Marching Cubes

Sara McMains

ME 290-R

University of California at Berkeley

Marching Cubes

Motivation

- Visualization for medical aps

Input

- Regular grid of points
- Density values at each point

Data acquisition

- MRI (Magnetic Resonance Imaging)
  - Excitation of water molecules
- CT scan (Computer Tomography)
  - Absorption of x-rays
- Ultrasound
  - Backscatter strength

Goal

Display “iso-surface”

- Surface of constant density
  - Assumption : sampling from a continuous such surface
- Medical visualization
  - Bone, flesh, organ densities differ
  - Operator selects desired density

Display

Outputs triangles

- Graphics hardware optimized for triangles
  - Today, everyone has graphics cards
  - Back in the “dark ages” had to do it in software

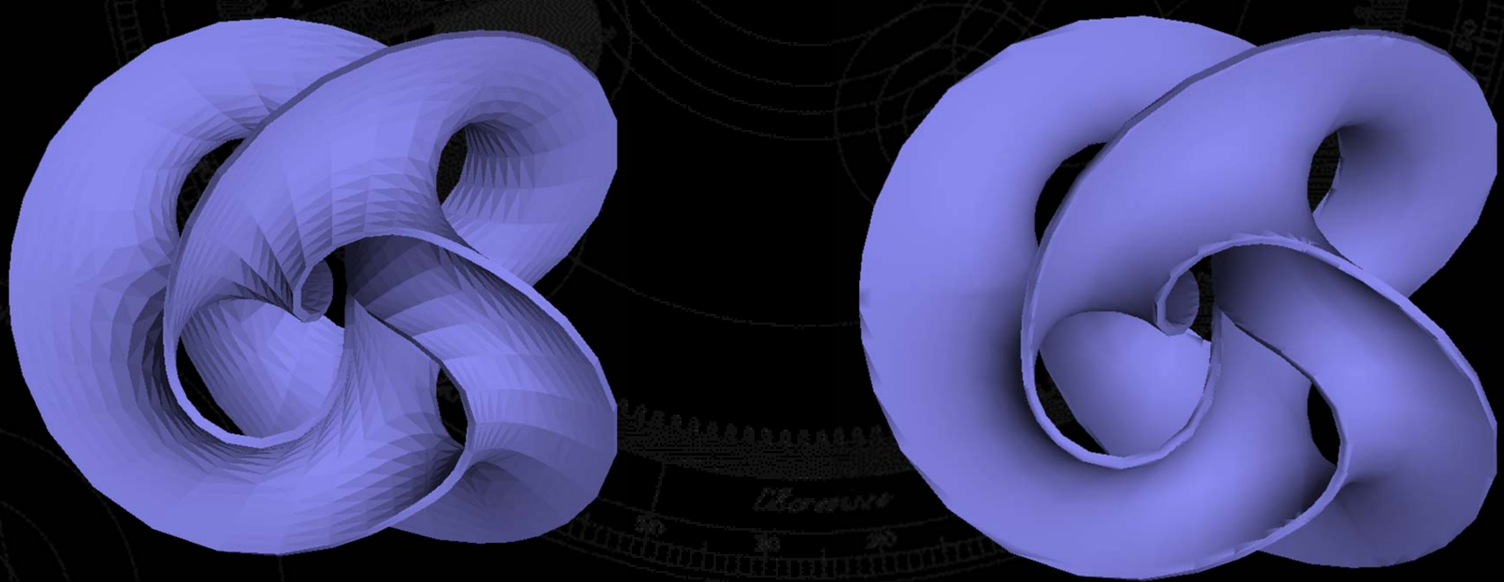
Surface normal for each vertex

- Improve rendered appearance via Gouraud shading

Gouraud Shading

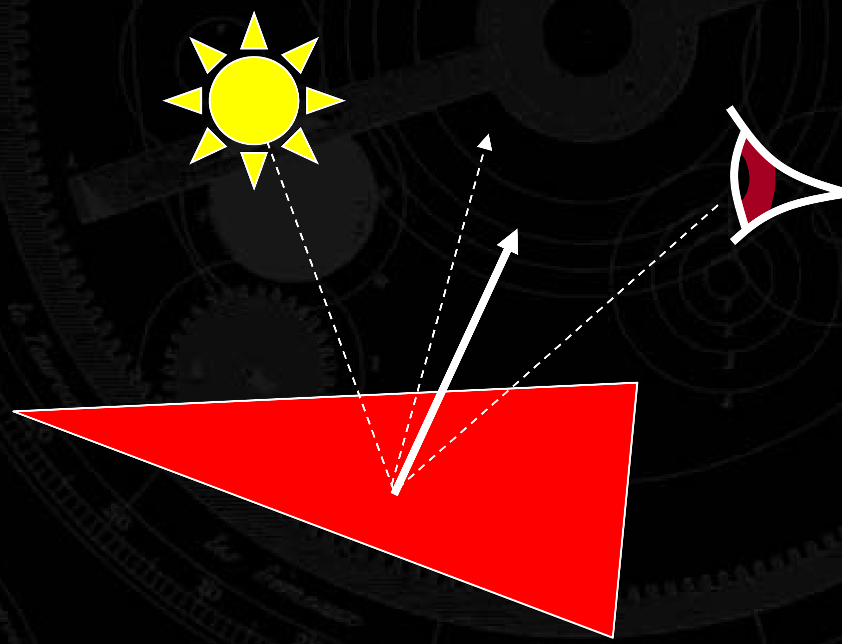
A simple, effective computer graphics hack

Make low-detail surfaces appear smooth



Standard Flat Shading

material + lighting + viewing angle -> color

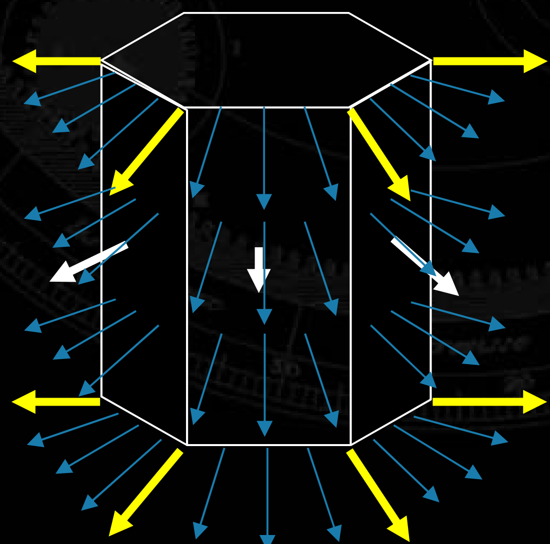


- Same color for whole triangle

Phong Shading

Pretend surface normal varies across triangle

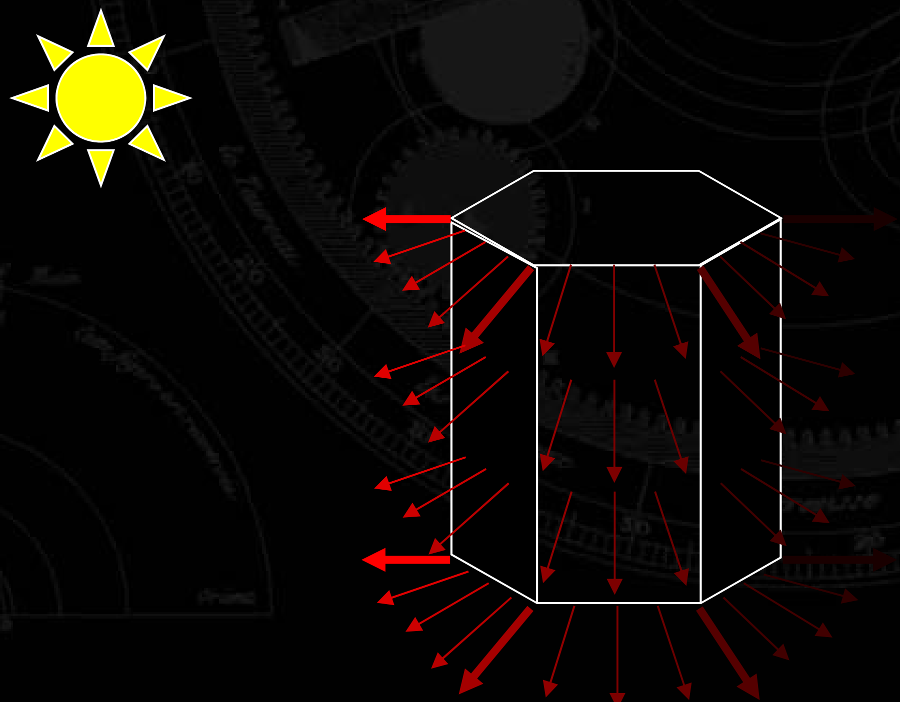
- Implementation
  - Store a surface normal at each vertex
  - Interpolate them to calculate each pixel color



