



Volume Rendering



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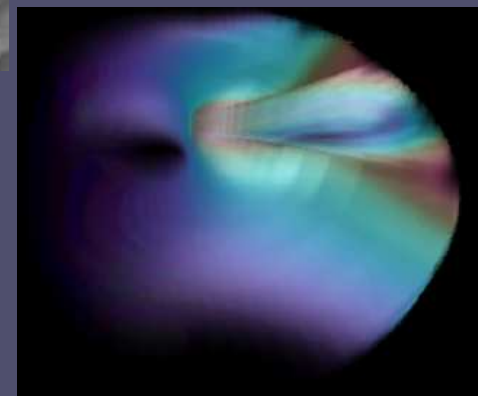
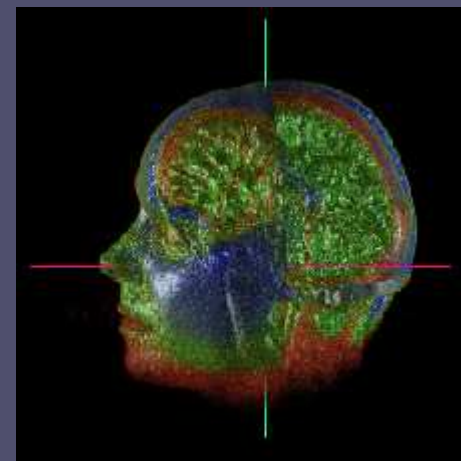
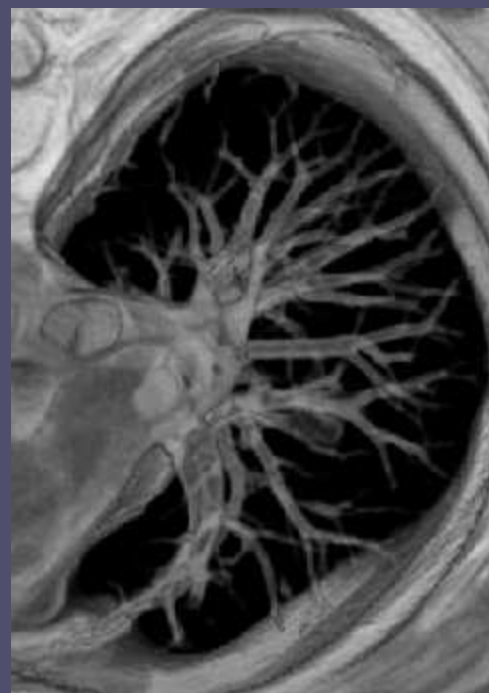
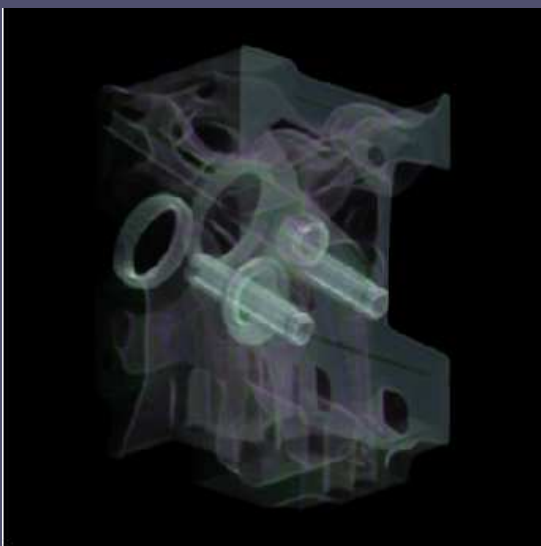
Creating 2D images of volume data

**Voxels (volume elements) typically stored
in regular lattice**

Voxel lattice represents 3D scalar field



Examples





Types of 3D Scalar Fields

X-ray absorption

Flow velocity (speed)

Temperature

Solidity (CSG, etc.)



