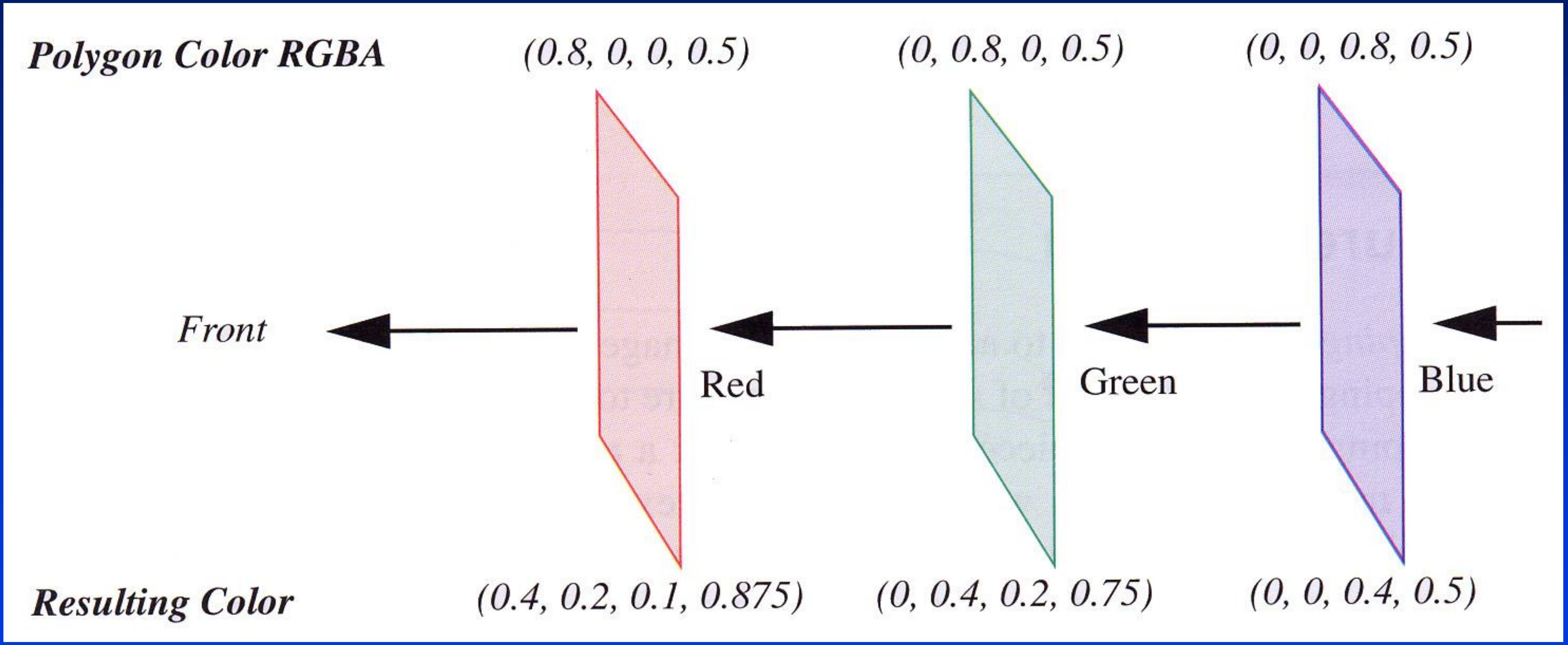
Advanced Volume Rendering Techniques

Transparency and Alpha Values

- Why is transparency useful?
- Peer into and through objects
- Volume visualization
- α = opacity
- $\alpha = 1 \rightarrow$ opaque
- Modern graphics hardware supports **alpha blending**
- Need to **composite** transparent actors
- Does order matter?
- Answer is: Yes

Alpha Compositing



Alpha Composition

$$R = A_s R_s + (1 - A_s) R_b$$
$$G = A_s G_s + (1 - A_s) G_b$$
$$B = A_s B_s + (1 - A_s) B_b$$
$$A = A_s + (1 - A_s) A_b$$

- *s* represents *surface* of actor
- *b* represents what is *behind* actor's surface
- Suppose $A_s = 0$? $A_s = 1$?

Alpha Compositing Example

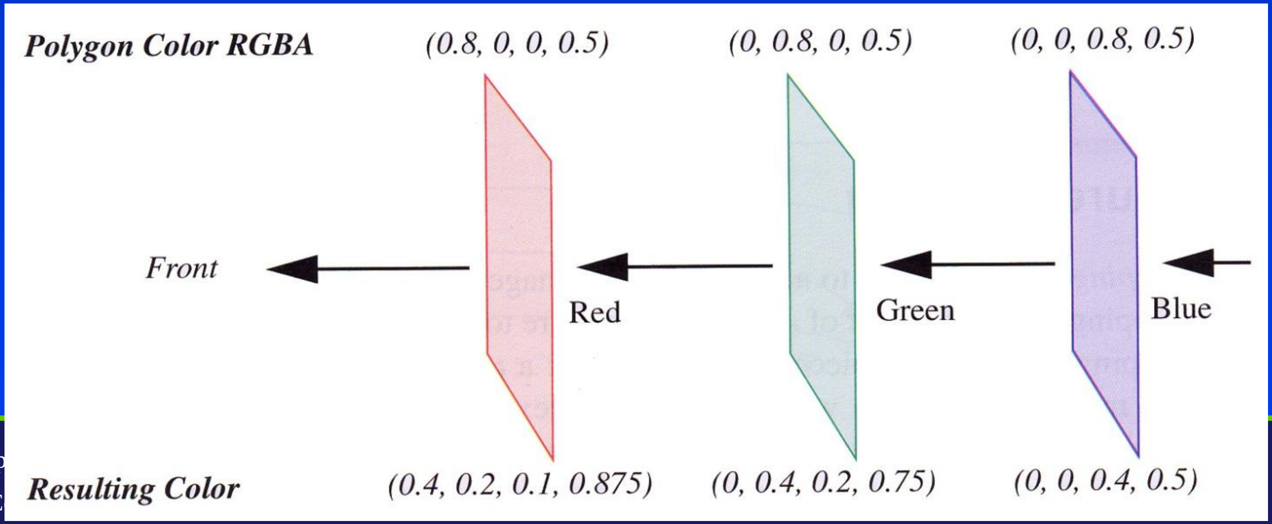
- Use α = 0.5 for all 3 polygons and work through the calculations

$$R = A_s R_s + (1 - A_s) R_b$$

$$G = A_s G_s + (1 - A_s) G_b$$

$$B = A_s B_s + (1 - A_s) B_b$$

$$A = A_s + (1 - A_s) A_b$$

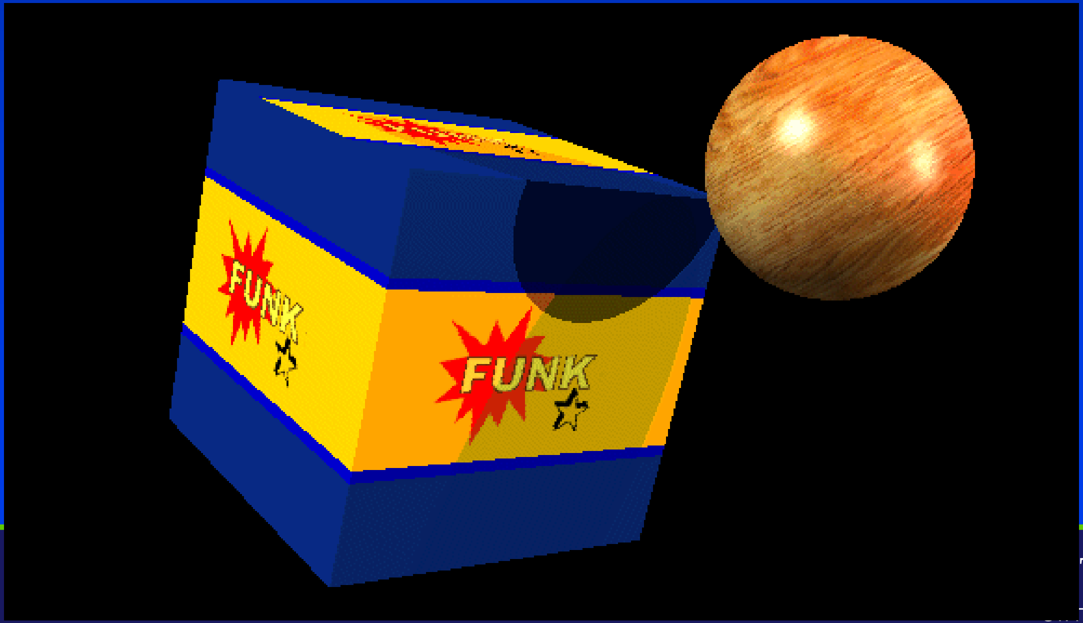


Compositing Order Matters!