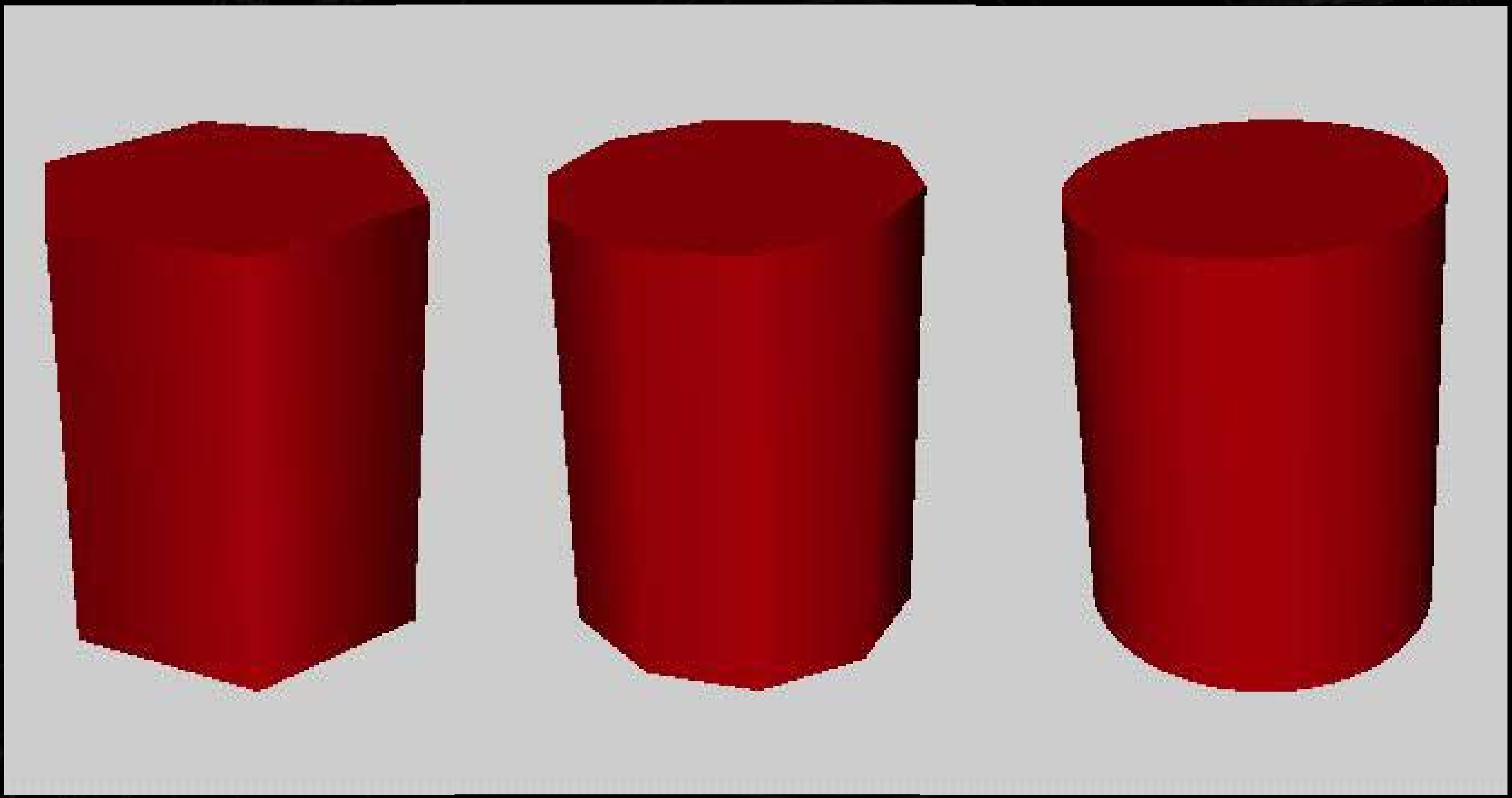
Gouraud Shading

Simplification of Phong shading

- Interpolate vertex colors instead of normals



Gouraud Shading



Back to Marching Cubes

Basic idea:

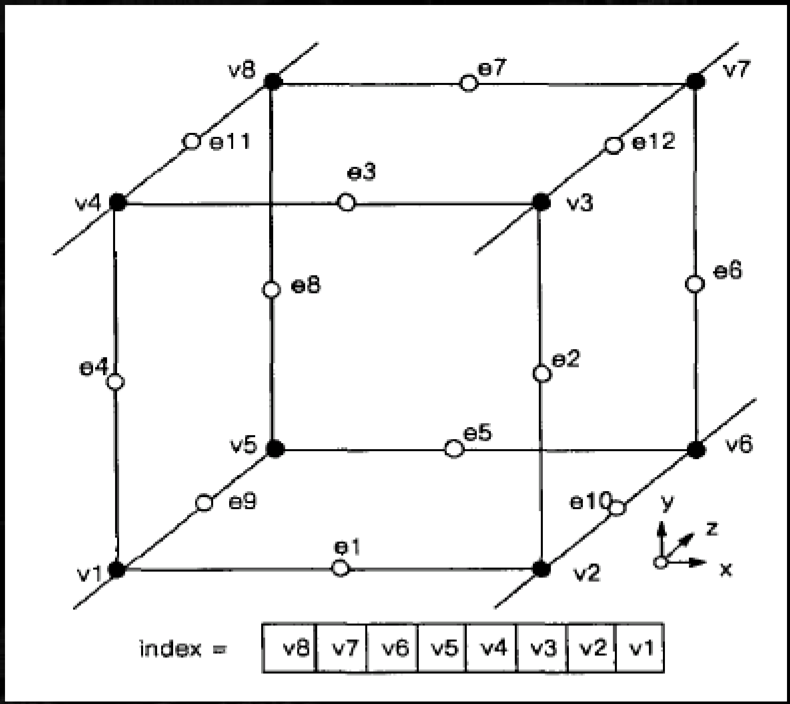
- Look at one “cube” of 8 samples at a time
- Determine if each corner inside or outside volume
  - Density above threshold => 0 label
  - Density below threshold => 1 label
- Pattern of labels tells topology of intersection

