3D (Volume) Scalar Fields:
Direct volume rendering, Slices,
(Textured) Isosurfaces, Glyphs

Example Videos
• Confocal visualization tool
• Rendering surfaces as peaks in DVR
Overview

- List of techniques
  - Appropriateness discussion for each
  - Implementation description for some
- Importance of stereo and motion
- Two examples

List of Techniques

- Displaying surfaces in the volume
  - Cutting planes (perhaps animated)
  - Isovalue surfaces
    - Making translucent surfaces perceptible
- Direct Volume Rendering
  - X-ray, Maximum Intensity Projection (MIP)
  - "Surface-extracting" transfer functions
    - Shading, shadows
    - Color for segmentation
- Glyphs

Cutting Planes

- One or more slices through the volume
- Along grid axes or arbitrary axes
- May be set in context of the 3D data
- Apply 2D visualization techniques
  - Relative benefits of 2D mappings apply
  - Height mapping?
Cutting Plane Characteristics

- **Strengths**
  - Same as strengths of 2D techniques in the planes they display data
  - Enable measurements along important axes
  - Enable display of interval/ratio fields
  - Can show fuzzy boundaries at surfaces they cross

- **Weaknesses**
  - Show miniscule subset of the data
  - Do not indicate 3D shape of non-symmetric objects
  - or surprising asymmetries in supposedly-symmetric objects
  - Either occlude each other or require transparency

Isovalue surfaces and other Extracted surfaces

- **Produce 2D surface in 3D...**
  - by following an iso-density contour at a threshold, or
  - Based on the surface of an object in the volume, or
  - By seeking ridge of maximum (valley of minimum), or
  - Using blood-vessel extraction software, or ...

- **Apply 2D visualization techniques on the surfaces**
  - Not height mapping. (Why?)
  - Usually using isoluminant colormaps. (Why?)

Translucent Isosurfaces

- **Pure Transparency Hides Surface Shape**
Translucent & Opaque Surface


Here, transparent surface is less important (only setting the frame) and is low-frequency and symmetric.

Isosurface + Spherical Surface

Rainbow color map never optimal.

Ambient Occlusion Opacity Mapping

- David Borland (RENCI)
AOOM + Props + Backface

- David Borland (RENCI)

Exploded Views

- Bruckner and Gröller, Vis 2006 [bruckner.avi]

Medical Illustration Inspired

- Correa et al., Vis 2006
**Extracted Surface Characteristics**

- **Strengths**
  - Same as strengths of 2D techniques on surfaces
  - Enable display of interval/ratio fields
  - Indicate 3D shape of even non-symmetric objects
  - Perception of 2D surfaces in 3D is what visual system is tuned for

- **Weaknesses**
  - Cannot show fuzzy boundaries very well
  - Can emphasize noise in any case and artifact if not at useful level
  - Show miniscule subset of the data
    - This is a strength if it is the relevant subset
  - Either occlude each other or require transparency

**Making Translucent Perceptible**

- **Add textured features**
  - Replace translucent surface with opaque bands
  - Add strokes of opaque texture to the surface
  - Add patterns of opaque texture to the surface

- **Add motion**
  - Animation of the object
  - User-controlled viewpoint or object orientation change

- **Add stereo**
  - Stereo + head-tracking is much better than the sum of the parts

**Basket Weave**

- Calculate contour lines at cross-sections parallel to coordinate planes
- Draw opaque bands
- Example from SIGGRAPH Education Workshop in 1988
1D curves in 3D

- Unit lines and high density

0D Points in 3D

- Lit spheres, not lit surface elements

Curvature-Directed Strokes

- Directed by surface normal variations
- Edges are manifested in marching cubes
Even-tessellation texture

Spotted Tumor Surfaces
- David Borland, Chris Weigle, Russ Gayle
  - Based on data-driven spots, early draft

Animation, Motion, and Stereo
- Adding additional depth cues helps greatly
  - Stereo + Head-tracking is the most effective
  - Use torsion-pendulum rocking for animation
Direct Volume Rendering Terms

- Voxel
  - Volume Element
  - Basic unit of volume data
- Interpolation
  - Trilinear common, others possible
- Compositing
  - “Over” operator
  - Transfer function (later)
- Gradient
  - Direction of greatest change (see next slide)

Gradient: Derived vector field

\[ \nabla f(x,y,z) = \left[ \frac{d}{dx}, \frac{d}{dy}, \frac{d}{dz} \right] \]

\[ \approx \left[ \frac{f(x+1,y,z) - f(x-1,y,z)}{2}, \right. \]

\[ \left. \text{similar for } y, \text{similar for } z \right] \]
Direct Volume Rendering (DVR)

