Volume Visualization

Part 3 (out of 3)
Hardware-Volume Visualization

Faster with Hardware?!
Two Approaches

- **3D-textures:**
  - Volume data stored in 3D-texture
  - Proxy geometry (slices) parallel to image plane, are interpolated tri-linearly
  - Back-to-front compositing

- **2D-textures:**
  - 3 stacks of slices (x-, y- & z-axis), slices are interpolated bi-linearly
  - Select stack (most “parallel” to image plane)
  - Back-to-front compositing
Variation of View Point

- **3D-textures:**
  - Number of slices arbitrary

- **2D-textures:**
  - Stack change: discontinuity

Viewport-Aligned Slices

Object-Aligned Slices
Special Hardware

- Hardware volume raycasting
  - In vertex and fragment operations of modern graphics cards
- Special Hardware
  - VolumePro board:
    - Special card for PC
    - Calculates shear-warp factorization, incl. compositing
    - Warp-step with “regular” graphics card (OpenGL)
Marching Cubes (MC)

Iso-Surface-Display
Repetition: Volume vs. Surface Rendering

Volume rendering:
- Direct volume visualization
- Usage of transfer functions
- Pros: look on the interior, semi-transparency

Surface rendering:
- Indirect volume visualization
- Intermediate representation: Iso-surface, “3D”
- Pros: shading $\rightarrow$ shape!, hardware rendering
Example 1:
- CT measurement
- Iso-stack-conversion
- Iso-surface-calculation (marching cubes)
- Surface rendering (OpenGL)
Iso-Surfaces

- Intermediate representation

- Aspects:
  - Preconditions:
    - expressive Iso-value, Iso-value separates materials
    - Interest: in transitions
  - Very selective (binary selection / omission)
  - Uses traditional hardware
  - shading $\Rightarrow$ 3D-impression!
Iso-Surface:
- Iso-value $f_0$
- Separates values $> f_0$ from values $\leq f_0$
- Often not known →
- Can only be approximated from samples!
- Shape / position dependent on type of reconstruction
Approximation of Iso-Surface

**Approach:**
- Iso-Surface intersects data volume = set of all cells

**Idea:**
- Parts of iso-surface represented on a(n intersected) cell basis
- As simple as possible: Usage of triangles
Marching Cubes

✓ Cell consists of 4(8) pixel (voxel) values: (i+[01], j+[01], k+[01])

1. Consider a Cell
2. Classify each vertex as inside or outside
3. Build an index
4. Get edge list from table[index]
5. Interpolate the edge location
6. Go to next cell

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MC 1: Create a Cube

✓ Consider a Cube defined by eight data values:
MC 2: Classify Each Voxel

Classify each voxel according to whether it lies outside the surface (value > iso-surface value) or inside the surface (value <= iso-surface value).
MC 3: Build An Index

Use the binary labeling of each voxel to create an index

Inside = 1
Outside = 0

Index:

v1 v2 v3 v4 v5 v6 v7 v8

11110100
00110000

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MC 4: Lookup Edge List

✓ For a given index, access an array storing a list of edges

✓ All 256 cases can be derived from 15 base cases

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MC 5: Example

✓ Index = 10110001
✓ triangle 1 = e4, e7, e11
✓ triangle 2 = e1, e7, e4
✓ triangle 3 = e1, e6, e7
✓ triangle 4 = e1, e10, e6
MC 6: Interp. Triangle Vertex

✓ For each triangle edge, find the vertex location along the edge using linear interpolation of the voxel values.

\[
x = i + \left( \frac{T - v[i]}{v[i+1] - v[i]} \right)
\]

where:
- \(T\) is the parameter value for the interpolation
- \(v[i]\) and \(v[i+1]\) are the voxel values at the vertices of the edge

Examples:
- \(T=5\) with \(v[i]=10\) and \(v[i+1]=0\)
- \(T=8\) with \(v[i]=10\) and \(v[i+1]=0\)

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MC 7: Compute Normals

✓ Calculate the normal at each cube vertex

\[
\begin{align*}
G_x &= V_{x-1,y,z} - V_{x+1,y,z} \\
G_y &= V_{x,y-1,z} - V_{x,y+1,z} \\
G_z &= V_{x,y,z-1} - V_{x,y,z+1}
\end{align*}
\]

✓ Use linear interpolation to compute the polygon vertex normal
MC 8: Ambiguous Cases

- Ambiguous cases: 3, 6, 7, 10, 12, 13
- Adjacent vertices: different states
- Diagonal vertices: same state
- Resolution: decide for one case
Danger: Holes!

Wrong vs. correct classification!

Figure 4: Two internal configurations for the Marching Cubes configuration 5

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MC 9: Asymptotic Decider

- Assume bilinear interpolation within a face
- hence iso-surface is a hyperbola
- compute the point \( p \) where the asymptotes meet
- sign of \( S(p) \) decides the connectedness

![Diagram of asymptotes and hyperbolas meeting at point p]
Marching Cubes - Summary 1

✓ 256 Cases
✓ reduce to 15 cases by symmetry
✓ Complementary cases - (swap in- and outside)
✓ Ambiguity resides in cases 3, 6, 7, 10, 12, 13
✓ Causes holes if arbitrary choices are made.

(a) Volume data  (b) Isosurface \( S = f(x, y, z) \)
(c) Polygonal Approximation

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Marching Cubes - Summary 2

- Up to 4 triangles per cube
- Dataset of $512^3$ voxels can result in several million triangles (many Mbytes!!!)
- Iso-surface does not represent an object!!
- No depth information
- Semi-transparent representation --> sorting
- Optimization:
  - Reuse intermediate results
  - Prevent vertex replication
  - Mesh simplification

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MC Examples

1 Iso-surface

2 Iso-surfaces

3 Iso-surfaces
Further Examples
Even Further Examples

13-Jul-1996 - 17:00
Surface Total Precipitation
Clouds & Reflectivity

11-Jul-1996 - 14:00
Surface Heat Index & Winds
Paper (more details):

Conclusion

Volume Visualization

General Remarks
Surface vs. Volume Rendering

- **Surface Rendering:**
  - Indirect representation / display
  - Conveys surface impression
  - Hardware supported rendering (fast?!)  
  - Iso-value-definition

- **Volume Rendering:**
  - direct representation / display
  - Conveys volume impression
  - Often realized in software (slow?!)  
  - Transfer functions

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Conclusion VolVis

- Introduction
- Direct volume visualization
  - Ray casting
  - Splatting
  - Shear-warp factorization
  - Hardware-based VolVis
- Indirect VolVis
  - Marching cubes (iso-surface-visualization)

*: Conclusion
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