- Recall the *z buffer* algorithm, which is used for depth?
- Will not necessarily composite polygons in right order
- Usually must use software to order actors by their increasing distance from camera

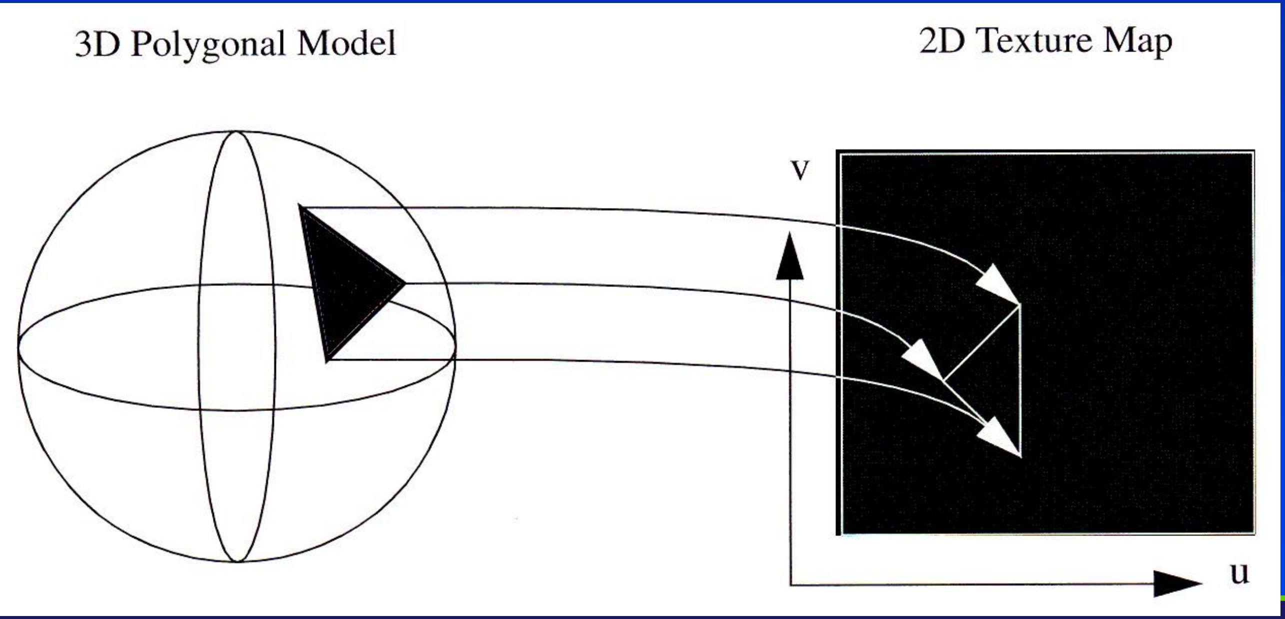
Texture Mapping

- Idea: add detail to image without requiring modeling detail
- Map picture called a **texture map** onto object
- **Texture coordinates** tell you where on object to put picture



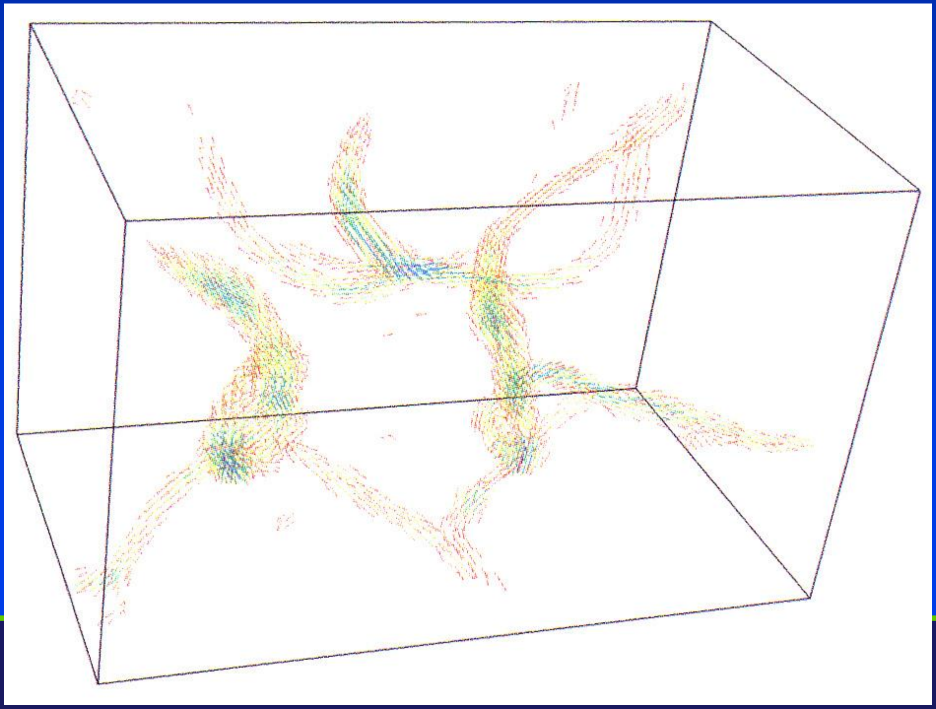
Texture Mapping

- 2D texture mapped onto 3D geometry
- Each 3D vertex assigned 2D texture coordinates, usually written (*u*,*v*)
- Texture is an RGBA image made of **texels**, texture elements



Texture Mapping in Visualization

- Animated texture maps
- Flow visualization
- Colors cycle in a loop to show direction of flow



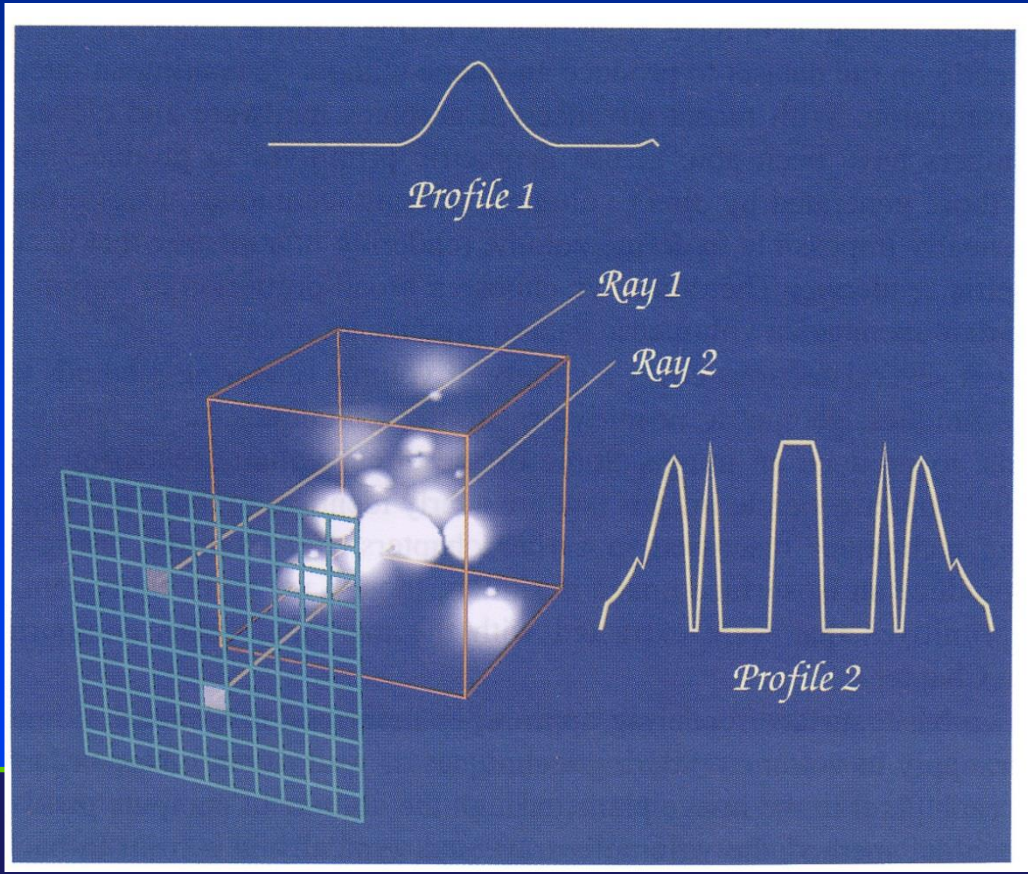
Advanced Volume Rendering

Volume Rendering

- Image-order and object-order volume rendering
- Ray-casting vs. splatting

Ray Casting

- Idea: send *viewing ray* into volume and examine data encountered to compute pixel's color

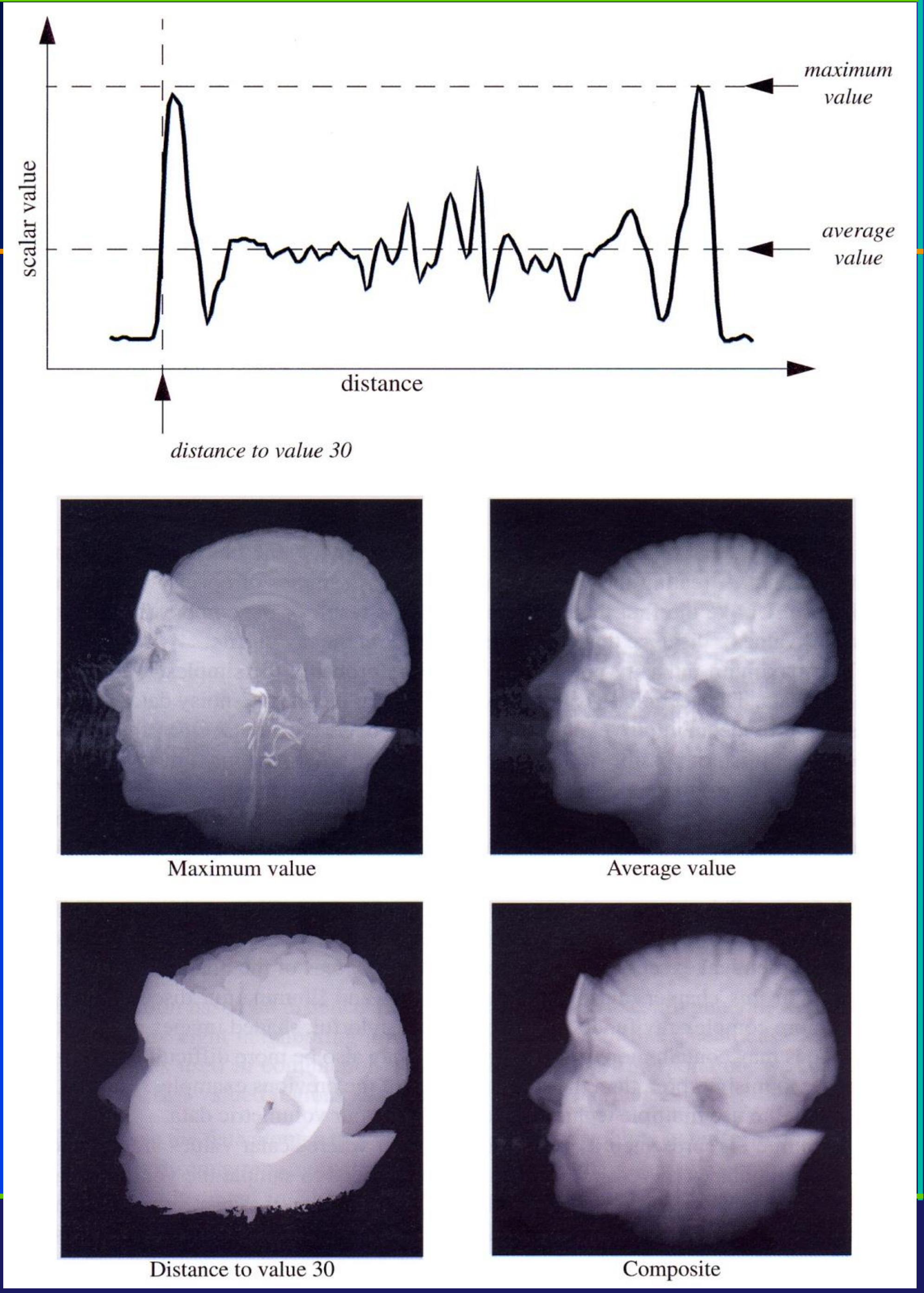


Ray Casting

- Each ray has a different profile we can draw as a 2D curve
- Essentially we will numerically integrate (?) the curve
- Material density, illumination parameters, other attributes affect this integration

