Comp/Phys/Mtsc 715

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

Example Videos

• Vis08-TbTFs: Texture-based volume rendering
• Confocal visualization tool
• Rendering surfaces as peaks in DVR

Administrative

• HW3 due tonight
  – Private posts to the homework page
  – No peeking at image files for other users before turning yours in
• HW4 data sets posted
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?
  – Only isoluminant colormaps. Why?
Translucent Isosurfaces

Translucent & Opaque Surface
• Kevin Mongomery, Visualization 1998.

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’s 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

- Unlit lines and high density

0D Points in 3D

- Lit spheres, not lit surface elements
- Interfaces composed of very spheres neural structures
Curvature-Directed Strokes

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
• \( \nabla f(x,y,z) = \left[ \frac{d}{dx}, \frac{d}{dy}, \frac{d}{dz} \right] \)
• \( \approx \left[ \frac{f(x+1,y,z) - f(x-1,y,z)}{2}, \frac{f(x,y+1,z) - f(x,y-1,z)}{2}, \frac{f(x,y,z+1) - f(x,y,z-1)}{2} \right] \)

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
Transfer Function

- Opacity and color maps may differ

Transfer Function

- Different colors, same opacity

Common Mixing Functions

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

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

- Composite (back-to-front, no color)
  Value(i) = D_i + (Value(i+1) * (1-D_i))
  (over operator)
Setting Transfer Function: Hard

Physical based transf. func.s

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: viddivx.avi (Salama)
  - 2D transfer function design
- Divx: Relation-aware volume rendering
- Volume transfer function generation

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
  - TVCG 2011
  - Shadow volume propagation
  - Spherical harmonic light
  - Dynamic ambient occlusion
  - Phong
  - Half angle slicing
  - Directional occlusion
  - Mutidirectional occlusion
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 (smaller is better)
  – Rank sizes

Advanced Illumination Models

• Lindemann & Ropinski, TVGC 2011
  – Relative depth perception error (smaller 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
  - Same for relative size and depth
  - Absolute depth: HAS+, Phong-

- Implications
  - Most “realistic” models inferior
  - Phong if don’t need absolute dist.
  - HAS for general or abs. dist.

Exotic Transfer Functions

- Ebert & Rheingans, Visualization 2000
Exotic Transfer Functions 2

- Ebert & Rheingans, Visualization 2000

Exotic Transfer Functions 3

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
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

Mixed-Mode Rendering

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

Hand
- Skin: MIP
- Bone: Tone shading
- Blood Vessels: Isosurface
Mixed-Mode Rendering

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

• Do Bokinsky’s Data-Driven Spots generalize to 3D
• See Multivariate Visualization lecture

Scaled Data-Driven Spheres

• 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
Stereo and Motion

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

- Stereo and Motion are important depth cues
  - Motion
    - Animation (torsion pendulum)
    - User-controlled motion of object
    - Head tracking
  - Especially powerful is stereo + head tracking
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, Occlusion

• 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

Examples

• Molecular lattice defects
• Many views of hydrogen
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

![Image of molecular dynamics simulation data]

Figure 21: Deposit 715: (a) Original X-ray data with two defects (b) 2D image showing shape of one defect (c) Volume rendering showing both defects.

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Figure 22: Deposit 715: (a) Original X-ray data with two defects (b) 2D image showing shape of one defect (c) Volume rendering showing both defects.

![Image of molecular dynamics simulation data]

Figure 23: Deposit 715: (a) Original X-ray data with two defects (b) 2D image showing shape of one defect (c) Volume rendering showing both defects.
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
• Isosurface + Spherical Surface: James S. Painter, 1996.
• Translucent Isosurfaces: Lloyd A. Treinish, 1988.

• Exotic Transfer Functions: Ebert & Rheingans, 2000.
• 1D curves in 3D: Zoe J. Wood, Visualization 2000.
• 0D curves in 3D: Keller & Keller p. 131.
• Data-Driven Spots: Alexandra Bokinsky
Credits