Generating 3D Scalar Fields

May be measured or simulated

Measured with CT scan or MRI

CFD simulation of flow and temperature

Sampling of CSG hierarchy

Conversion from B-Rep to Solid



Field Reconstruction

Tri-linear interpolation

Quadratic or cubic splines

Convolution with filter kernel

- Each voxel's contribution to a point, p , measured by value in kernel, which is centered at p



Mapping Values to Appearance

Often only a single value at each voxel

Want mapping to color and opacity

**May emphasize certain value ranges or give
all ranges equal emphasis in final image**



Emphasizing a Single Isosurface

R



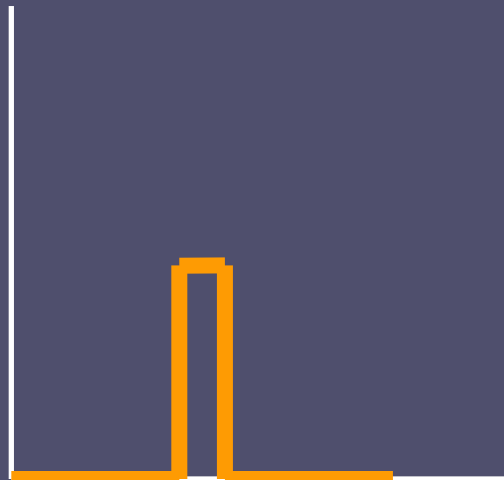
G



B

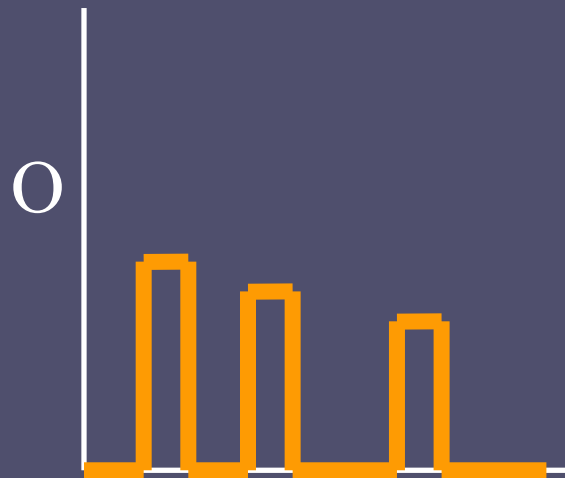
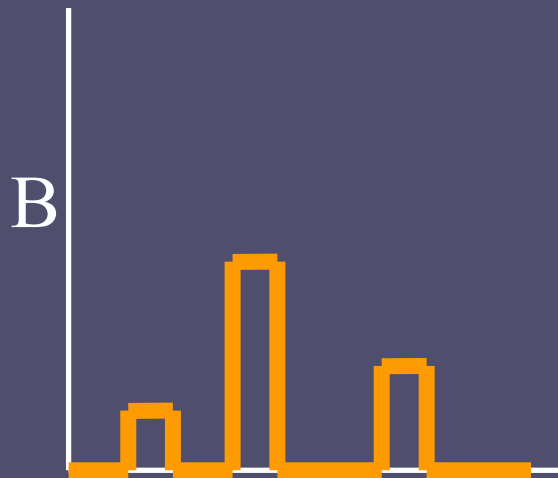


O





Emphasizing 3 Isosurfaces





Visualizing Values as Opacity





Methods of Rendering

Solid texturing

Isosurface extraction

Image-space accumulation (ray casting)

Object-space accumulation (splatting)