Calculation of topology and geometry separated

Cases

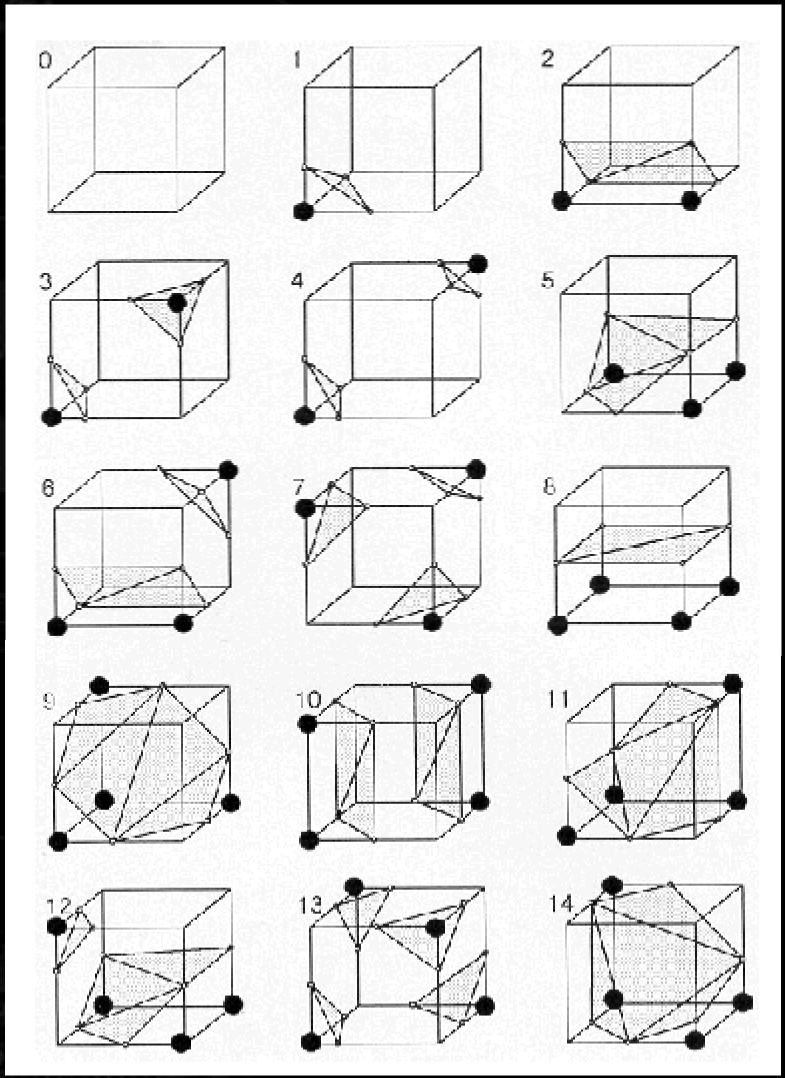
256 (2^8) cases total

- Build a look-up table
  - Index : ordered 8-bits of in/out labels from cube corners
  - Output: which edges intersected, triangles formed



