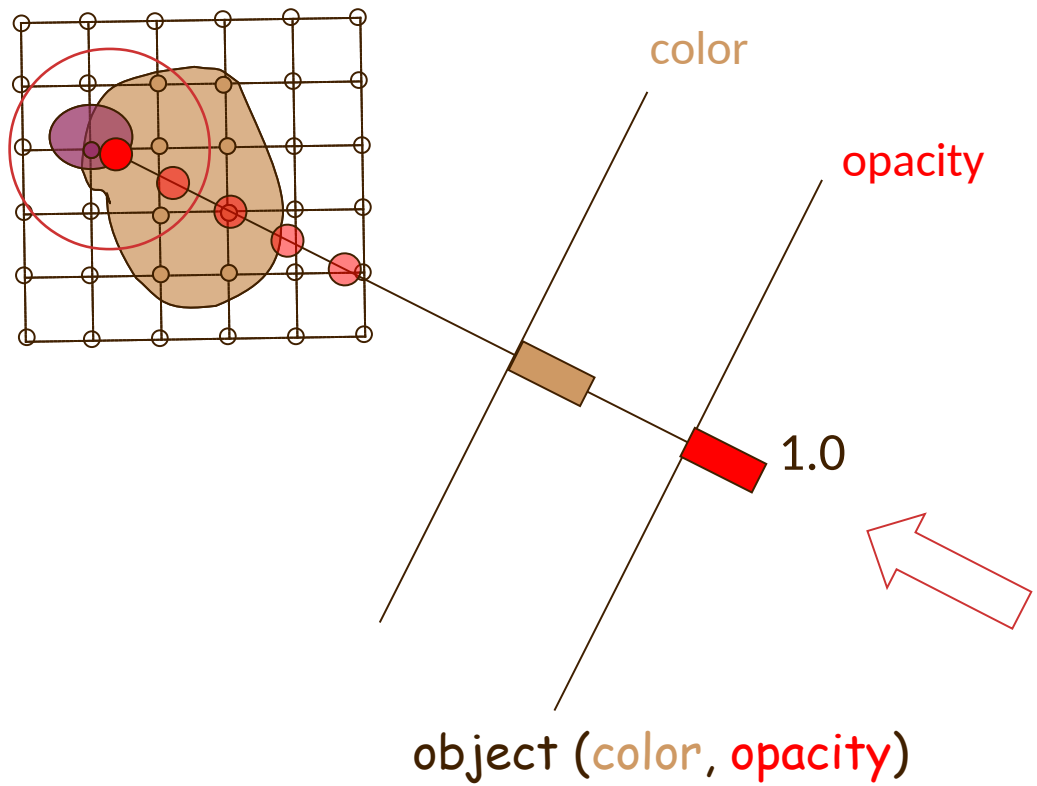
Raycasting

volumetric compositing



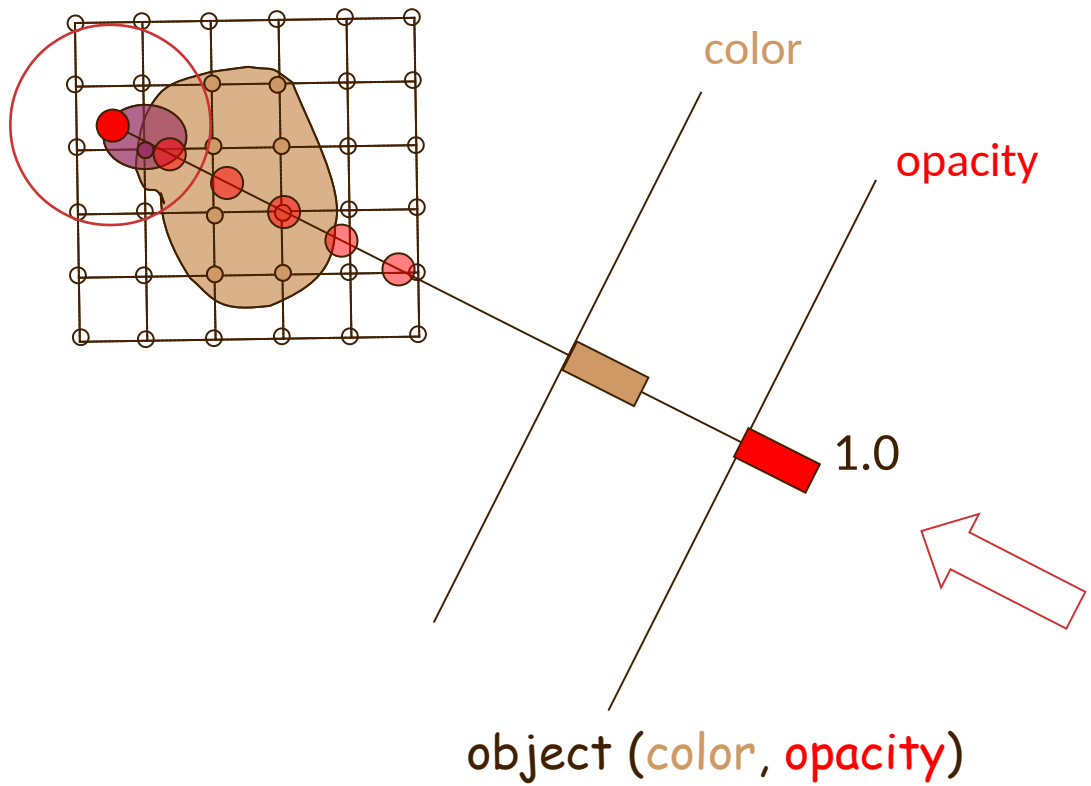
Raycasting

volumetric compositing