Marching Cubes Algorithm

Performs isosurface extraction from voxel data

Creates a B-Rep, typically a set of triangles

B-Rep then rendering using standard rendering techniques



Finding/Creating the Surface

**Assume linear interpolation between data,
stored at voxel corners**

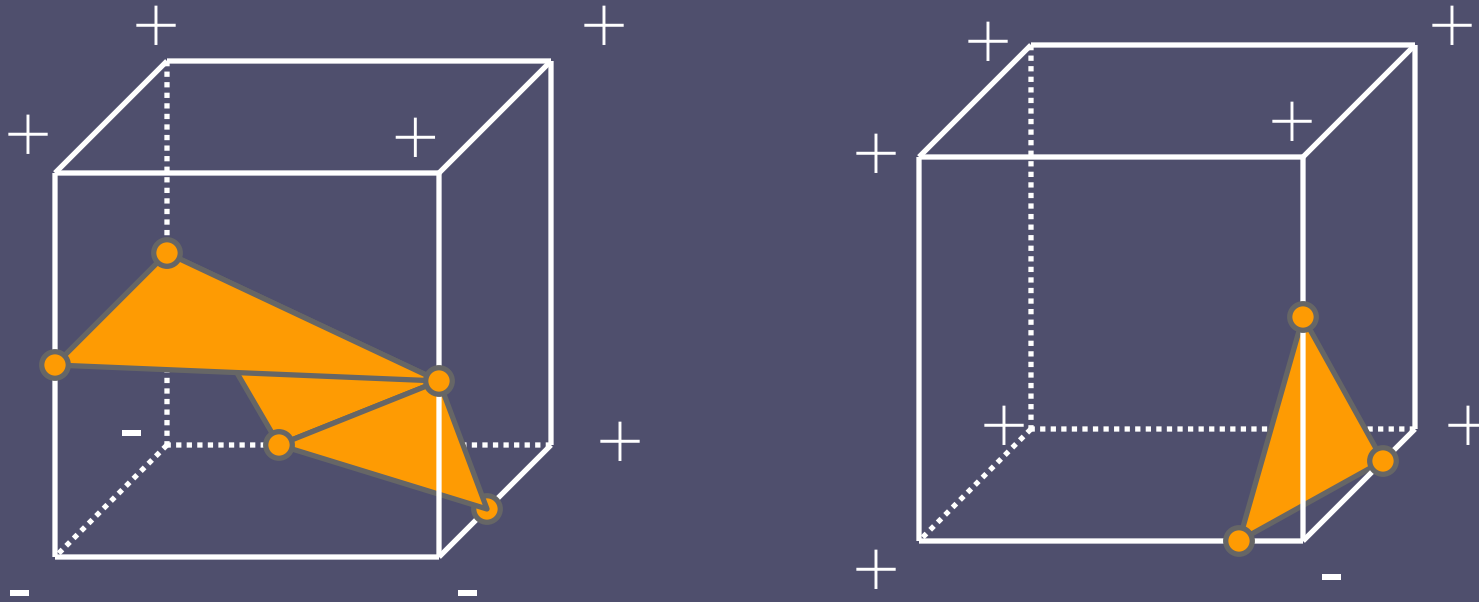
Mark corners as inside or outside surface

Find surface intersections along voxel edges

**Construct triangles connecting
intersections**



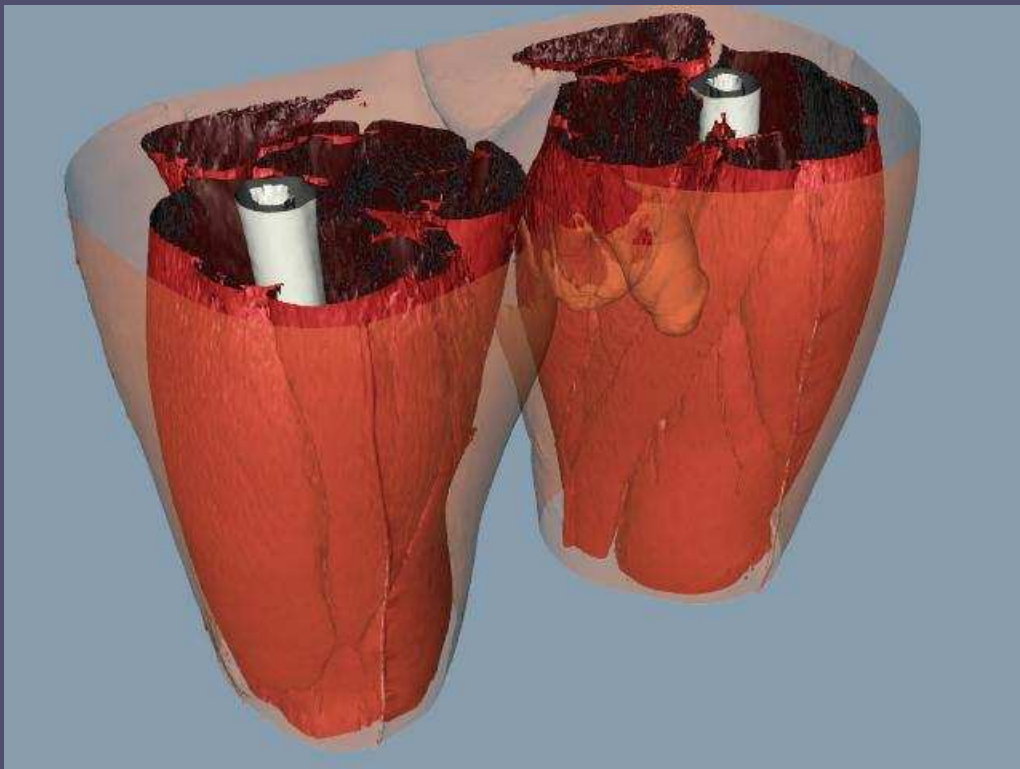
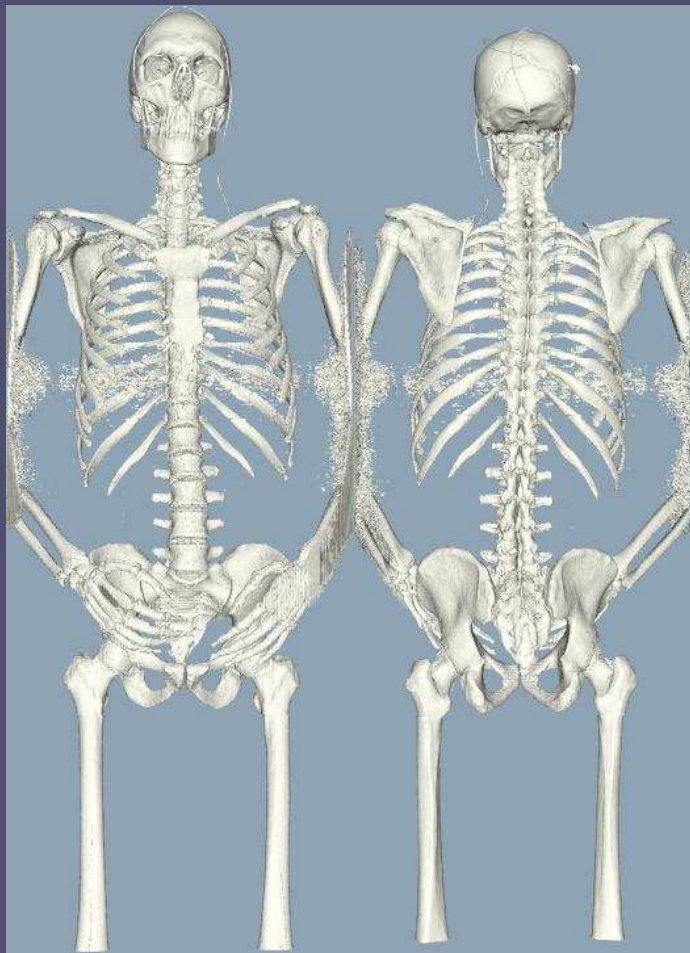
Marching Cubes Illustrations



