Modeling: Acquisition

Marching Cubes

(Lorensen and Cline)
Types of Sensors

Imaging (2D/3D)

Laser Imaging (2D/3D)
Sensing Technologies - Imaging

- Capture multiple 2D images
- Use image processing tools to create initial geometry data

Requirements
- Many cameras
- Specific locations
3D Imaging

- Wave based sensors
  - Ultrasound,
  - Magnetic Resonance Imaging (MRI)
  - X-Ray
  - Computed Tomography (CT)

- Outputs
  - volumetric data (voxels)
Range Scanners

- Laser/Optical range scanner provides 2D array of depth data
- Some capture colour (texture)
- Multiple views for complete object scan:
  - Rotate object
  - Rotate sensor
- Output - point set
Voxels

- Define iso-surfaces (between data values)
- Triangulate iso-surface
  - Marching Cubes
Marching Cubes: Overview

- Marching cubes: method for approximating surface defined by isovalue $\alpha$, given by grid data

- **Input:**
  - Grid data (set of 2D images)
  - Threshold value (isovalue) $\alpha$

- **Output:**
  - Triangulated surface that matches isovalue surface of $\alpha$
Voxels

- Voxel – cube with values at eight corners
  - Each value is above or below isovalue $\alpha$
  - Method processes one voxel at a time
- $2^8=256$ possible configurations (per voxel)
  - reduced to 15 (symmetry and rotations)
- Each voxel is either:
  - Entirely inside isosurface
  - Entirely outside isosurface
  - Intersected by isosurface
Algorithm

- First pass
  - Identify voxels which intersect isovalue

- Second pass
  - Examine those voxels
  - For each voxel produce set of triangles
    - approximate surface inside voxel
Figure 2. Configurations.
Configurations

- For each configuration add 1-4 triangles to isosurface

- Isosurface vertices computed by:
  - Interpolation along edges (according to pixel values)
    - better shading, smoother surfaces
  - Default – mid-edges
Example
Marching Cubes method can produce erroneous results

- E.g. isovalue surfaces with "holes"

Example:

- voxel with configuration 6 that shares face with complement of configuration 3:
Solution

- Use different triangulations
- For each problematic configuration have more than one triangulation
- Distinguish different cases by choosing pairwise connections of four vertices on common face
Ambiguous Face

- **Ambiguous Face**: face containing two diagonally opposite marked grid points and two unmarked ones

- Source of the problems in MC method
Solution by Consistency

Problem:
- Connection of isosurface points on common face done one way on one face & another way on the other

Need consistency → use different triangulations

If choices are consistent get topologically correct surface
Asymptotic Decider

- **Asymptotic Decider**: technique for choosing which vertices to connect on ambiguous face

- Use bilinear interpolation over ambiguous face
Bilinear Interpolation

- Bilinear interpolation over face - natural extension of linear interpolation along an edge
- Consider face as unit square

\[
B(s, t) = (1 - s) s \begin{pmatrix} B_{00} & B_{01} \\ B_{10} & B_{11} \end{pmatrix} \begin{pmatrix} 1 - t \\ t \end{pmatrix}
\]

\[
\{(s, t): 0 \leq s \leq 1, \quad 0 \leq t \leq 1\}
\]

\(B_{ij}\) - values of four face corners
Bilinear Interpolation (cont.)

Figure 5. Bilinear interpolation.
Asymptotic Decider Test (cont).

\[ B(S_\alpha, T_\alpha) = \frac{B_{00} B_{11} + B_{10} B_{01}}{B_{00} + B_{11} - B_{01} - B_{10}}. \]

- If \( \alpha > B(S_\alpha, T_\alpha) \)
  - connect \((S_1,1)-(1,T_1)\) & \((S_0,0)-(0,T_0)\)
- else
  - connect \((S_1,1)-(0,T_0)\) and \((S_0,0)-(1,T_1)\)
Various Cases

- Configurations 0, 1, 2, 4, 5, 8, 9, 11 and 14 have no ambiguous faces $\Rightarrow$ no modifications

- Other configurations need modifications according to number of ambiguous faces
Configuration 3+6

- Exactly one ambiguous face

- Two possible ways to connect vertices
  - two resulting triangulations

- Several different (valid) triangulations
Configuration 12

- Two ambiguous faces $\implies 2^2 = 4$ boundary polygons
Configuration 10

- As in configuration 12 - two ambiguous faces

- When both faces are separated (10A) or not separated (10C) there are two components for the isovalue surface
Configuration 7

- Three ambiguous faces $\Rightarrow 2^3 = 8$ possibilities
- Some are equivalent $\Rightarrow$ only 4 triangulations
Configuration 13

Figure 16.
Remarks

- Modifications add considerable complexity to MC

- No significant impact on running time or total number of triangles produced

- New configurations occur in real data sets
  - But not very often
### Table 1. Frequency of configurations

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<th>Config</th>
<th>Example 1</th>
<th>Example 2</th>
<th>Example 3</th>
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