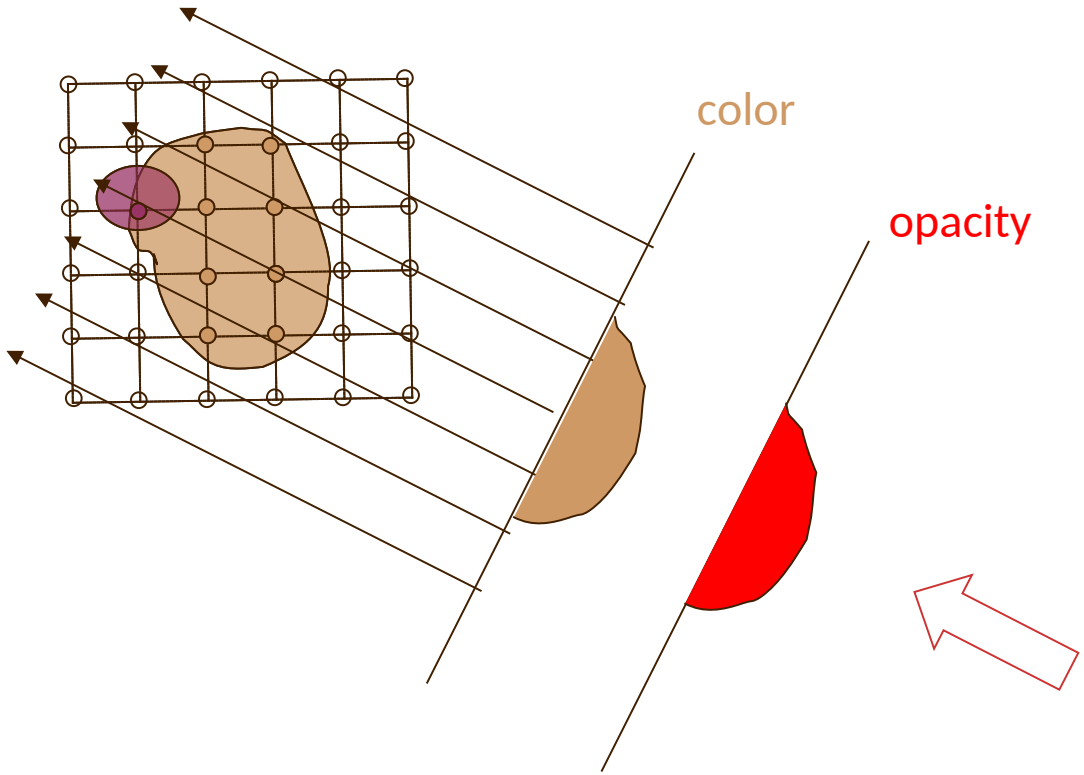
Raycasting

volumetric compositing



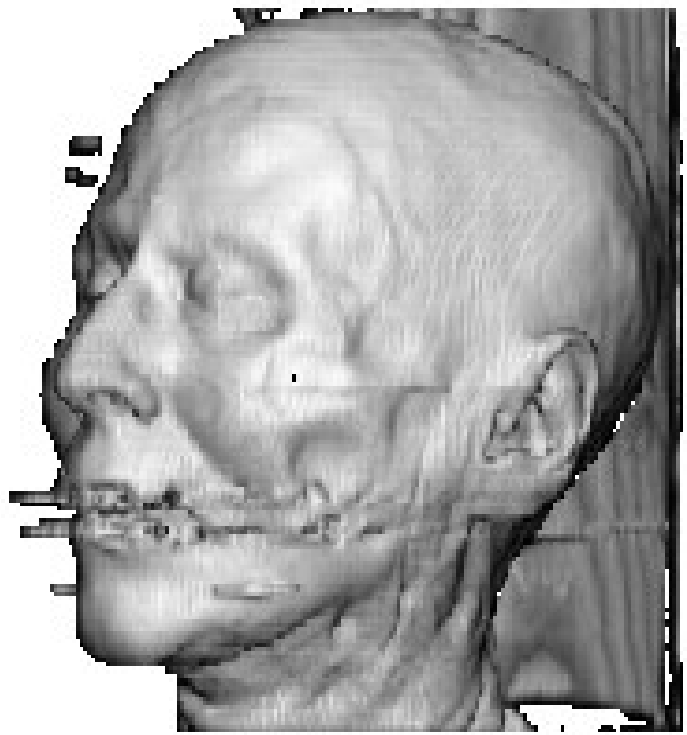
Raycasting

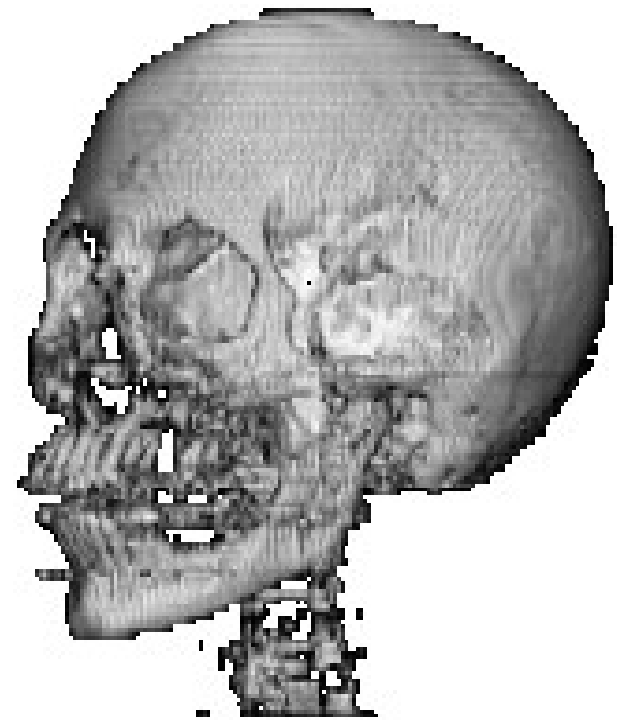
volumetric compositing