- $2^8 = 256$ possible configurations (only 16 unique)
- Store all cases in table, including number and connectivity of triangles
- Must connect properly along voxel sides for continuity



Visible Man Isosurfaces



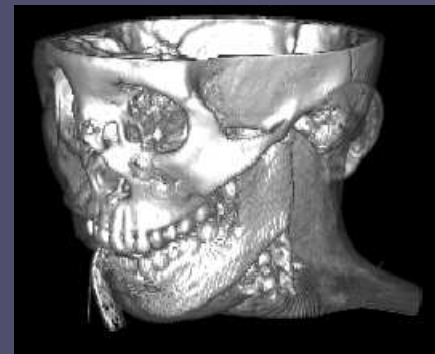
from Lorensen, “Marching Through the Visible Man, *Proceedings of IEEE Visualization '95*.”



Rendering Isosurfaces

One or more isosurfaces may be rendered as totally opaque or partially transparent

Clipping planes may be used to illustrate interior surfaces



From Pekar et al., “Fast Detection of Meaningful Isosurface for Volume Visualization,” *Proceedings of IEEE Visualization 2001*.



Volume Ray Casting

Loop over pixels, generating rays

- at least one per pixel, typically

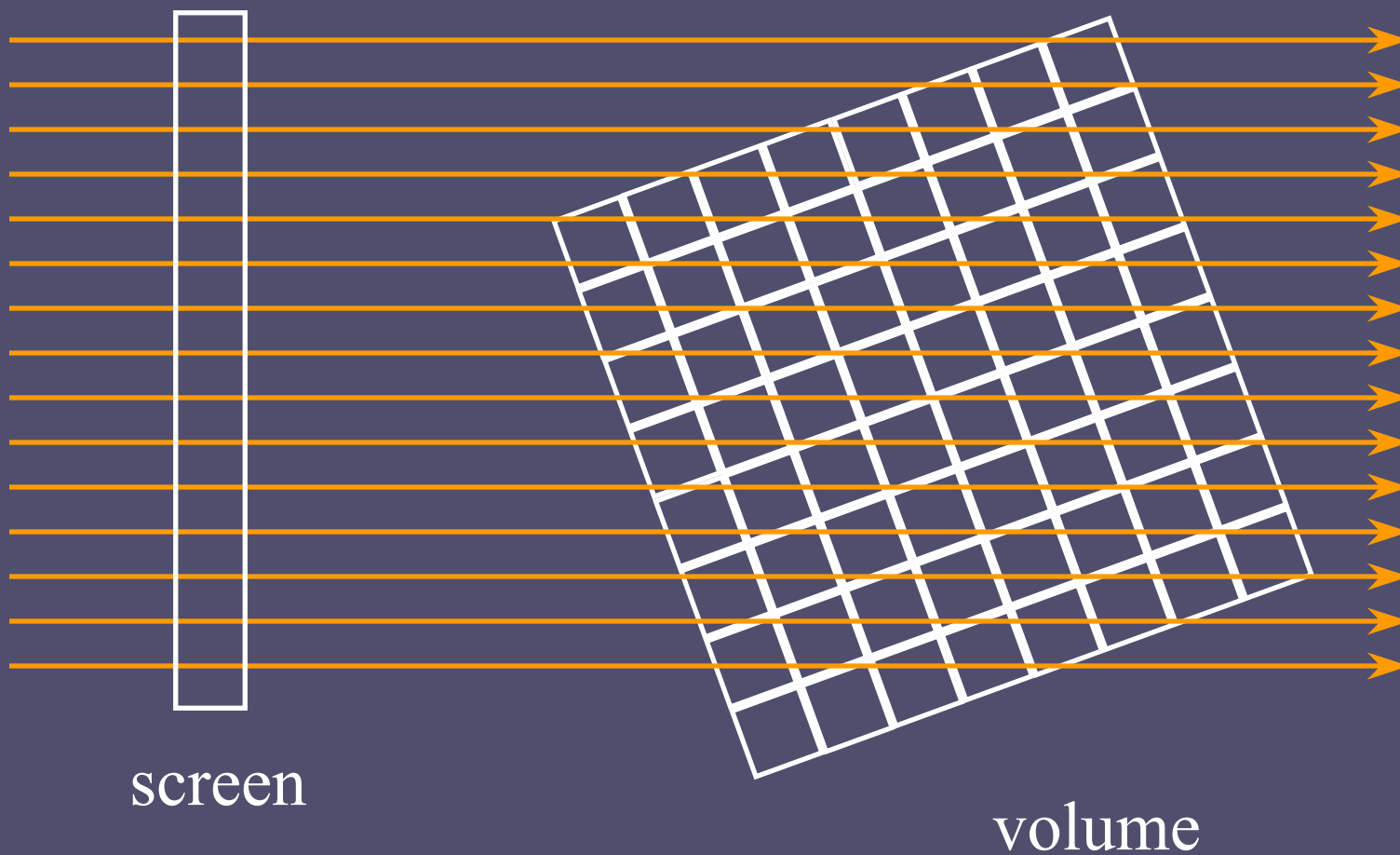
Trace each ray through the voxel grid

Accumulate color and opacity along ray

Stop when ray exits grid or reaches full opacity



Ray Casting Illustration





Volume Splatting

Traverse voxels in front to back order

- **traverse each voxel in plane, then move to next plane**

For each voxel, accumulate color and opacity to each pixel it covers

- **like throwing snowballs at the screen**

Voxel projection covers hexagonal footprint

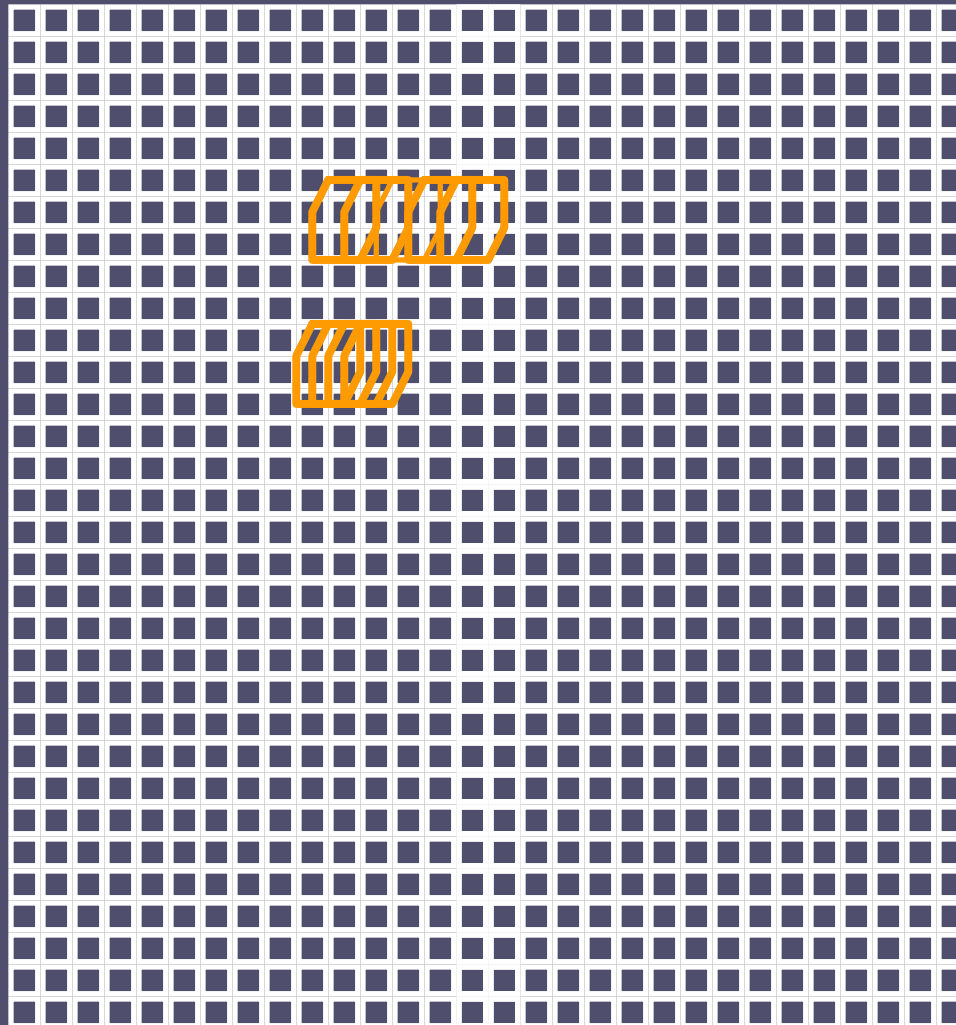
Smoother interpolation possible by applying kernel with fall-off away from sample point



Volume Splatting Illustration



footprint



screen



Ray Casting vs. Splatting

Ray Casting

- Point samples
- Random data access
- Easy for parallel or perspective projection

Splatting

- Area samples
- Ordered data access
- More difficult for perspective projection