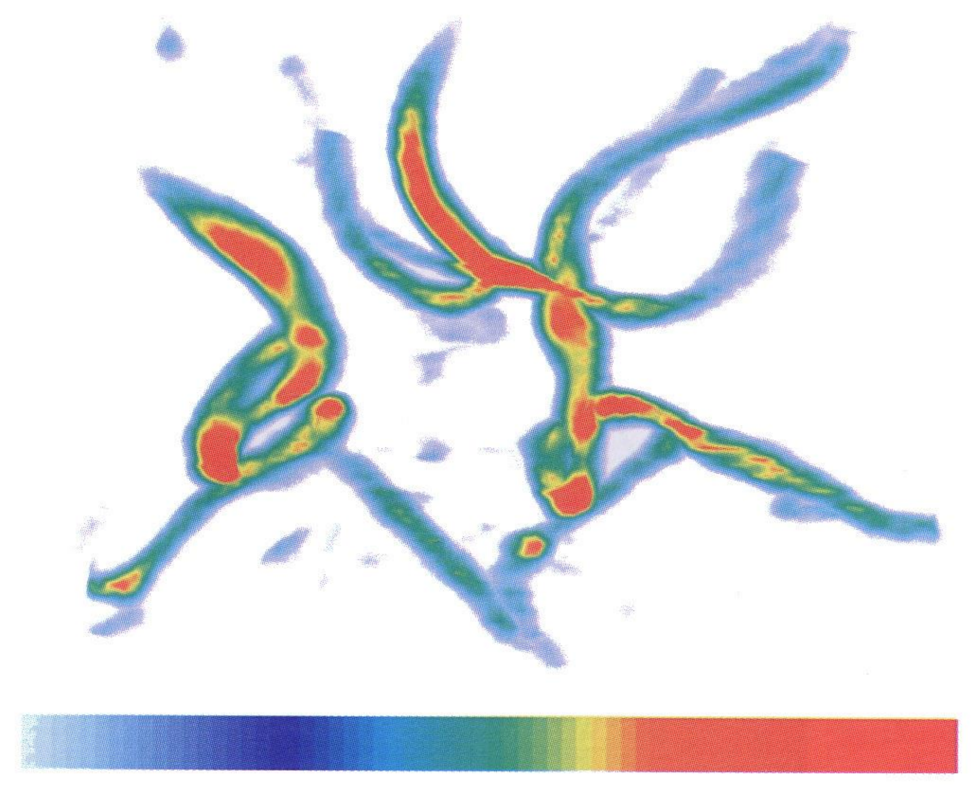
Ray Profile Example

- 8-bit density volume
- Range: 0…255
- x-axis: distance from view plane
- y-axis: density
- Image 3: distance to first voxel with 30+ density value
- Image 4: alpha compositing



Maximum Intensity Projection (MIP)

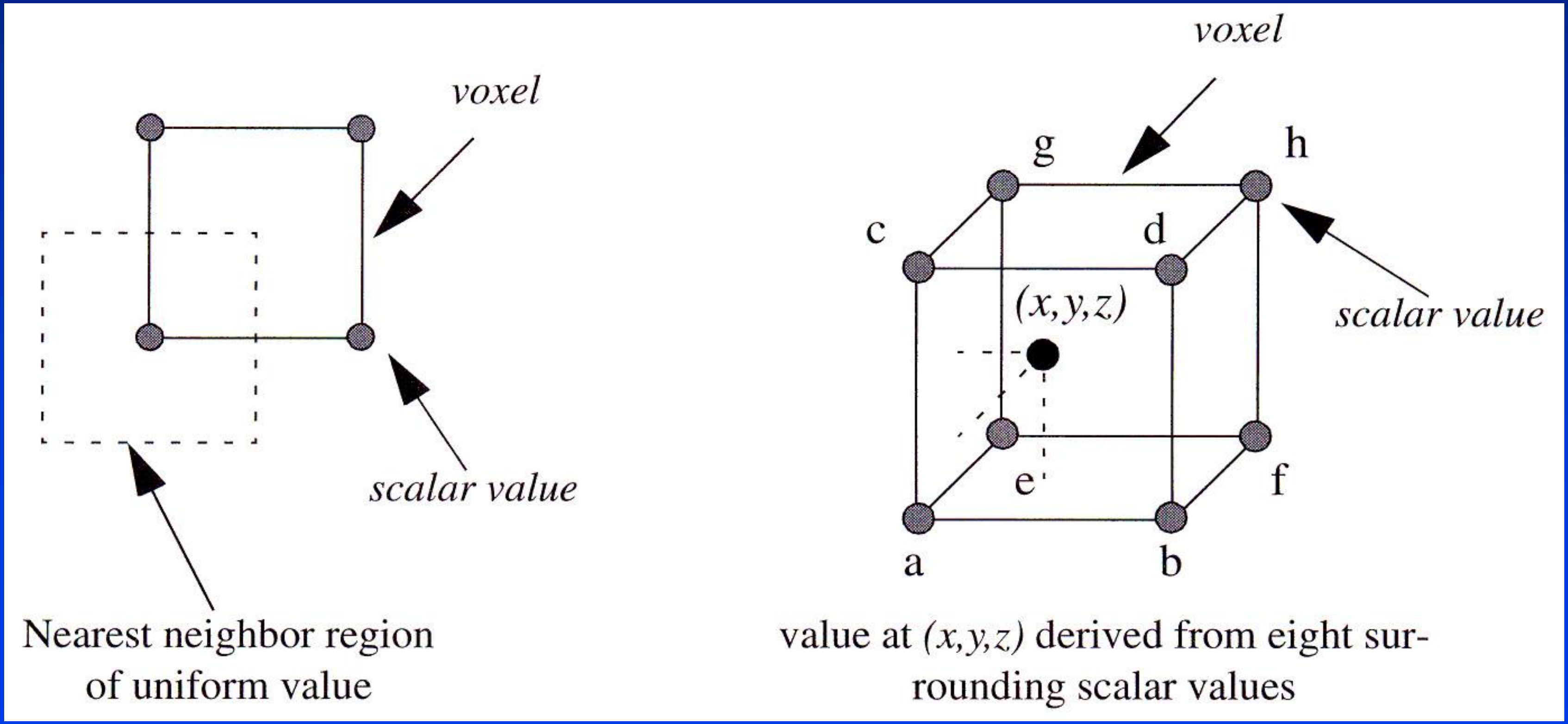
- MIP simple yet effective technique
- Depth perception lost, though
- Can do colored MIP also
- Which blood vessel is in front of the others?
- No compositing, so colors don't blend together



Ray Traversal

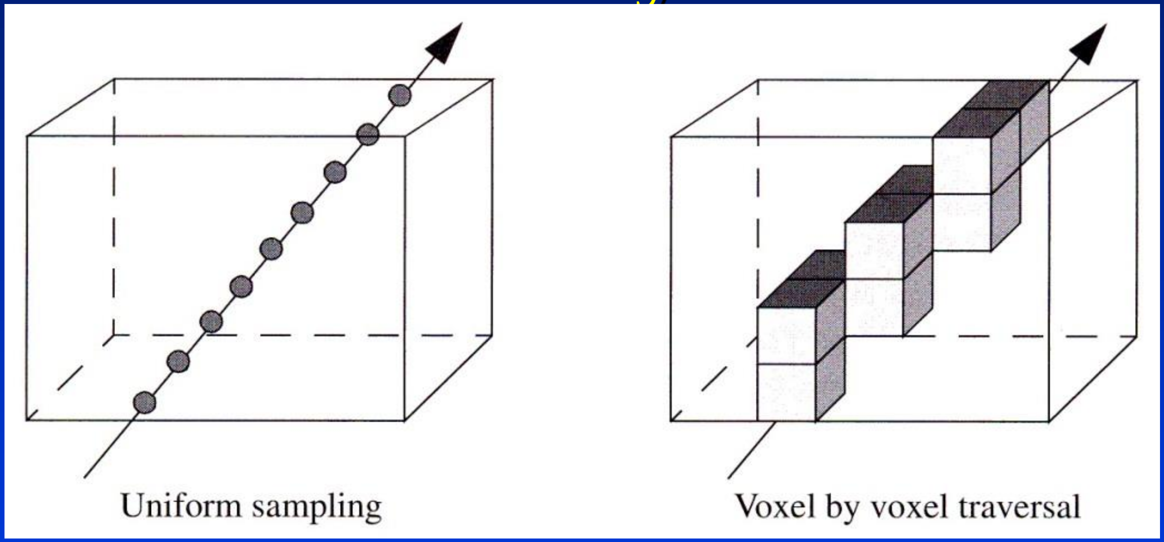
- We take small steps along the ray
- Don’t always land on a voxel
- Need to estimate density somehow (?)
- Interpolation!
- **Nearest neighbor interpolation**: just find closest voxel and use its density
- **Trilinear interpolation**: take some weighted sum of 8 nearest voxels’ densities

