

# Volume Visualization

## Part 1 (out of 3)

### Volume Data

- Where do the data come from?
  - ◆ **Medical Application**
    - Computed Tomographie (CT)
    - Magnetic Resonance Imaging (MR)
  - ◆ **Materials testing**
    - Industrial-CT
  - ◆ **Simulation**
    - Finite element methods (FEM)
    - Computational fluid dynamics (CFD)
  - ◆ **etc.**

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### Overview: Volume Visualization

- Introduction to volume visualization
  - ◆ On volume data
  - ◆ Surface vs. volume rendering
  - ◆ Overview: Techniques
- Simple methods
  - ◆ Slicing, cuberille
- Direct volume visualization
  - ◆ Introduction, types of combinations
  - ◆ Transfer functions

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### 3D Data Space

- How are volume data organized?
  - ◆ **Cartesian resp. regular grid:**
    - CT/MR: often  $dx=dy<dz$ , e.g. 135 slices (z) á 512<sup>2</sup> values (as x & y pixels in a slice)
    - **Data enhancement:** iso-stack-calculation = Interpolation of additional slices, so that  $dx=dy=dz \Rightarrow 512^3$  Voxel
    - Data: **Cells** (cuboid), Corner: **Voxel**
  - ◆ **Curvi-linear grid resp. unstructured:**
    - Data organized as tetrahedra or hexahedra
    - Often: conversion to tetrahedra

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### Volume Visualization

- Introduction:
  - ◆ **VolVis = visualization of volume data**
    - Mapping 3D→2D
    - Projection (e.g., MIP), slicing, vol. rendering, ...
  - ◆ **Volume data =**
    - 3D×1D data
    - Scalar data, 3D data space, space filling
  - ◆ **User goals:**
    - Gain insight in 3D data
    - Structures of special interest + context

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### VolVis – Challenges

- **Rendering projection,** so much information and so few pixels!
- **Large data sizes,** e.g. 512×512×1024 voxel á 16 bit = 512 Mbytes
- **Speed,** Interaction is very important, >10 fps!

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### Voxels vs. Cells

- Two ways to interpret the data:
  - Data: set of voxel
    - voxel** = abbreviation for volume element (cf. pixel = "picture elem.")
    - voxel = point sample in 3D
    - Not necessarily interpolated
  - Data: set of cells
    - cell = cube primitive (3D)
    - Corners: 8 voxel (see above)
    - Values in cell: interpolation used

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### Gradients as Normal Vector Replacement

- Gradient  $\nabla f = (\partial f/\partial x, \partial f/\partial y, \partial f/\partial z)$
- $\nabla f|_{x_0}$  normal vector to iso-surface  $f(x_0)=f_0$
- Central difference in x-, y- & z-direction (in voxel):
 
$$\nabla f(x,y,z) = 1/2 \begin{pmatrix} f(x+1)-f(x-1) \\ f(y+1)-f(y-1) \\ f(z+1)-f(z-1) \end{pmatrix}$$
- Then tri-linear interpolation within a cell
- Alternatives:
  - Forward differencing:  $\nabla f(x)=f(x+1)-f(x)$
  - Backwards differencing:  $\nabla f(x)=f(x)-f(x-1)$
  - Intermediate differencing:  $\nabla f(x+0.5)=f(x+1)-f(x)$

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### Interpolation

$$v = (1-x)(1-y)(1-z)S(0,0,0) + (x)(1-y)(1-z)S(1,0,0) + (1-x)(y)(1-z)S(0,1,0) + (x)(y)(1-z)S(1,1,0) + (1-x)(1-y)(z)S(0,0,1) + (x)(1-y)(z)S(1,0,1) + (1-x)(y)(z)S(0,1,1) + (x)(y)(z)S(1,1,1)$$

$v = S(\text{rnd}(x), \text{rnd}(y), \text{rnd}(z))$

Nearest Neighbor                      Trilinear

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### Concepts and Terms

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### Interpolation – Results

Nearest Neighbor Interpolation                      Trilinear Interpolation

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### Concepts and Terms

- Example 1:
  - CT measurement
  - Iso-stack-conversion
  - Iso-surface-calculation (marching cubes)
  - Surface rendering (OpenGL)

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### Concepts and Terms

- Example 2:
  - MR measurement
  - Iso-stack-conversion
  - MIP (maximum intensity proj.)
  - Image: blood-vessels in hand

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### Surfaces vs. Volume Rendering

- Surface rendering:
  - Indirect volume visualization
  - Intermediate representation: iso-surface, "3D"
  - Pros: Shading→Shape!, HW-rendering
- Volume rendering:
  - Direct volume visualization
  - Usage of transfer functions
  - Pros: illustrate the interior, semi-transparency

