Volume Rendering

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Course 600.456: Rendering Techniques, Professor: Jonathan Cohen

Volume Rendering
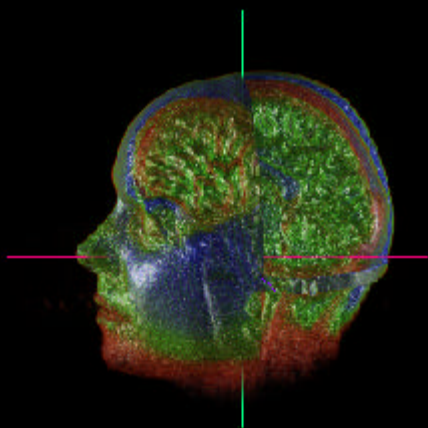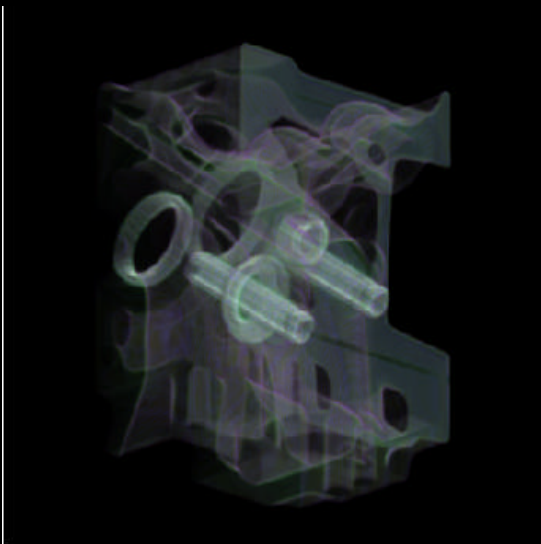
Creating 2D images of volume data

Voxels (volume elements) typically stored
in regular lattice

Voxel lattice represents 3D scalar field

Examples

Types of 3D Scalar Fields

X-ray absorbtion

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
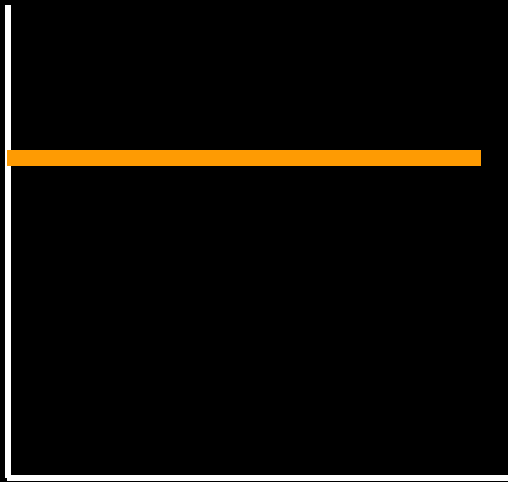
Often only a single value at each voxel

Want mapping to color and opacity

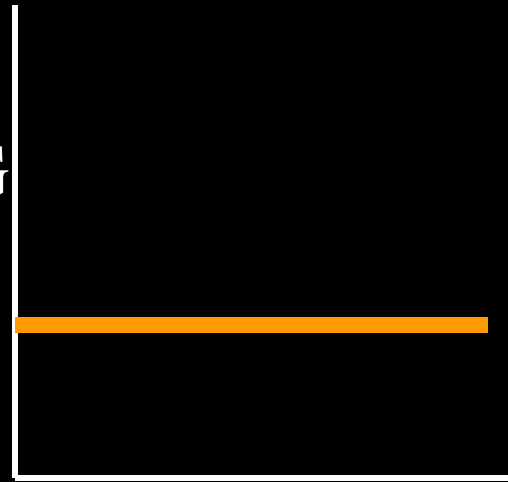May emphasize certain value ranges or give all ranges equal emphasis in final image