Interpolation Techniques



Ray Traversal

- Usually we traverse the ray at uniform intervals



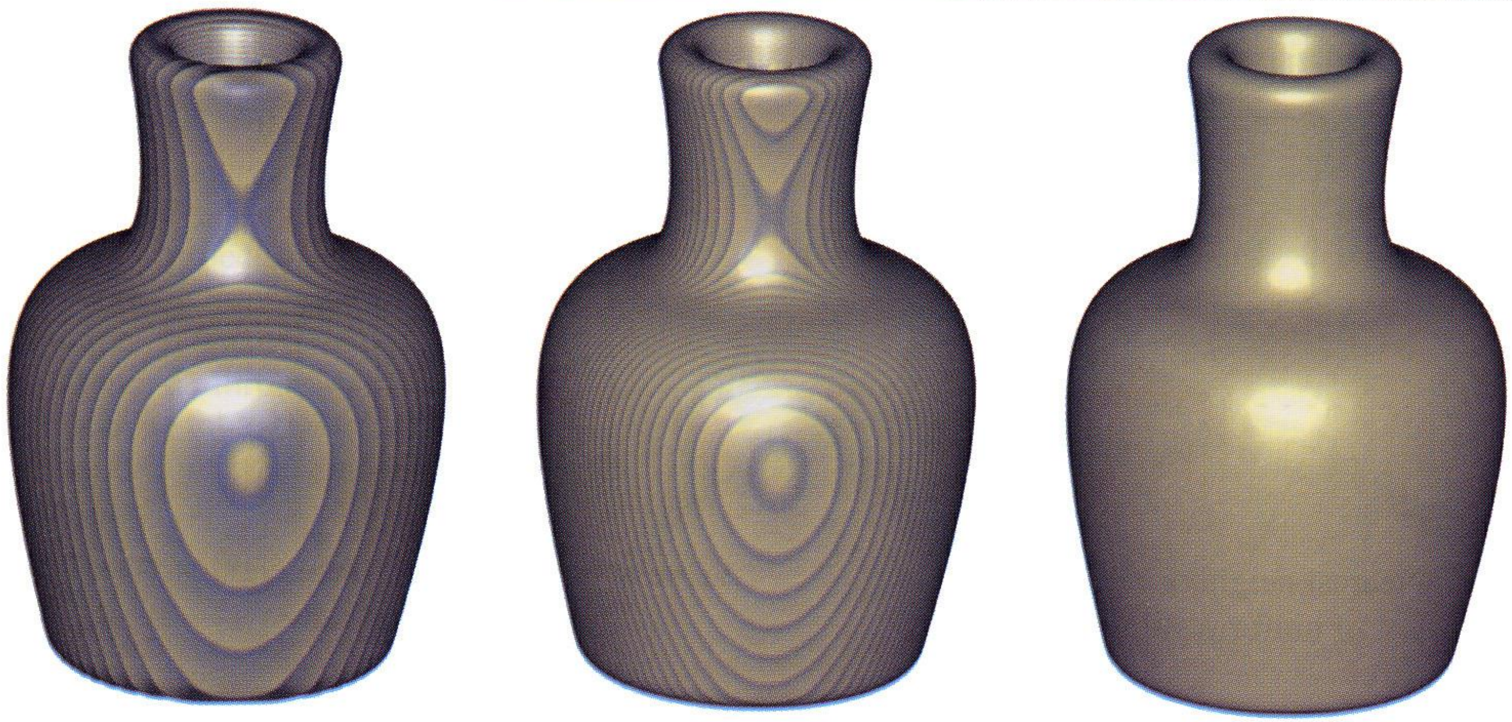
- Parametric form: $(x, y, z) = (x_0, y_0, z_0) + (a, b, c)\,t$
- (x_0, y_0, z_0) is the origin of the ray
- (a, b, c) is the normalized ray direction vector

Ray Traversal Pseudo-code

```
t = t1;
v = undefined;
while ( t < t2 )
  {
  x = x0 + a * t;
  y = y0 + b * t;
  z = z0 + c * t;
  v = EvaluateRayFunction( v, t );
  t = t + delta_t;
  }
```

- t1 and t2 are distances where ray enters and leaves volume, respectively

Step Size Affects Image Quality



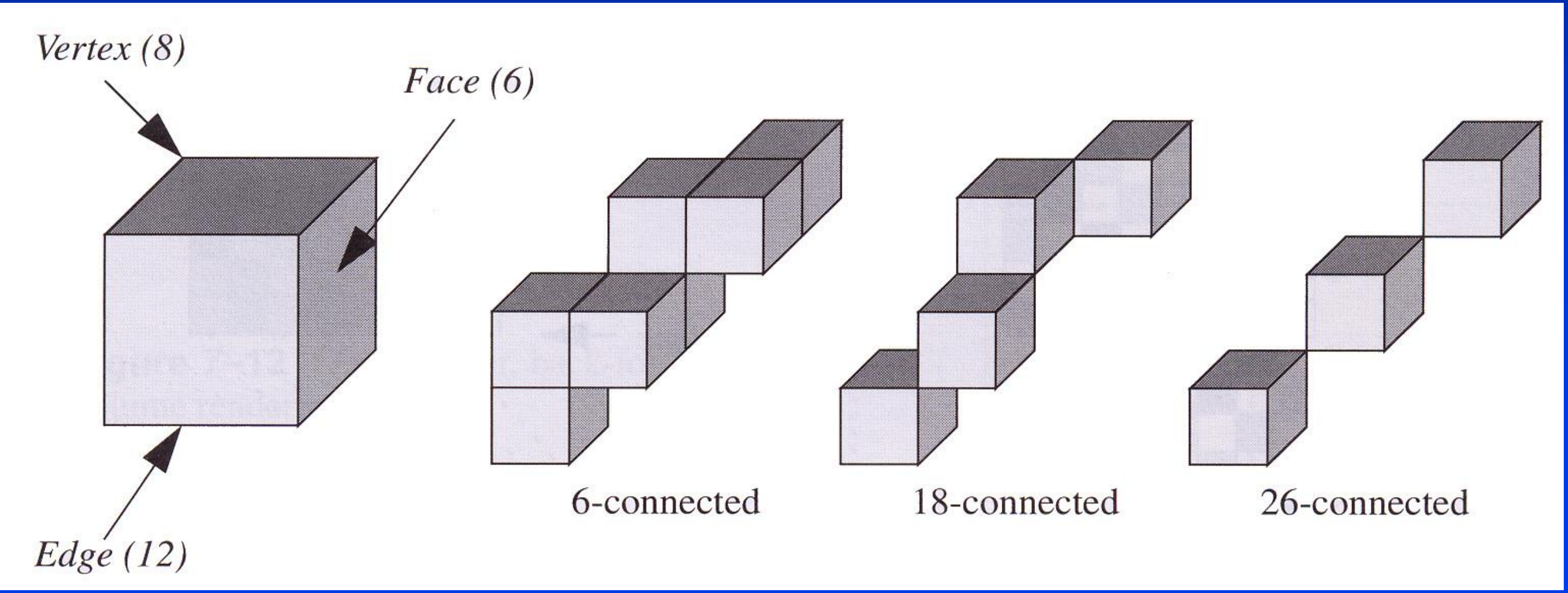
Step size = 2.0 Step size = 1.0 Step size = 0.1

Step Size

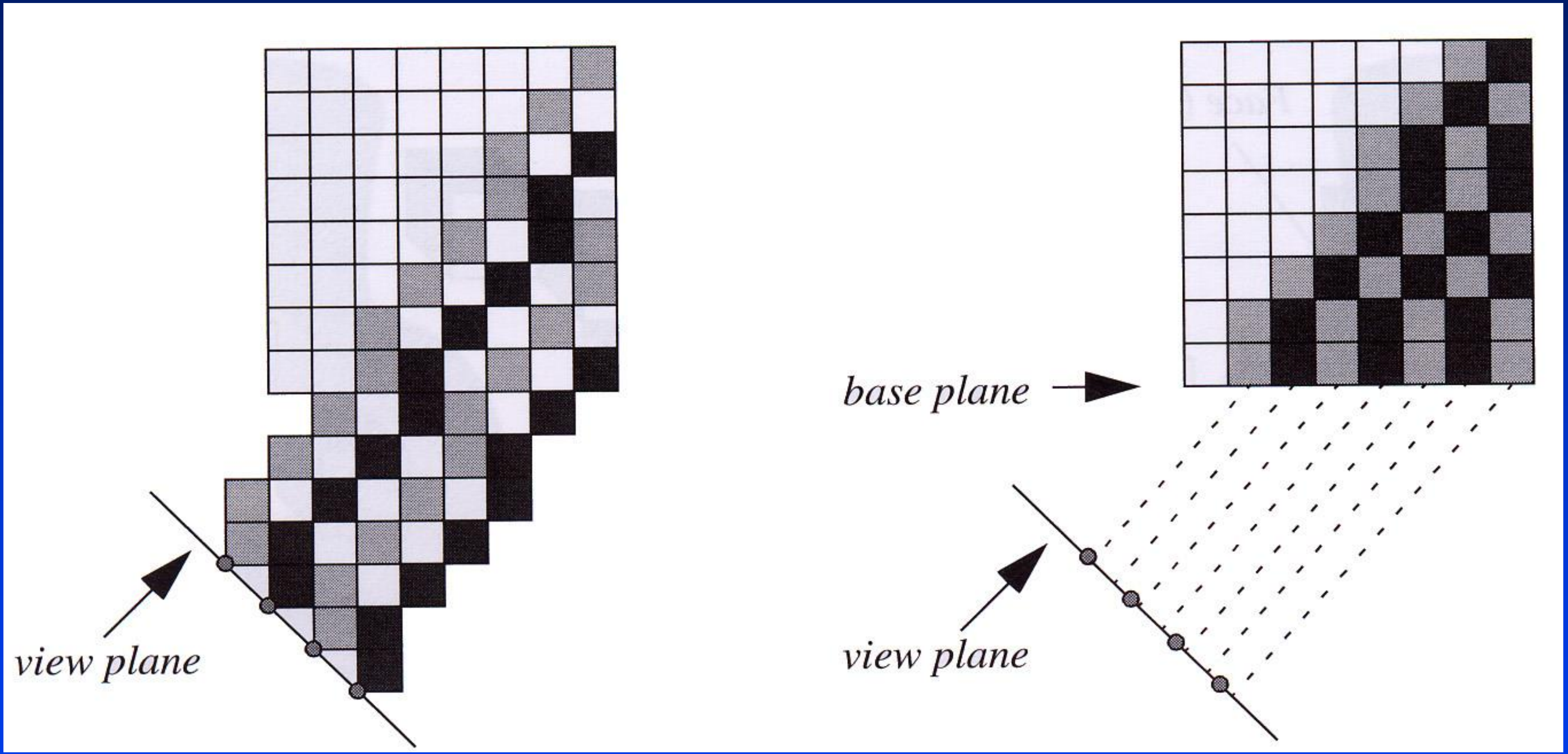
- Small step size = higher quality, slow speed
- Large step size = converse
- Large step size causes the banding effect