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### Concepts and Terms

- Example 3:
  - potential function  $\rho(x,y,z)$
  - Iso-surface  $\rho(x,y,z)=\rho_0$
  - Surface: ray tracing

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### Surfaces vs. Volume Rendering

hybrid rendering = surfaces + volumes

volume rendering

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### Concepts and Terms

- Example 4:
  - X-Ray Modelling
  - Surface-definition
  - Sampling (voxelization), combination
  - Direct volume rendering

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### VoIVis-Techniques – Overview

- Simple methods:
  - Slicing, MPR (multi-planar reconstruction)
- Direct volume visualization:
  - Ray casting
  - Shear-warp factorization
  - Splatting
  - 3D texture mapping
  - Fourier volume rendering
- Surface-fitting methods:
  - Marching cubes (marching tetrahedra)

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## Image-Order vs. Object-Order



- Image-order:
  - ◆ FOR every pixel DO: ...
  - ◆ Cost, complexity  $\approx$  image size
  - ◆ Example: ray casting (tracing viewing rays)
- Object-order:
  - ◆ FOR every object (voxel) DO: ...
  - ◆ Cost, complexity  $\approx$  object size (# of voxels)
  - ◆ Examples: splatting ("throwing snow balls")



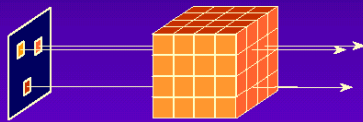
## Simple Methods

Slicing, etc.

## Image-Order Approach



Image-Order Approach: Traverse the image pixel-by-pixel and sample the volume.

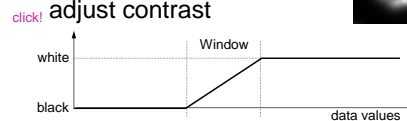
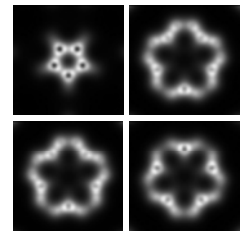


Ray Casting

## Slicing



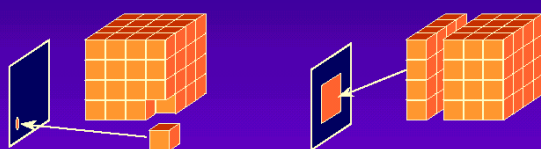
- Slicing:
  - ◆ Axes-parallel slices
  - ◆ regular grids: simple
  - ◆ without transfer function no color
  - ◆ Windowing: adjust contrast



## Object-order approach



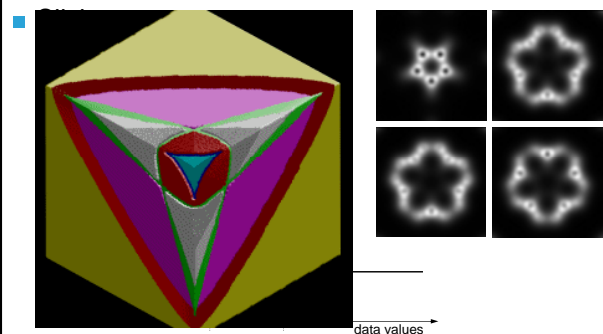
Object-Order Approach: Traverse the volume, and project to the image plane.



Splatting  
cell-by-cell

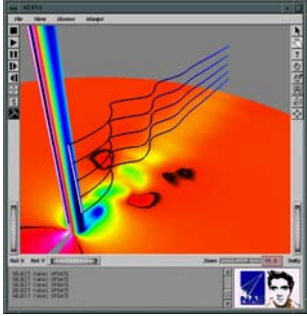
Texture Mapping  
plane-by-plane

## Slicing



## Slicing

- Not so simple:
  - ◆ Slicing through general grid
  - ◆ Interpolation necessary
- Slicing:
  - ◆ well combinable with 3D-visualization
- Multi-planar reformation (MPR):
  - ◆ arbitrary axes, 3D



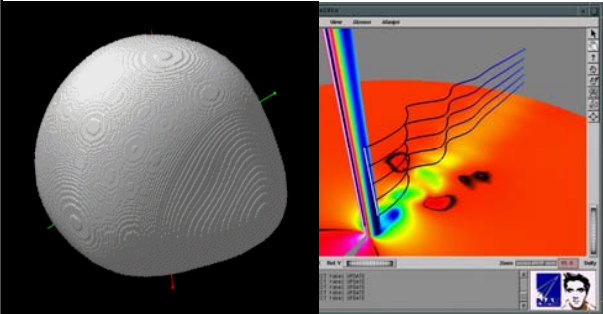
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## Direct Volume Visualization