• Basic Idea:
  – Integrate through volume

• “Every voxel contributes to the image”
• No intermediate geometry extraction (faster)
• More flexible than isosurfaces
  – May be X-ray-like
  – May be surface-like
  – Results depend on the transfer function (see next)

Transfer Function

• Maps from scalar value to opacity

<table>
<thead>
<tr>
<th>Scalar value</th>
<th>Opacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Transfer Function

• Opacity and color maps may differ

<table>
<thead>
<tr>
<th>Scalar value</th>
<th>Opacity</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Transfer Function

- Different colors, same opacity

Scalar value
Intensity
Color

Color
Intensity
Scalar value

Common Mixing Functions

- Maximum Intensity Projection (MIP)
  Value = \( \max(D_0, D_1, D_2, D_3) \)

- X-ray-like (inverse of density attenuation)
  Value = clamp(sum(D_0, D_1, D_2, D_3))

- Composite (back-to-front, no color)
  Value(i) = D_i + (Value(i+1) \times (1-D_i))
  (over operator)

Setting Transfer Function: Hard

Chris Johnson
Utah SCI
Physical based transf. func.s

Material Classification
- Use a probability, rather than a threshold.
- Bayesian estimate
- Zone centered
- We know the x-ray absorptions of the materials (bone, ...)

Transfer function unintuitive

Picking 3D transfer functions
- Kniss, Kindlmann, Hansen, Vis 2001, “Interactive Volume Rendering Using Multi-Dimensional transfer Functions and Direct Manipulation Widgets”
Demonstration of Kniss Transfer Function Generator

Occlusion Spectrum

- Carlos Correa, VisWeek
- Occlusion spectrum for volume rendering

More Transfer-Function Design

- Vis 2006: addiso.xj (Salama)
  - 2D transfer function design
- Volume Transfer Function generator
- VURB-TF: Texture-based volume rendering
WYSIWYG Volume Visualization

- Guo, Mao, Yuan; TVCG 2011
  - Brushing in volume determines visible voxels there
  - Statistics on brushed voxels + clusters \rightarrow features
  - Tunes transfer function to produce desired effect

Direct Volume Rendering: How Is it Done?

- Image (eye-screen) order
  - Ray Casting
- Object (volume being displayed) order
  - Splatting
  - Texture-mapping

Ray Casting
Splatting (Westover)

- Render image one voxel at a time:
  - Apply transfer function
  - Determine image extent of voxel
  - Composite

Texture-mapping (Object Order)

Exploits certain graphics hardware
- "Texture-memory": fast trilinear interp.
- volume data sampled by parallel slices
- slices composited in hardware

Adding Lighting and Shadows

- Lighting
  - Compute Gradient at each voxel
  - Use Phong illumination model
  - May scale by gradient magnitude

- Shadows
  - Cast secondary ray towards light
  - Attenuate using transfer function
Adding Color

- Transfer function can include color (density label)
- Can vary color by location (to label organs)

Advanced Illumination Models

- Lindemann & Ropinski
  - TVGC 2011

- Subjective preference (larger is better)
- Which liked?
Advanced Illumination Models

• Lindemann & Ropinski, TVGC 2011
  – Relative size perception error (larger is better)
  – Rank sizes

Advanced Illumination Models

• Lindemann & Ropinski, TVGC 2011
  – Relative depth perception error (larger is better)
  – Which closer?

Advanced Illumination Models

• Lindemann & Ropinski, TVGC 2011
  – Absolute depth perception error (smaller is better)
  – How far?
Illumination Illuminated

- Rankings
  - Phong preferred, then HAS
  - Directional Occlusion overall best
  - HAS best for absolute depth

- Implications
  - What looked best didn’t perform best
  - Best technique depended on task
  - Test techniques on tasks

Exotic Transfer Functions

- Ebert & Rheingans, Visualization 2000

Exotic Transfer Functions 2

- Ebert & Rheingans, Visualization 2000
Importance-Driven Volume Rendering

• Viola, Kanitsar, Groller, Vis ’04
  – Segment volume into objects
  – Indicate relative importance of each object
  – Auto-generate cut-away views
  – Link to video

• Vis 2005
  – Bruckner et. al
  – VolumeShop
Flexible-Occlusion Rendering
• David Borland
• UNC Chapel Hill

Flexible-Occlusion Rendering
• David Borland
• UNC Chapel Hill
• Link to video
• PDF repeat in folder

Mixed-Mode Rendering
• Markus Hadwiger, Christoph Berger, Helwig Hauser, Vis 2003
• Renders Segmented Volumes in mixed modes

• Hand
  – Skin: Shaded DVR
  – Bone: Shaded DVR
  – Blood Vessels: Shaded DVR
Mixed-Mode Rendering