Voxel-based Ray Traversal

- Jump from one voxel to another instead of along a continuous ray
- Related to concept of **connectedness**

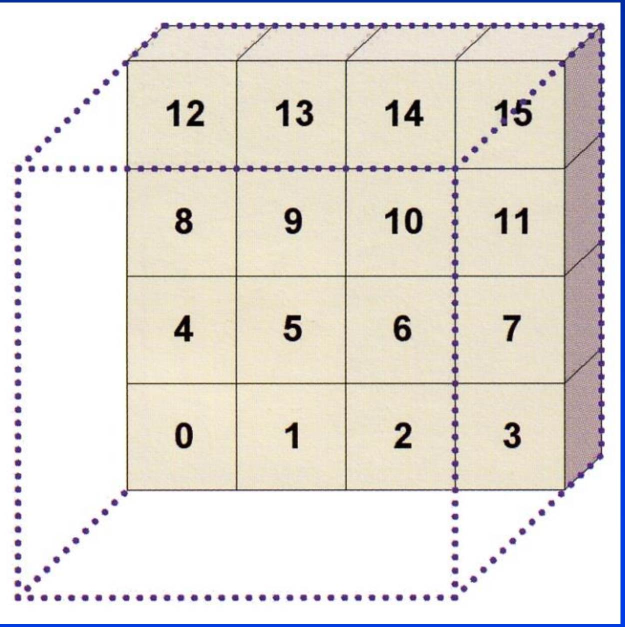


Voxel-based Ray Traversal



Object-Order Volume Rendering

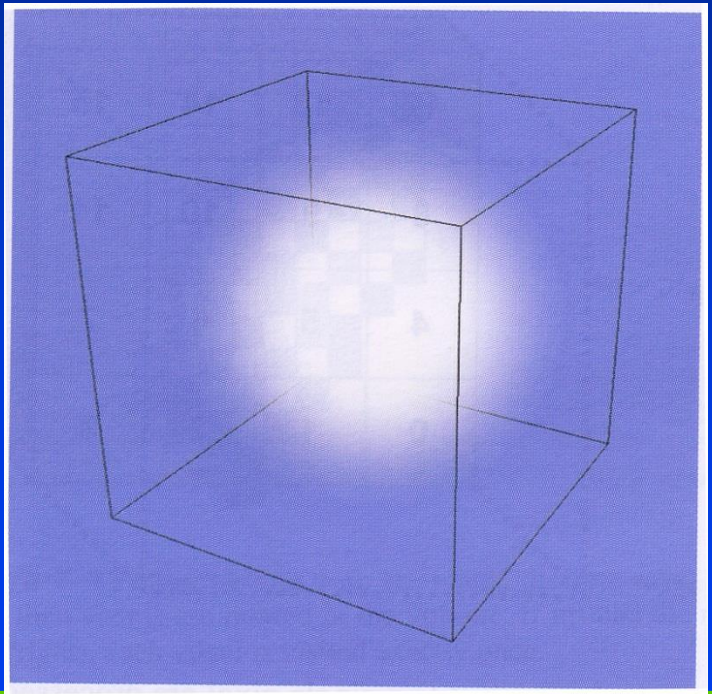
- Back-to-front or front-to-back processing of voxels
- Requires a triply nested loop
- **for** z = …. {
  for y = …. {
  for x = …. {
  ….
  }
  }
  }



- Select plane most parallel to image plane

Splatting

- Fuzzy sphere (called the kernel) placed around each voxel
- Kernel projected onto viewing plane, producing a **footprint**
- Repeat for all voxels
- Kernel size affects image quality
- Footprint *discretized* to a resolution appropriate for image resolution



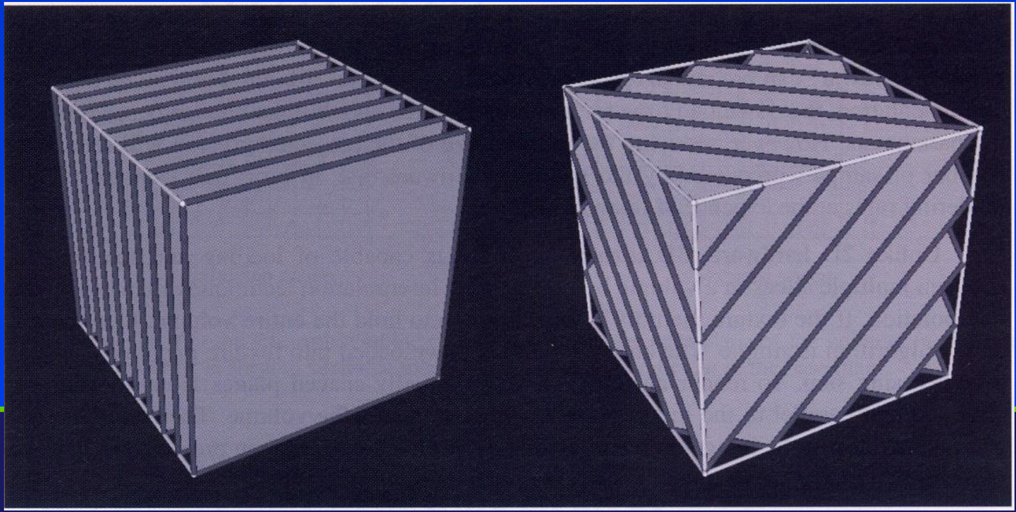
Implementing Splatting

- Software-only vs. hardware-assisted
- Footprint table – slices generic kernel into image-aligned slabs

Texture Mapping-based Volume Rendering

- In 2D: project and composite *axis-aligned* slices onto image plane
- In 3D: cut volume into slices that are *parallel* to the image plane ("image-aligned slices")
- Use interpolation and compositing in both cases

using 2D texture mapping hardware



using 3D texture mapping hardware

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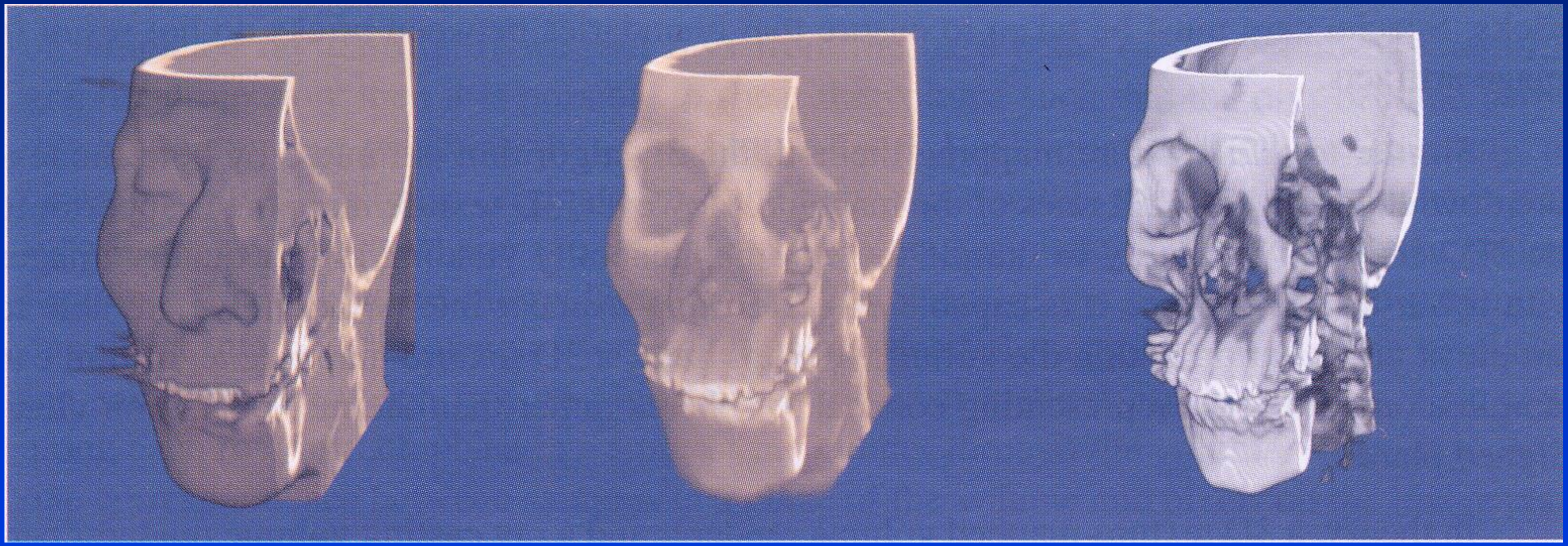
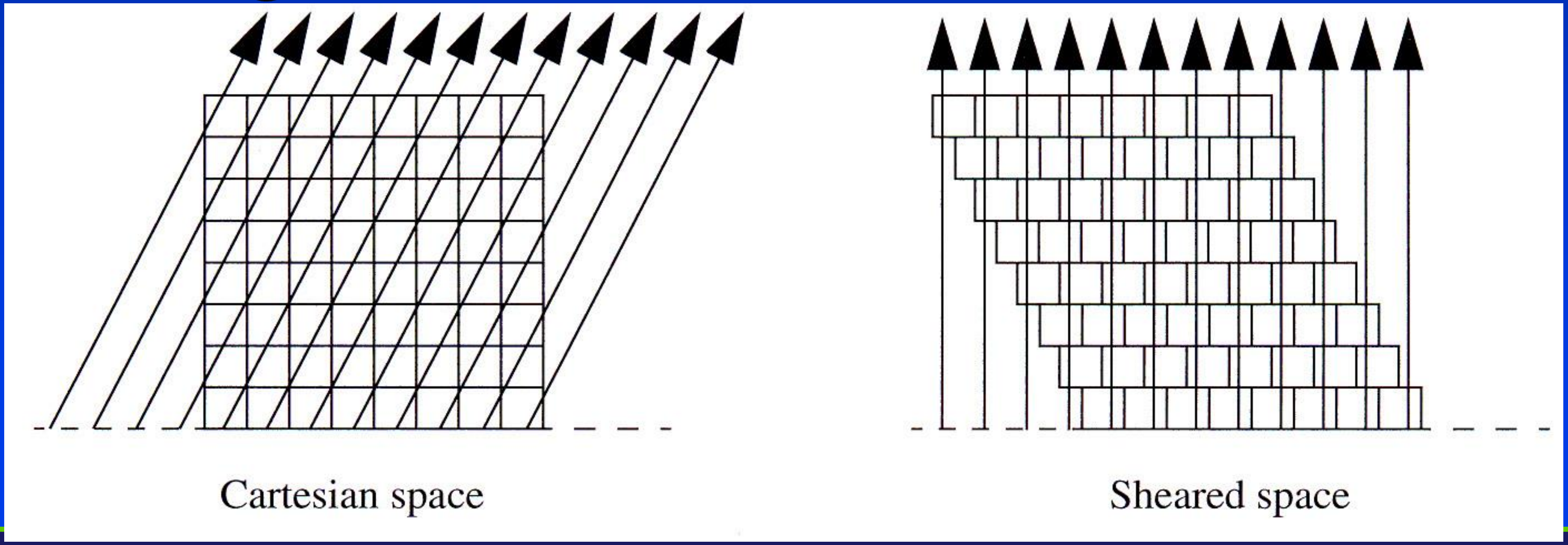
2D Texture-Mapped Volume Rendering Example