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

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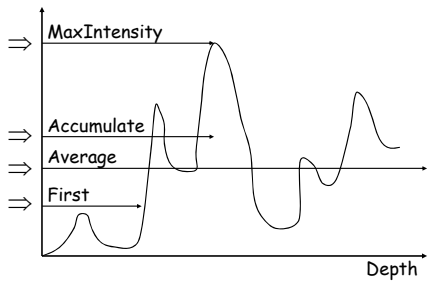
## Slicing



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## Types of Combinations

- Overview:
  - ◆ MIP ⇒
  - ◆ Compositing ⇒
  - ◆ X-Ray ⇒
  - ◆ First hit ⇒



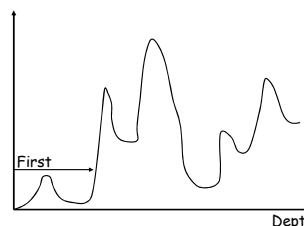
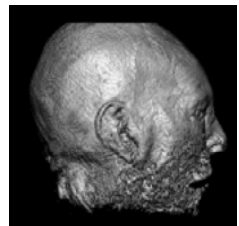
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# Direct Volume Visualization, Introduction

## Classification – Transfer Functions

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## First Hit: Iso-Surface Extraction

**First:** Extracts iso-surfaces (again!), done by Tuy&Tuy '84

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### Average: as X-Ray Images

The graph shows a fluctuating line representing the average intensity across different depths. The X-ray image shows a hand with bones visible, representing the result of an average projection.

**Average:** Produces basically an X-ray picture

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### Types of Combination

- ◆ Possibilities:
  - ◆  $\alpha$ -compositing
  - ◆ Shaded surface display
  - ◆ Maximum-intensity projection
  - ◆ X-ray simulation
  - ◆ Contour rendering

The diagram shows four small images: NPR (Non-Photorealistic Rendering), x-ray, MIP (Maximum Intensity Projection), and DVR (Direct Volume Rendering). A larger image shows a combination of these techniques, with SSD (Shaded Surface Display) overlaid on a DVR image.

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### MIP: Maximum-Intensity Projection

The graph shows a line representing the maximum intensity at each depth. The MIP image shows a branching structure where the most intense pixels are projected, making the structure appear as a solid white mass.

**Max:** Maximum Intensity Projection used for Magnetic Resonance Angiograms, for example

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### Classification

- ◆ Assignment data  $\Rightarrow$  semantics:
  - ◆ Assignment to objects, e.g., bone, skin, muscle, etc.
  - ◆ Usage of data values, gradient, curvature
  - ◆ Goal: segmentation
  - ◆ Often: semi-automatic resp. manual
  - ◆ Automatic approximation: transfer functions (TF)

**Example**

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### Compositing: Semi-Transparency

The graph shows a line representing the accumulated intensity across different depths. The semi-transparent image shows a hand where overlapping layers are visible, allowing the underlying structure to be seen through the top layer.

**Accumulate:** Make transparent layers visible! Levoy '88

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### Transfer Functions (TF)

- ◆ Mapping data  $\rightarrow$  "renderable quantities":
  - ◆ 1.) data  $\rightarrow$  color
  - ◆ 2.) data  $\rightarrow$  opacity (non-transparency)

The graph shows a transfer function mapping data values to color and opacity. The x-axis is labeled "data values" and the y-axis is labeled "opacity". Three regions are identified: "air" (low data values, low opacity), "skin" (medium data values, semi-transparent yellow), and "bone" (high data values, red and opaque). A color bar at the bottom shows the mapping from data values to colors.

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### Different Transfer Functions

- Image results:
  - Strong dependence on transfer functions
  - Non-trivial specification
  - Limited segmentation possibilities

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### Gradient-Based Transfer Functions

- 2D-Transfer function:
  - Levoy '88
  - Specific opacity at certain threshold
  - but: close-by variation according gradient magnitude
  - highlights transitions (large gradients)
  - dampens homogeneous areas

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### Lobster – Different Transfer Functions

- Three objects: media, shell, flesh

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### Multi-Dimensional Transfer Functions (1)

- $f, f', f''$  histograms to depict material boundaries

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### Inclusion of the Gradient

- Emphasis of changes:
  - Special interest often in transitional areas
  - Gradients: measure degree of change (like surface normal)
  - Larger gradient magnitude  $\Rightarrow$  larger opacity

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### Multi-Dimensional Transfer Functions (2)

- Direct manipulation widgets

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