- Markus Hadwiger, Christoph Berger, Helwig Hauser, Vis 2003
- Renders Segmented Volumes in mixed modes

Hand
- Skin: NPR contour/MIP
- Bone: DVR
- Blood Vessels: Tone shading

Head
- Skin: MIP (clipped)
- Teeth: MIP
- Blood Vessels: Shaded DVR
- Eyes: Shaded DVR
- Skull: Contour Rendering
- Vertebrae: Shaded DVR
Mixed-Mode Rendering

- Volume Interval Segmentation and Rendering.
- Isosurfaces and intervals
- Render both together

DVR Characteristics

- Transfer function determines characteristics
  - X-ray-like and MIP
  - Surface-like
    - without lighting
    - lighting, color, and shadows
  - Physically-based with soft edges
  - Custom and exotic transfer functions
- Each has different strengths and weaknesses
  - Try to discuss each group of these

DVR Char: X-ray + MIP

- Strengths
  - X-ray is like traditional radiography
  - Every voxel contributes to image
  - Can show fuzzy boundaries

- Weaknesses
  - Visual system not tuned for this
  - Can be hard to interpret correctly
DVR Char: Surface-like

- Unlit compositing
  - Strengths
    - Opaque surfaces occlude others
    - Can show fuzzy boundaries
  - Weaknesses
    - May confuse surface perception machinery
    - Similar, but not exactly like, surfaces
- Lit, colored surfaces
  - Just like isosurfaces
  - Similar strengths & weaknesses
  - Done for speed reasons

DVR Char: Physically-based

- Strengths
  - Extracts known materials from the data
  - Can show fuzzy boundaries
- Weaknesses
  - Fuzzy volumes hard to see

DVR Char: Custom & Exotic

- Strengths
  - Lots of flexibility
  - Can be tuned to particular task
- Weaknesses
  - Artifacts due to function may overwhelm data
  - Need to carefully consider what you're seeing
Glyphs

- Discrete icons drawn throughout the volume
- Icon characteristics vary based on data
  - Size
  - Color
  - Shape
- Can be a huge variety of these
- Two examples seen here

Color- & Size-changing Glyphs

Figure 5: Particles colored by the number of neighbor links.
Scaled Data-Driven Spheres

- Do Bokinsky’s Data-Driven Spots generalize to 3D?
- Yes! – see Multivariate Visualization lecture

Glyph Characteristics

- Hard to generalize, since can be so varied
  - Glyph volume display still a research area

- Strengths
  - Glyph itself is a surface in space, understood as such
  - Can see around near glyphs to far ones (into volume)

- Weaknesses
  - Frequency can’t be too high: need separate glyphs with space between them
  - Overall surface normal for extracted surfaces not preattentively seen
Summary

• 2D Reduction
  – Slices
    • Good: Same as 2D data display
    • Bad: Miniscule subset of data, occlude one another
  – Isovalue (or other) extracted surfaces
    • Good: Can show interval/ratio using 2D techniques on top of them. Other characteristics are like those of a height field
    • Bad: No fuzzy boundaries, can emphasize noise, obscuration

• Volume display techniques
  – Direct Volume Rendering
    • Completely depends on the transfer function used
  – Glyphs
    • Good: Are 2D surfaces in space, can see past first
    • Bad: Low-frequency data only, no overall surface normal

Stereo and Motion

• Perceiving volume data is very difficult
• All available depth cues should be used

• Stereo and Motion are important depth cues
  – Motion
    • Head tracking
    • User-controlled motion of object
    • Animation (torsion pendulum)
  • Stereo + Head Tracking is especially powerful
Examples

- Many views of hydrogen
- Molecular lattice defects
Detection and Visualization of Anomalous Structures in Molecular Dynamics Simulation Data

• Mehta, et. al. Vis 2004
  – Lattice defect in stick, slice and X-ray projection
  – When slice passes through defect

Figure 11: Dataset 1 (a) Original and (b) Lattice with two defects (c) View showing shape of one defect (d) Views rendering showing 3DPV.
Credits

- Descriptions of volume rendering techniques, colored volume renderings, Shear-Warp: David Ebert’s visualization course.
- Direct Volume Rendering example, Translucent Surfaces: UNC-CH GRIP project slide archives.
- Basket Weave: Gitta Domik
- Curvature-directed Strokes, Animation Motion and Stereo: Victoria Interrante, 1996.
- Even-tessellation textures: Penny Rheingans, 1996.
- Terms, Gradient, DVR Approaches, Splatting, Ray Casting, Texture Mapping, Setting Transfer Function slides: Chris Johnson
- 0D curves in 3D: Keller & Keller p. 131.
- Data-Driven Spots: Alexandra Bokinsky
Credits