Shear-Warp Volume Rendering

- Hybrid technique – aspects of object-order and image-order rendering
- Idea: convert a rotation of the camera into a *shearing* of the volume

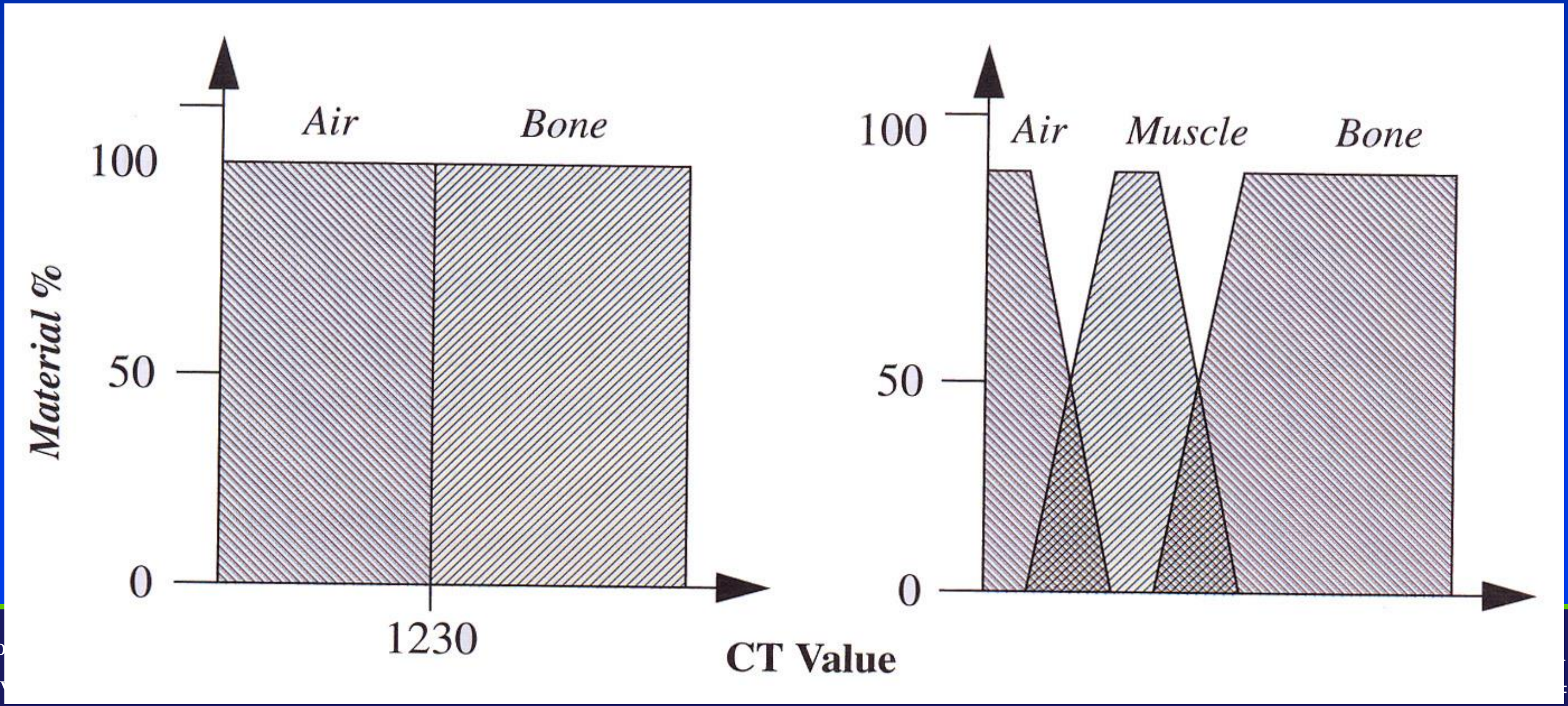


Shear-Warp Volume Rendering

- Need to use **bilinear interpolation** to resample the slices
- Front-to-back ray traversal
- Essentially a very efficient form of ray-casting
- Downside? Extra interpolations introduce error and hurt image quality
- Requires 3 copies of the volumes so we can shear volume along direction most parallel to image plane
- Shear in xy-plane, xz-plane or yz-plane
- Need to be able to process raster in any order

Volume Classification

- Assignment of density ranges to categories
- Represented by transfer functions
- "Material percentage" transfer functions:



Volume Classification

- Usually we classify a volume using red, green, blue and opacity transfer functions
- Two possibilities to apply classification during ray traversal:
  1. Interpolate voxel densities and then compute color
  2. Assign colors to voxels and then interpolate colors
- Option 1 tends to make nicer looking images

Volume Classification

- We can also compute the **gradient** of the density field and use that to modulate the color
- Gradient is a vector that tells you how the material is changing at a position
- Vector of first partial derivatives in x, y and z:

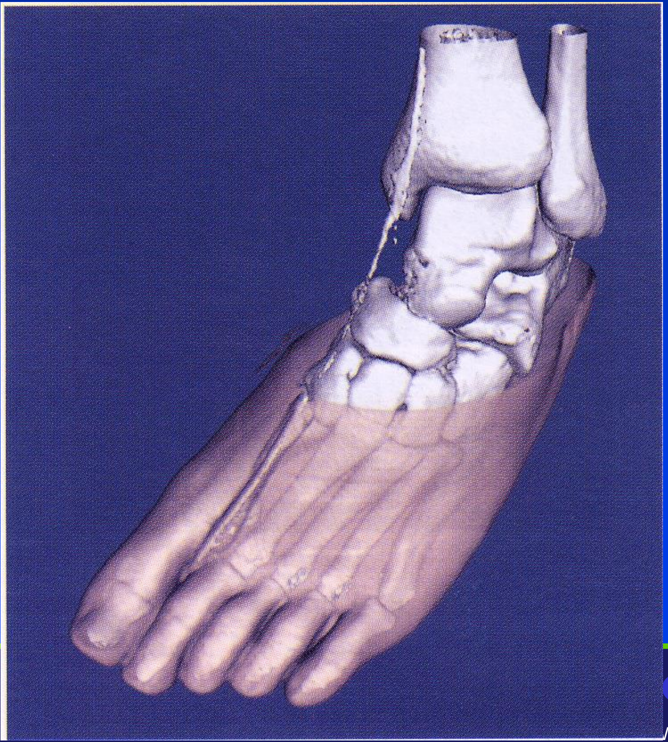
$$g_x = \frac{f(x+\Delta x, y, z) - f(x-\Delta x, y, z)}{2\Delta x}$$