Cases

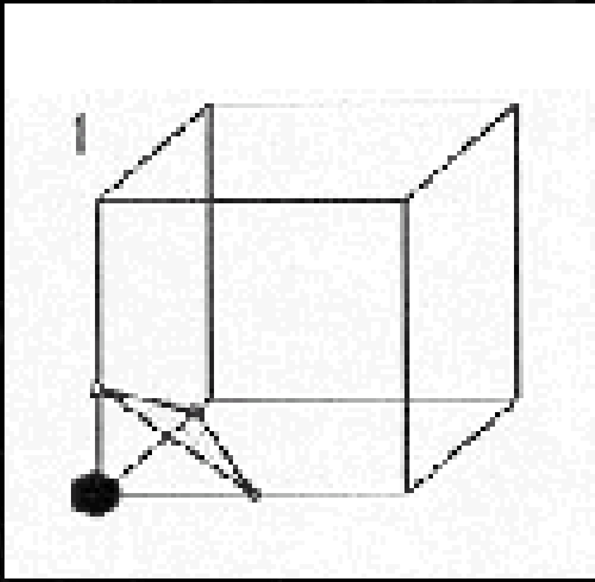
Only 15 patterns

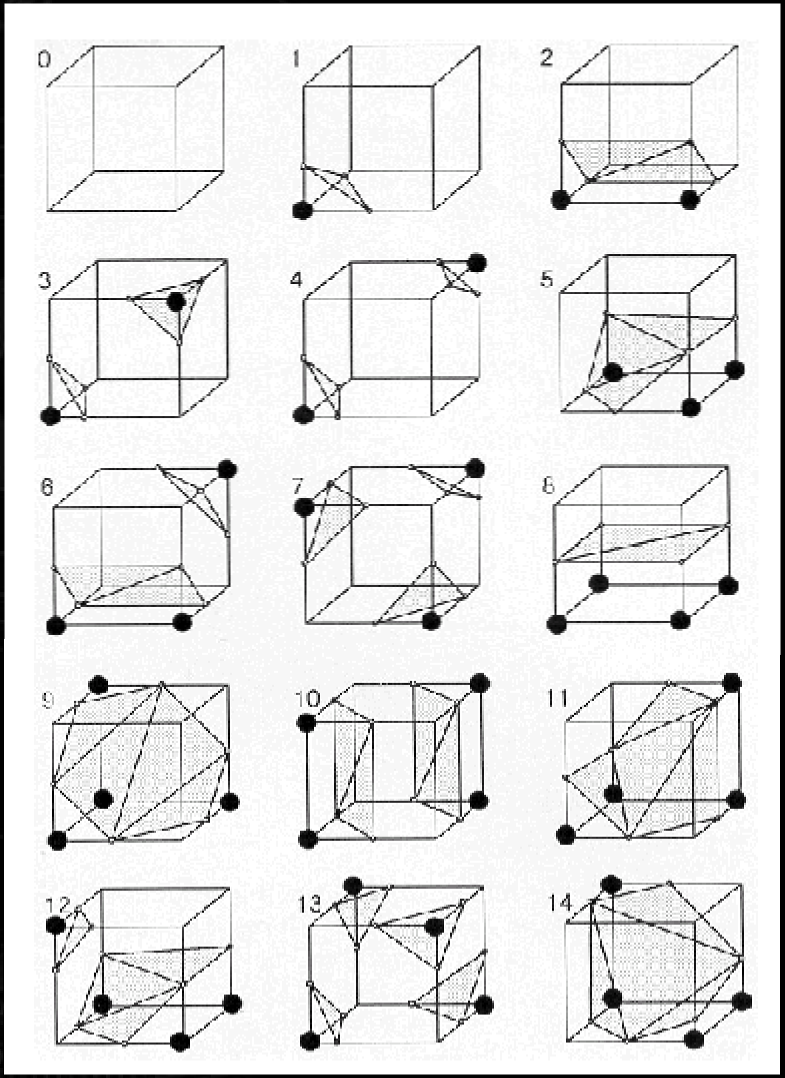


Cases

Only 15 patterns

- Use symmetry

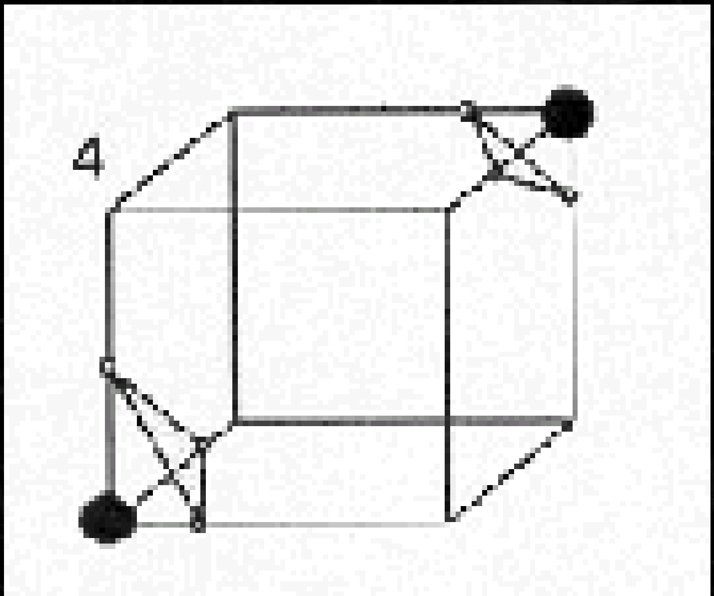


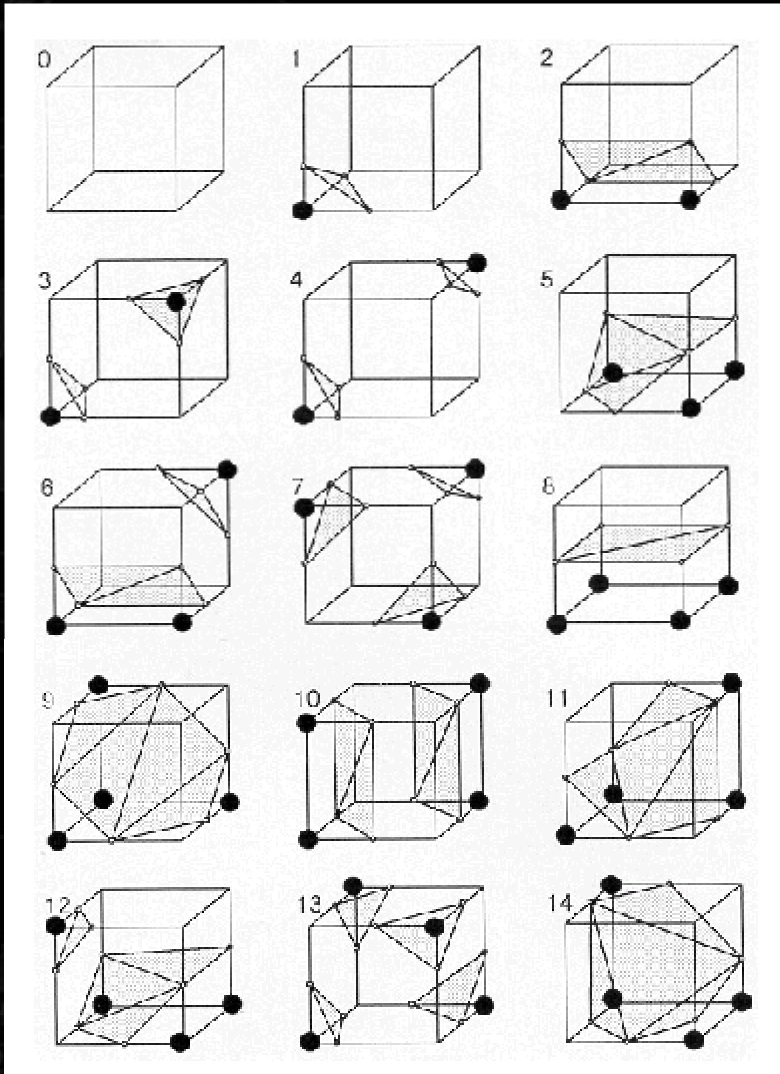


Cases

Only 15 patterns

- Use symmetry



