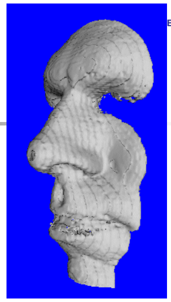
# Modeling: Acquisition

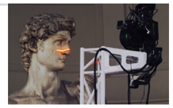
## Marching Cubes

(Lorensen and Cline)



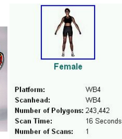


## Types of Sensors



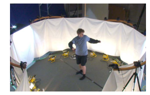
Laser

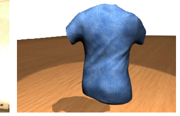
Imaging (2D/3D)




## Sensing Technologies - Imaging

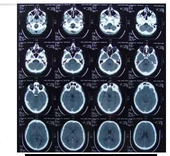
- Capture multiple 2D images
- Use image processing tools to create initial geometry data
- Requirements
  - Many cameras
  - Specific locations

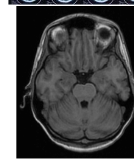




## 3D Imaging

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

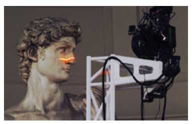






## Range Scanners

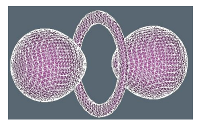
- Laser/Optical range scanner provides 2D array of depth data
- Some capture colour (texture)
- Multiple views for complete object scan:
  - Rotate object
  - Rotate sensor
- Output – point set

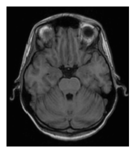


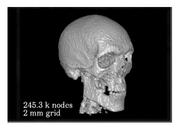


## Voxels

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









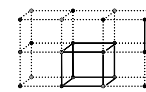

## Marching Cubes: Overview

- 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



## Configurations

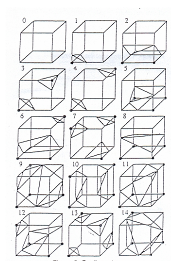


Figure 2. Configurations.



## Configurations

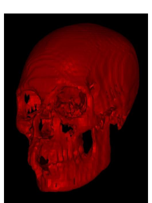
- For each configuration add 1-4 triangles to isosurface
- Isosurface vertices computed by:
  - Interpolation along edges (according to pixel values)
    - better shading, smoother surfaces
  - Default – mid-edges

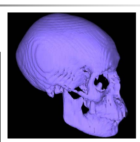


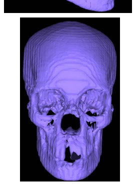
## Example



## Example









## MC Problem

- 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:

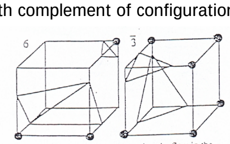



Figure 3. An example illustrating the flaw in the marching cubes method.



## 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

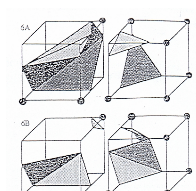


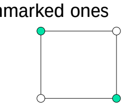

Figure 4. Two possible triangulations which yield a topologically correct isovalue surface.

2.0 Asymptotic Decider



## 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

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

$$\{(s,t): 0 \le s \le 1,\quad 0 \le t \le 1\}$$

- $B_{ij}$ - values of four face corners



## Bilinear Interpolation (cont.)

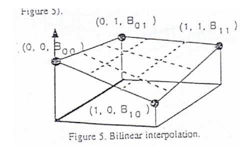


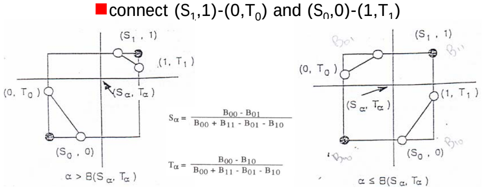
Figure 5. Bilinear interpolation.



## 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 $(S_0,0)$-$(1,T_1)$




$$S_\alpha = \frac{B_{00} - B_{01}}{B_{00} + B_{11} - B_{01} - B_{10}}$$

$$T_\alpha = \frac{B_{00} - B_{10}}{B_{00} + B_{11} - B_{01} - B_{10}}$$

## Various Cases

- Configurations 0, 1, 2, 4, 5, 8, 9, 11 and 14 have no ambiguous faces → 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

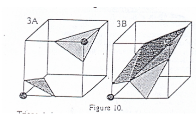


Figure 10.



## Configuration 12

- Two ambiguous faces → $2^2$ = 4 boundary polygons

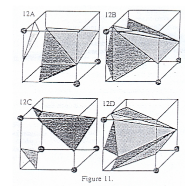


Figure 11.



## 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

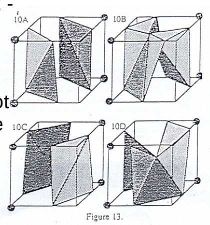


Figure 13.



## Configuration 7

- Three ambiguous faces → $2^3$=8 possibilities
- Some are equivalent → only 4 triangulations

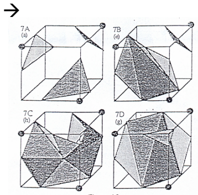


Figure 15.



## Configuration 13

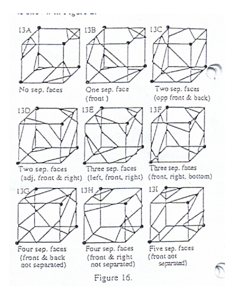


Figure 16.



## 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



## Examples and Remarks (cont)

| Config. | Example 1 | Example 2 | Example 3 |
|---|---|---|---|
| 0 | 263.519 | 285.074 | 110.993 |
| 1 | 7.705 | 1.912 | 1.673 |
| 2 | 8.710 | 2.065 | 2.421 |
| 3A | 60 | 0 | 6 |
| 3B | 46 | 0 | 6 |
| 4 | 28 | 0 | 0 |
| 5 | 5.611 | 1.228 | 1.143 |
| 6A | 20 | 0 | 0 |
| 6B | 47 | 0 | 0 |
| 7A | 3 | 0 | 0 |
| 7B,D | 3 | 0 | 0 |
| 7C | 3 | 0 | 0 |
| 8 | 4.637 | 906 | 1.146 |
| 9 | 1.003 | 304 | 261 |
| 10A,C | 13 | 0 | 0 |
| 10B,D | 1 | 0 | 0 |
| 11 | 36 | 0 | 0 |
| 12A,C | 7 | 0 | 0 |
| 12B,D | 4 | 0 | 0 |
| 13 | 0 | 0 | 0 |
| 14 | 69 | 0 | 0 |

Table 1. Frequency of configurations