Emphasizing a Single Isosurface

R

G
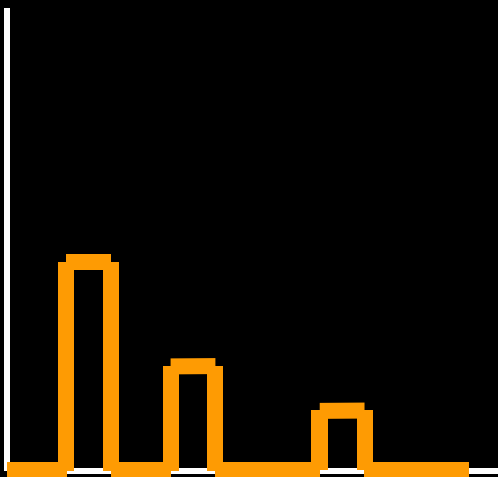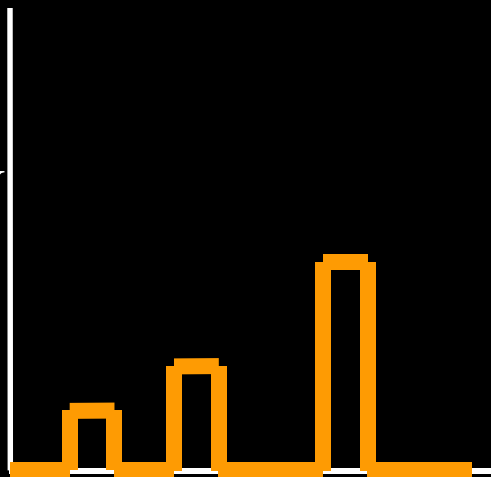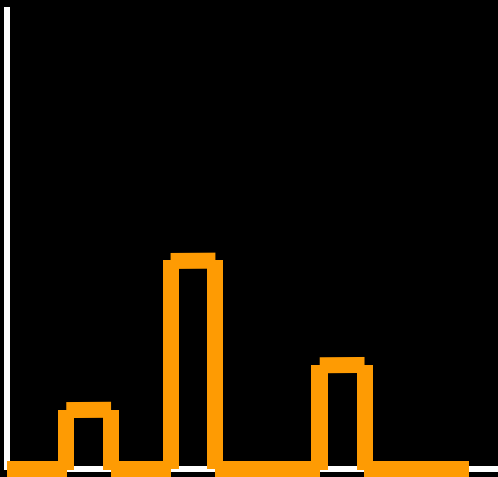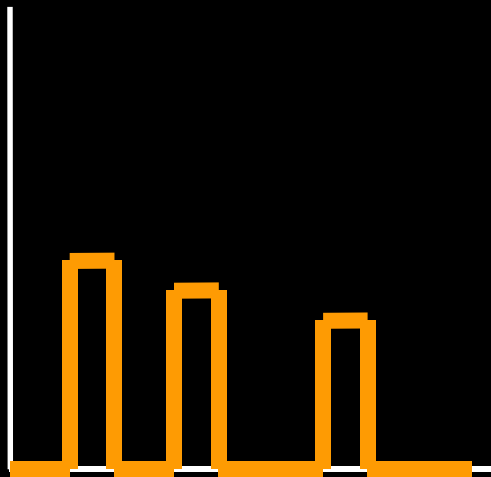
B

O

Emphasizing 3 Isosurfaces

Visualizing Values as Opacity
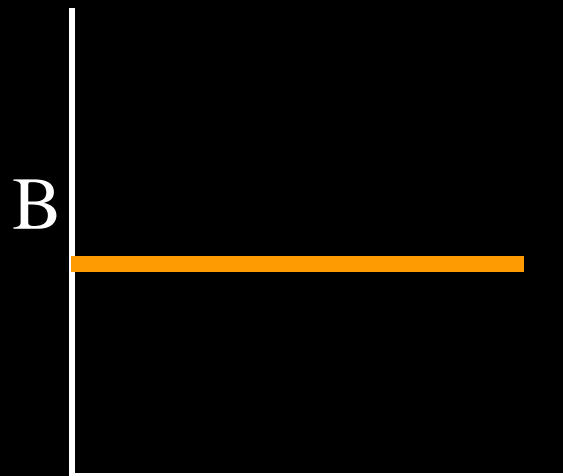
Methods of Rendering