$$g_y = \frac{f(x, y+\Delta y, z) - f(x, y-\Delta y, z)}{2\Delta y}$$

$$g_z = \frac{f(x, y, z+\Delta z) - f(x, y, z-\Delta z)}{2\Delta z}$$

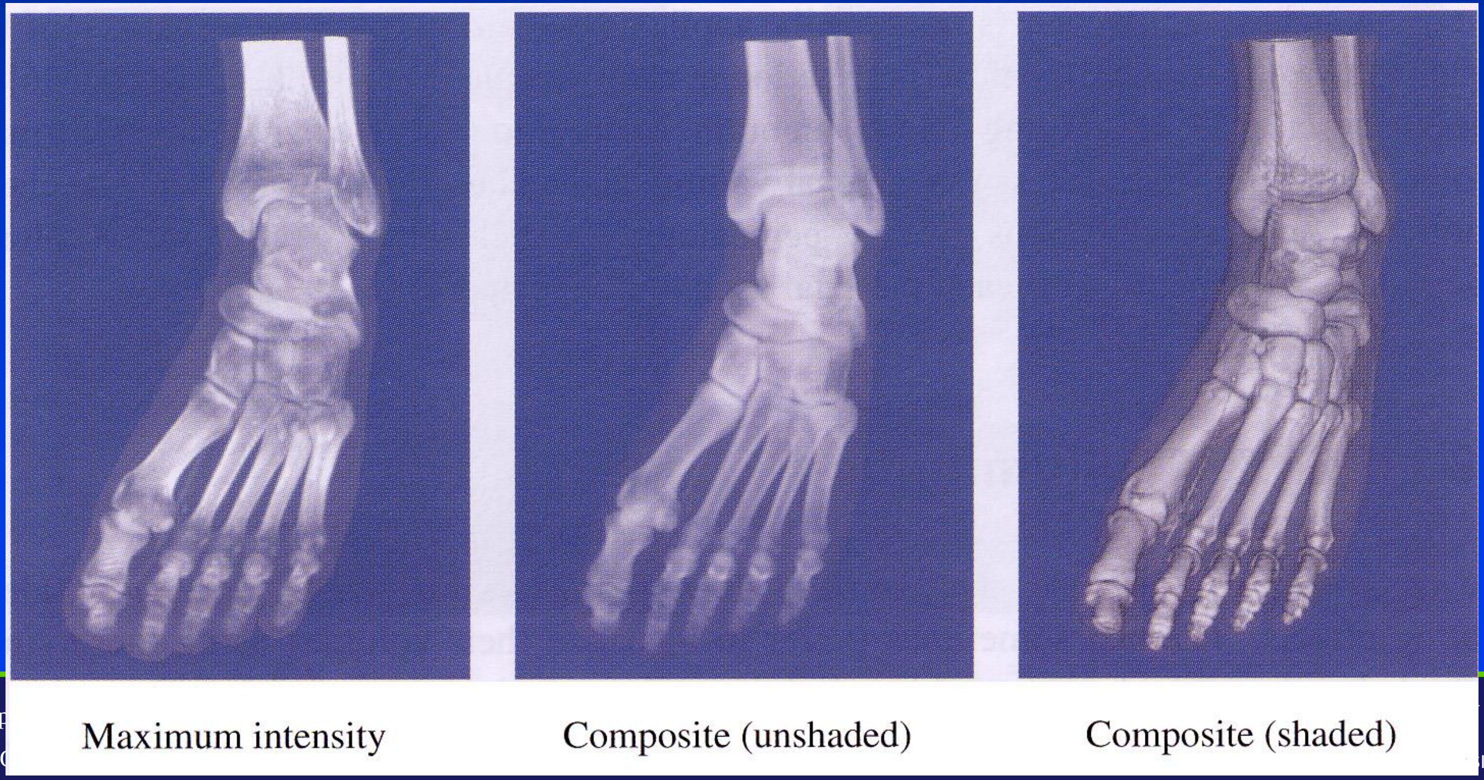
Volume Classification

- If the vector **g** is long, that means the material is changing quickly
- Example: boundary between bone and flesh
- Implies presence of a surface
- Modulate color based on gradient magnitude to ignore regions of **homogeneous** material distributions
- Small magnitude = little or no change of material



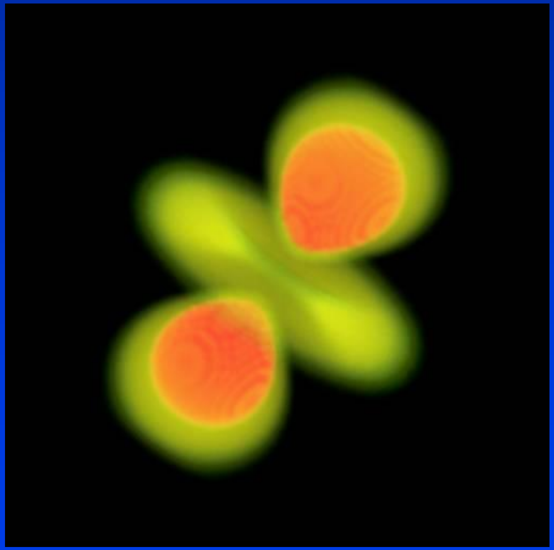
Uses of the Gradient Vector

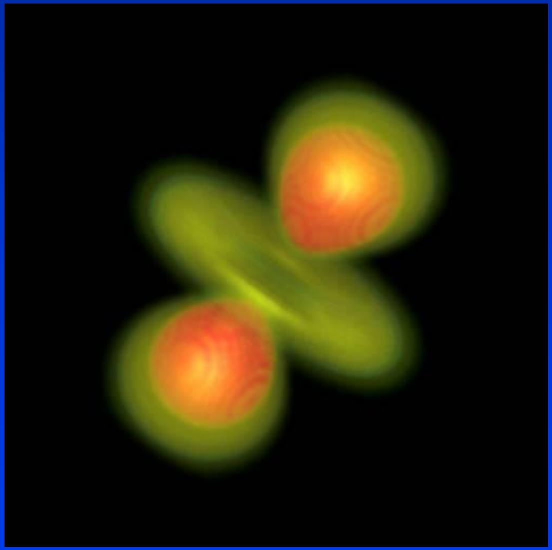
- We can treat the gradient as a normal vector and evaluate the lighting equation to shade and illuminate volumes

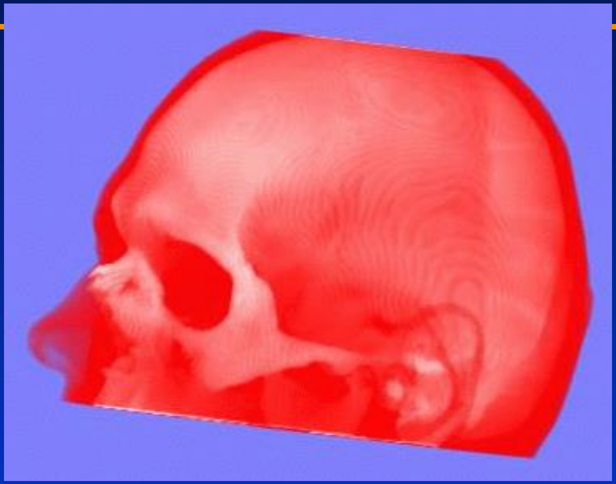


Volumetric Shading

- Can reveal surfaces inside the data
- Compare:







Volumetric Shading: How?

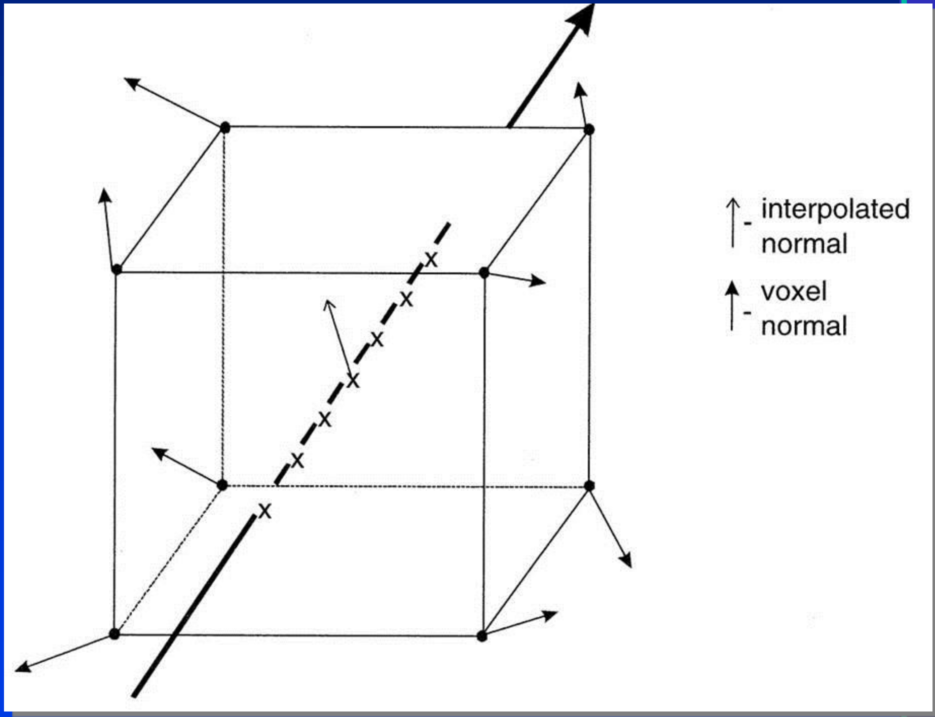
- Gradient allows us assigns a direction vector to each voxel
- This (normalized) vector is used just like the normal vector in surface graphics
- It will modulate the color we assign to samples and thereby allow us to create 3D effects
- Look at the skull on the right

Volumetric Shading

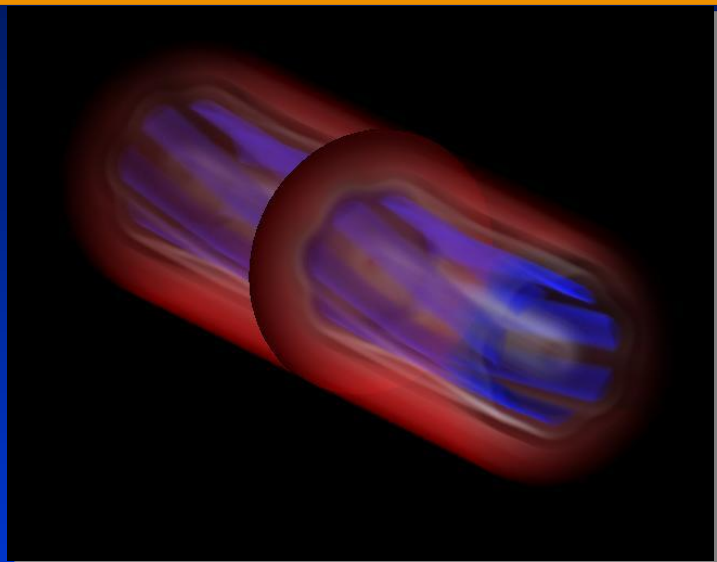
- But how do we incorporate color, opacity, and shading information?
- First we interpolate the density at a given sample position
- Interpolate gradient at same position
- Then assign color and opacity to each sample, and shade using interpolated gradient
- When we shoot the rays through the volume, we have to composite all these samples together