Color/Opacity Accumulation

Assume that each voxel emits a single color and filters colors by its opacity

$$C' = C * \alpha$$

$$C'_{out} = C'_{in} + C'_{voxel} * (1 - \alpha_{in})$$

$$\alpha_{out} = \alpha_{in} + \alpha_{voxel} * (1 - \alpha_{in})$$

$$C_{out} = C'_{out} / \alpha_{out}$$



Accumulation Example

Suppose ray passes through 3 voxels (r,g,b,a):

$$V_1 = (.3, .1, .1, .2)$$

$$V_2 = (.1, .3, .1, .3)$$

$$V_3 = (.1, .3, .1, .3)$$



Premultiply colors by opacity:

$$V_1' = (.06, .02, .02, .2)$$

$$V_2' = (.03, .09, .03, .3)$$

$$V_3' = (.03, .09, .03, .3)$$



Accumulation Example (cont.)

After passing through V_1 , we have

$$(0,0,0,0) + (.06,.02,.02,.2)*(1-0) = (.06,.06,.02,.2)$$

After passing through V_2 , we have

$$(.06,.02,.02,.2) + (.03,.09,.03,.3)*(1-.2) =$$
$$(.084,.092,.044,.44)$$

After passing through V_3 , we have

$$(.084,.092,.044,.44) + (.03,.09,.03,.3)*(1-.44) =$$
$$(.1008,.1424,.0608,.608)$$

Dividing by the final alpha, we get

$$(.17, .23, .1, 1)$$



Volume Illumination

Several possible models

- identify surfaces within voxels
- allow not only voxel emission, but attenuation of incoming light and surface reflection
- model as particle clouds of various densities

Drebin et al. 98 models voxels as mixtures of materials

- all measurements continuous, not discrete
- measure surface “strength” based on differences in material densities
- measure surface normals as value gradients



Parallel vs. Perspective Projection

Parallel

- Even sampling
- Regular access
- Simple footprints

Perspective

- Uneven sampling
- Irregular access
- Complex footprints