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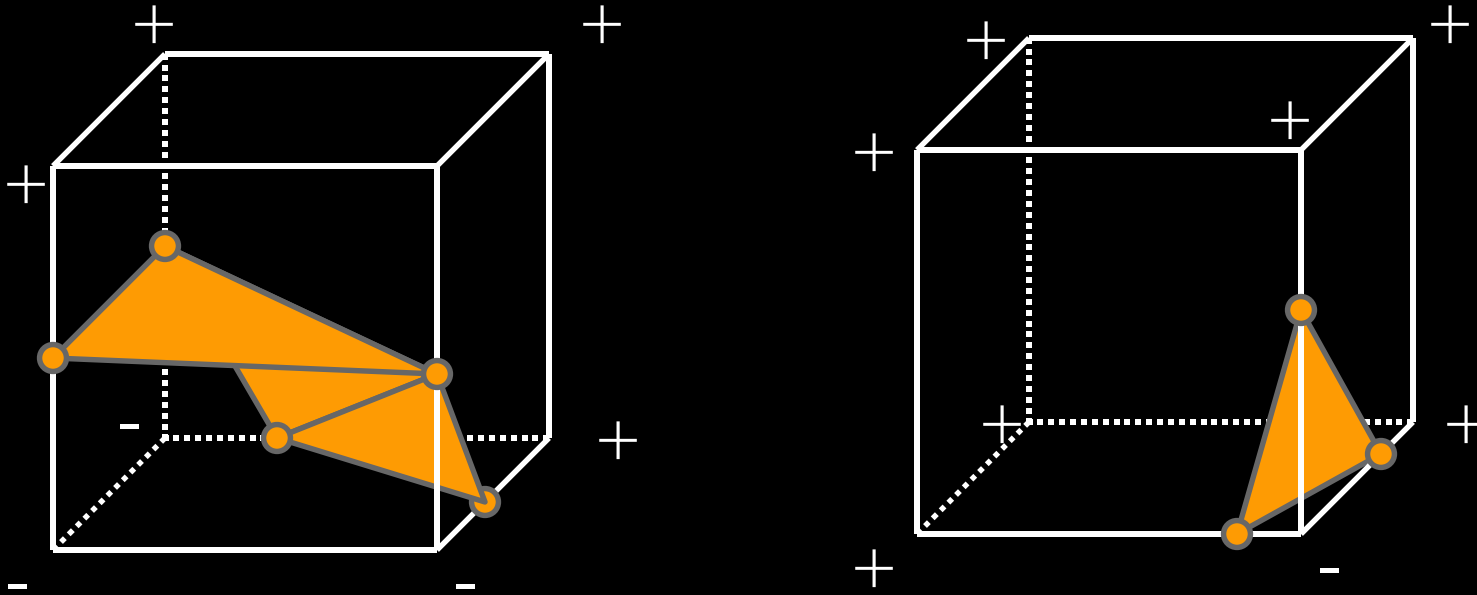
- $2^8 = 256$ possible configurations (only 16 unique)
- Store all cases in table, including number and connectivity of triangles
- Must connect properly along voxel sides for continuity

Rendering Isosurfaces

One or more isosurfaces may be rendered

as totally opaque or partially transparent

Clipping planes may be used to illustrate

interior surfaces

(see Figure 15 in Watt's *3D Computer Graphics*)