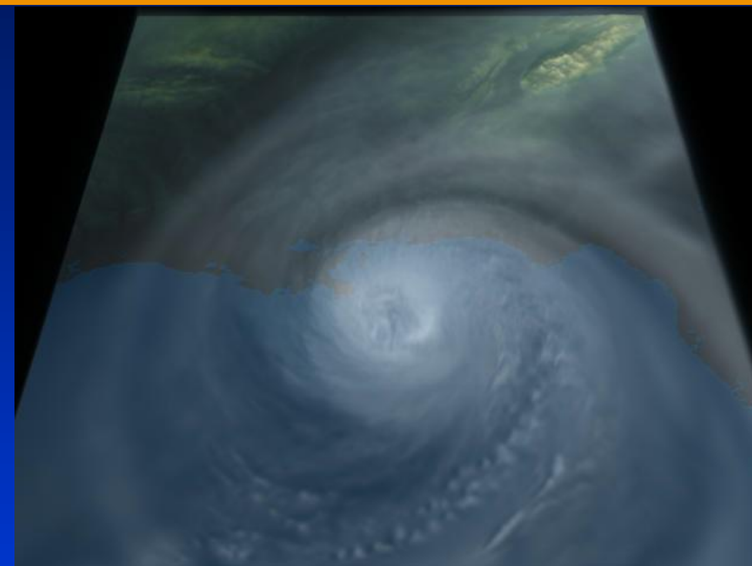
Gradient Interpolation

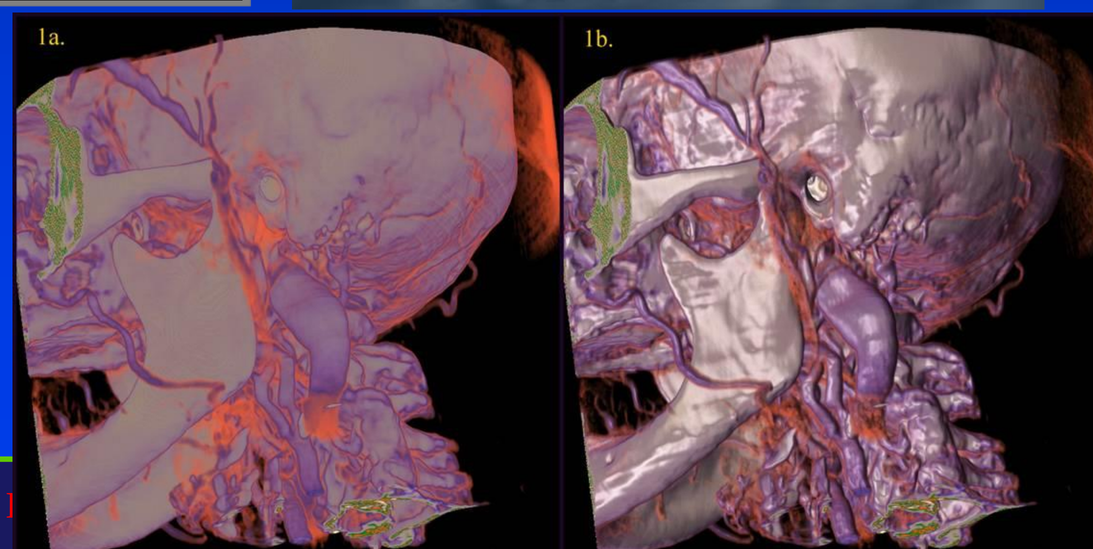
- At start of processing, compute gradient at each voxel
- During ray traversal, estimate gradient with trilinear interpolation
- Like densities (and unlike colors), gradients are **intrinsic** attributes of models



Volumetric Shading Examples







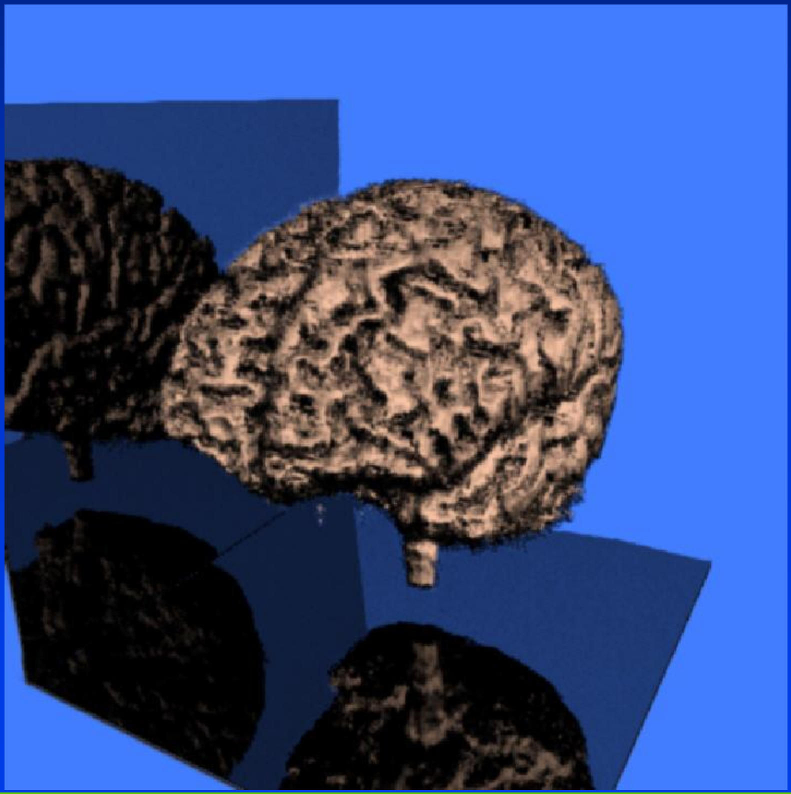
Gradient Modulation

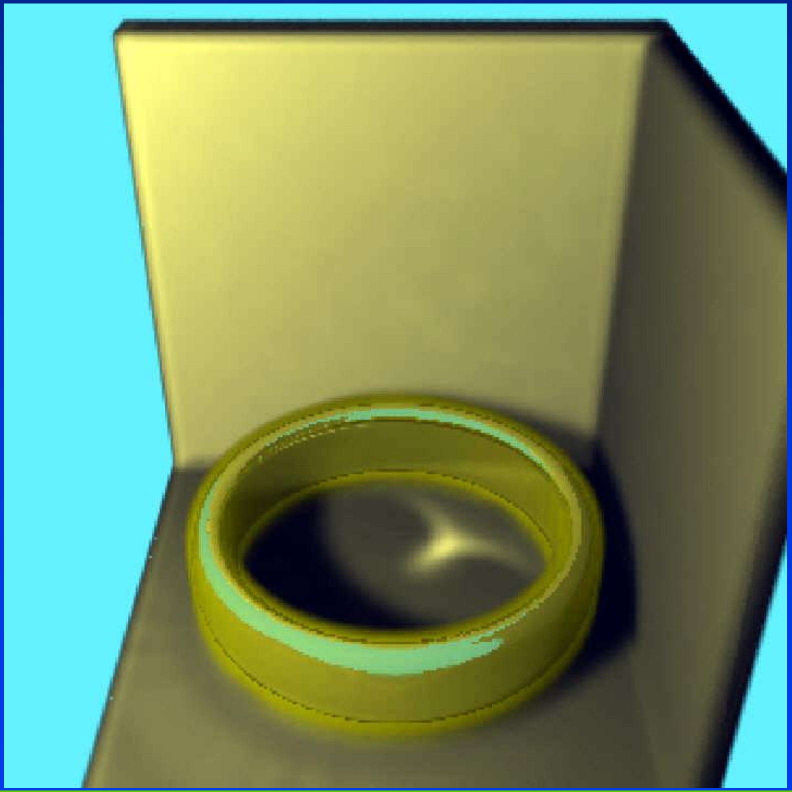
- With **gradient modulation** we modulate opacity/color of a voxel by gradient
- We multiply opacity and color by some function of gradient magnitude (or given by a transfer function, #5)
- Regions of high gradient magnitude increase opacity; regions of low gradient magnitude decrease opacity

- Explain this image

Volumetric Global Illumination

- Global illumination refers to reflections, shadows, and other effects that cannot be computed locally





Regions of Interest (ROIs)

- An ROI is simple a portion of the data-set of particular importance
- Use **cropping planes** to reveal interior
- Simple idea, but very, very useful
- Eliminate sets of voxels from consideration

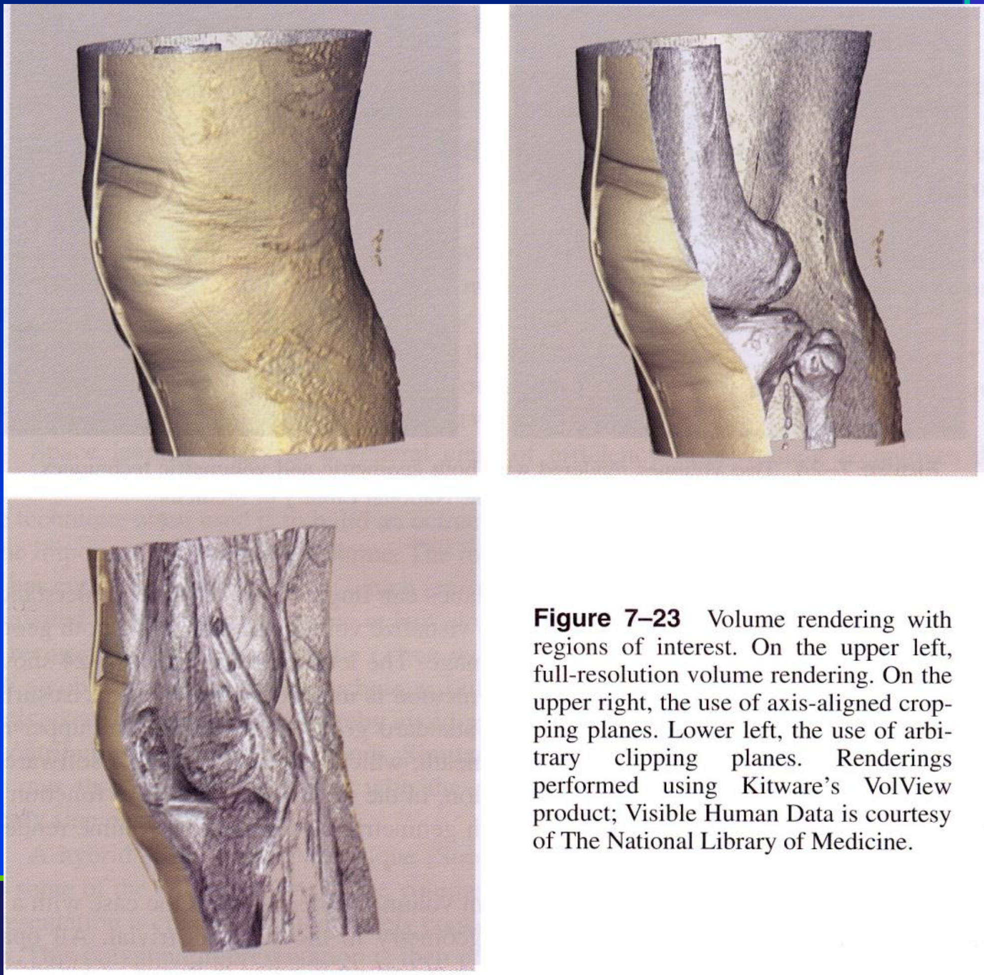


Figure 7–23 Volume rendering with regions of interest. On the upper left, full-resolution volume rendering. On the upper right, the use of axis-aligned cropping planes. Lower left, the use of arbitrary clipping planes. Renderings performed using Kitware's VolView product; Visible Human Data is courtesy of The National Library of Medicine.