Ray Casting – Examples

Different transfer functions (quasi-surface rend.),
256 x 256 x 113 CT data





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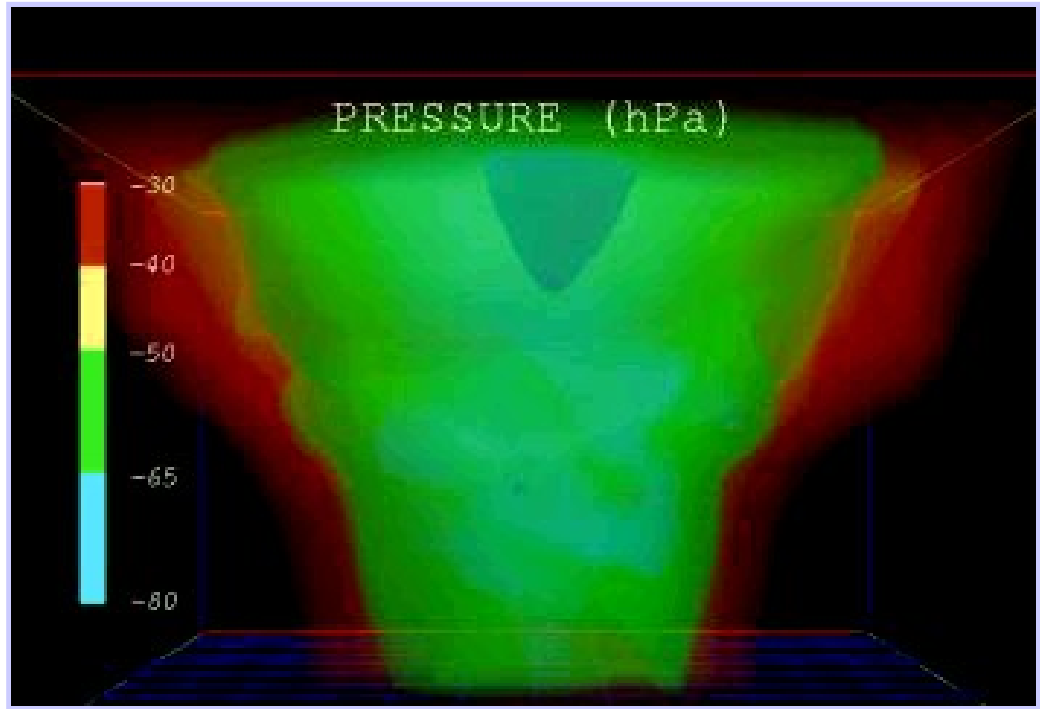
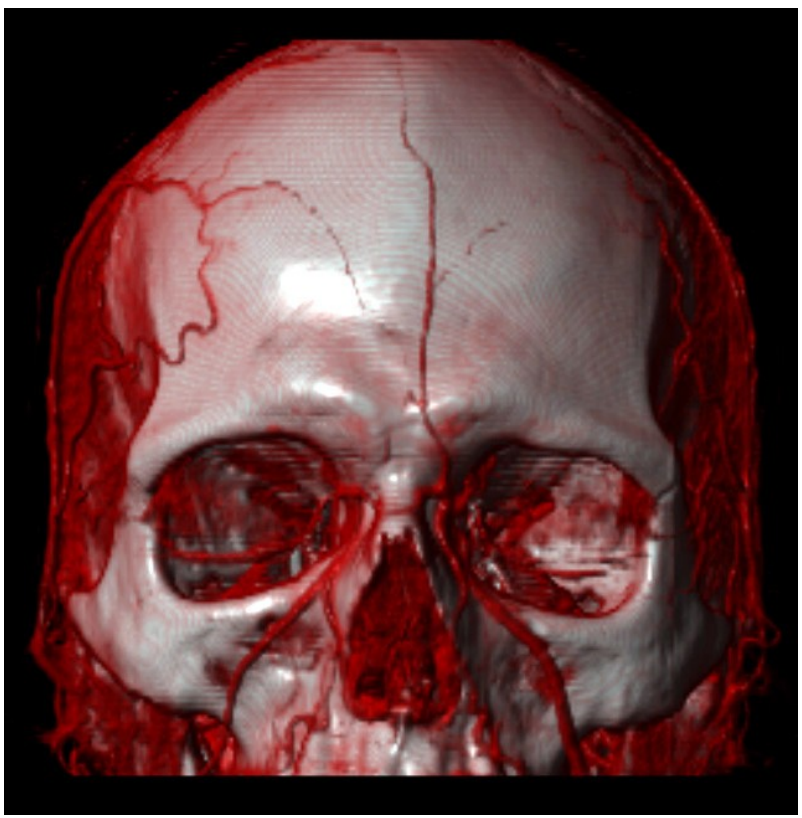
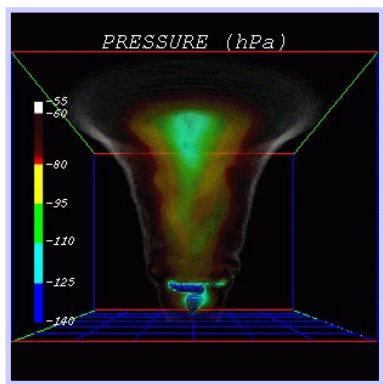
Ray Casting – More Examples

- Tornado Viz:
- Head data:







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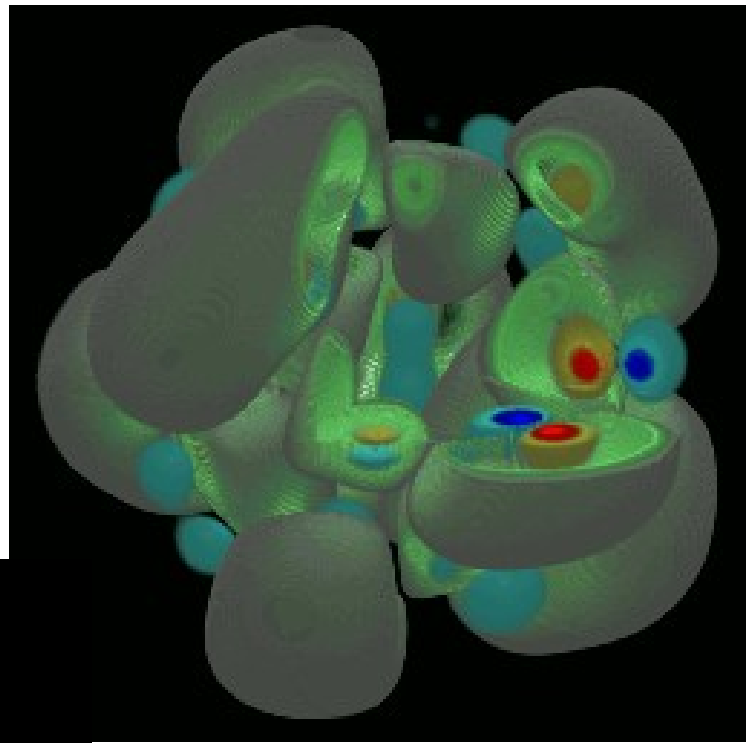
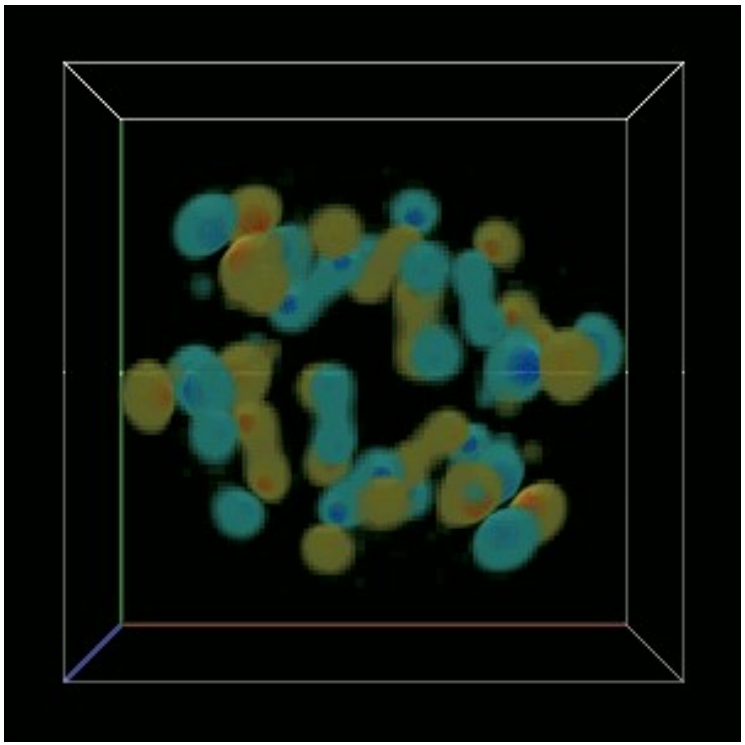
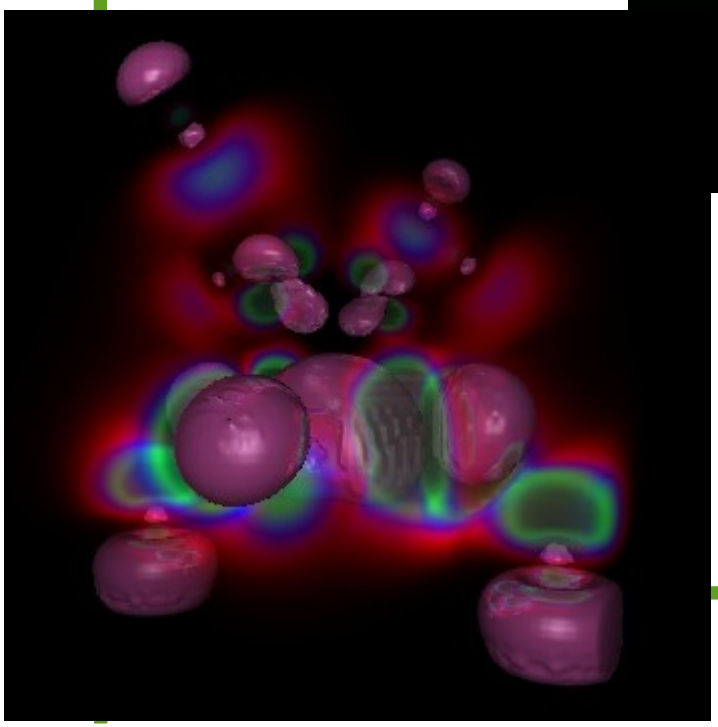
Ray Casting – more Examples

Molecular data:







Literature

Paper (more details):

- Marc Levoy: "**Display of Surfaces from Volume Data**" in *IEEE Computer Graphics & Applications*, Vol. 8, No. 3, June 1988

For more, see also

- **Data Visualization, Principles and Practice**, **Chapter 10 Volume Visualization**, by A. Telea, AK Peters, 2008

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- Torsten Möller
- Roberto Scopigno,
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- M. Eduard Gröller
- Helwig Hauser

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