Volume Ray Casting

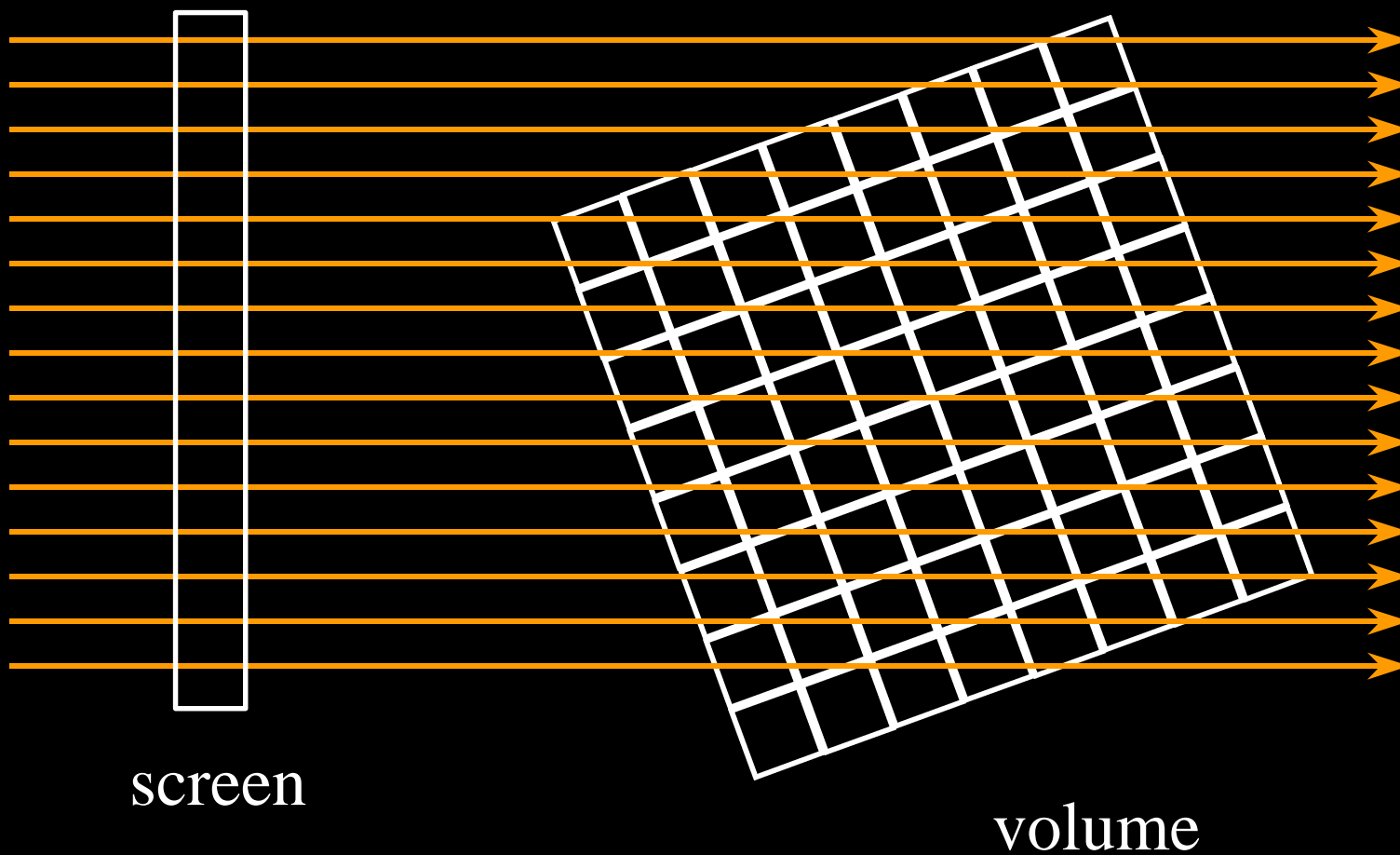**Loop over pixels, generating rays**

- **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

screen

volume

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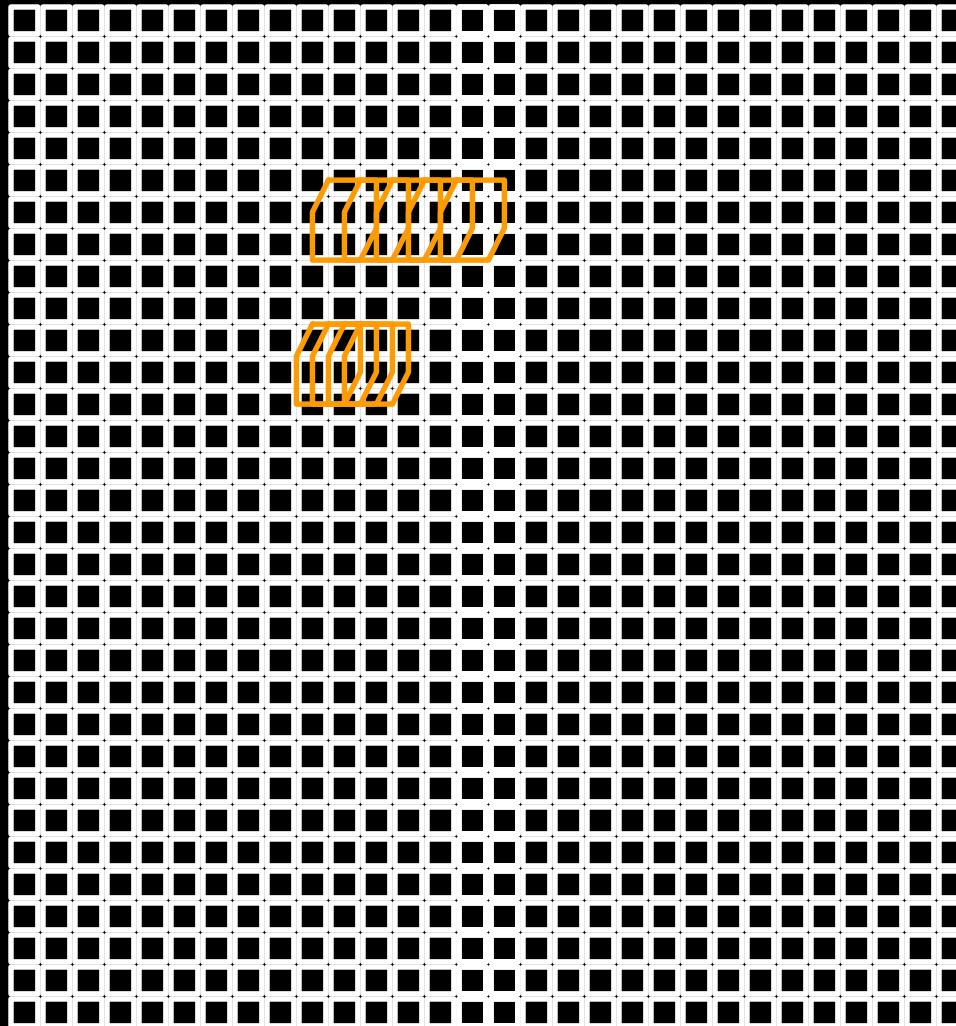
Smoother interpolation possible by applying kernel with fall-off away from sample point

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 pases 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