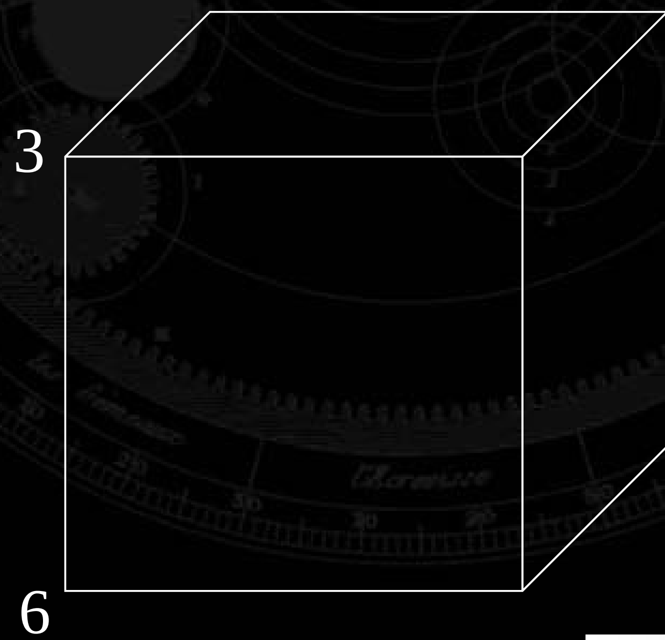


Geometry calculations

Edge intersection positions

- Linear interpolation of density values at corners

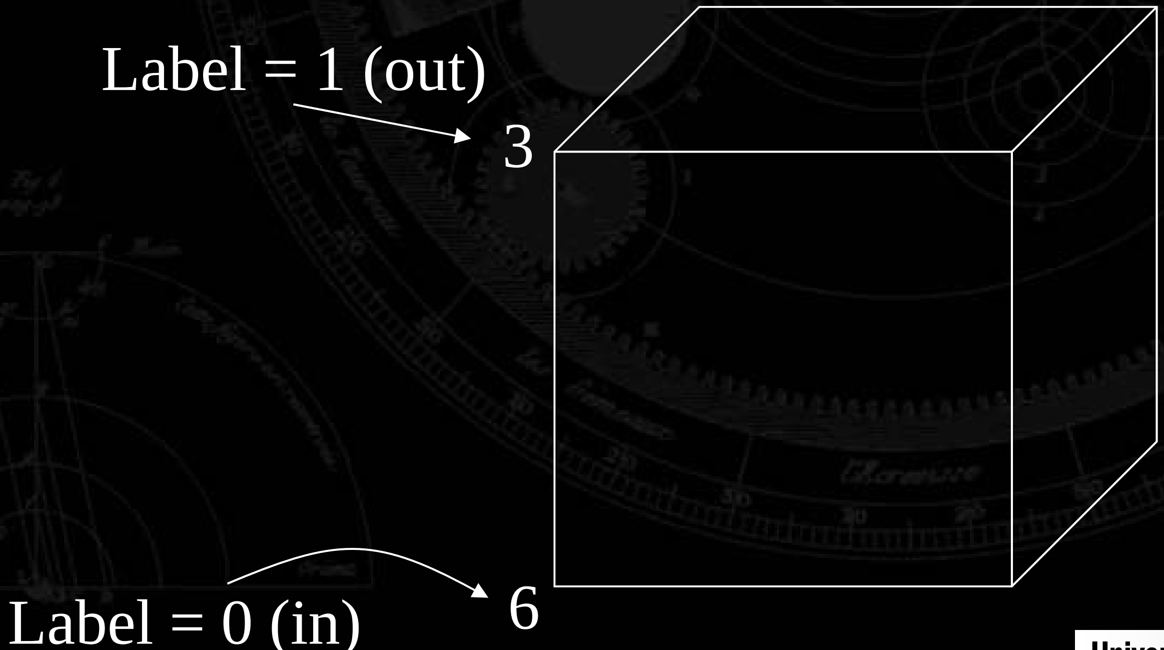
Isosurface density 5



Geometry calculations

Edge intersection positions

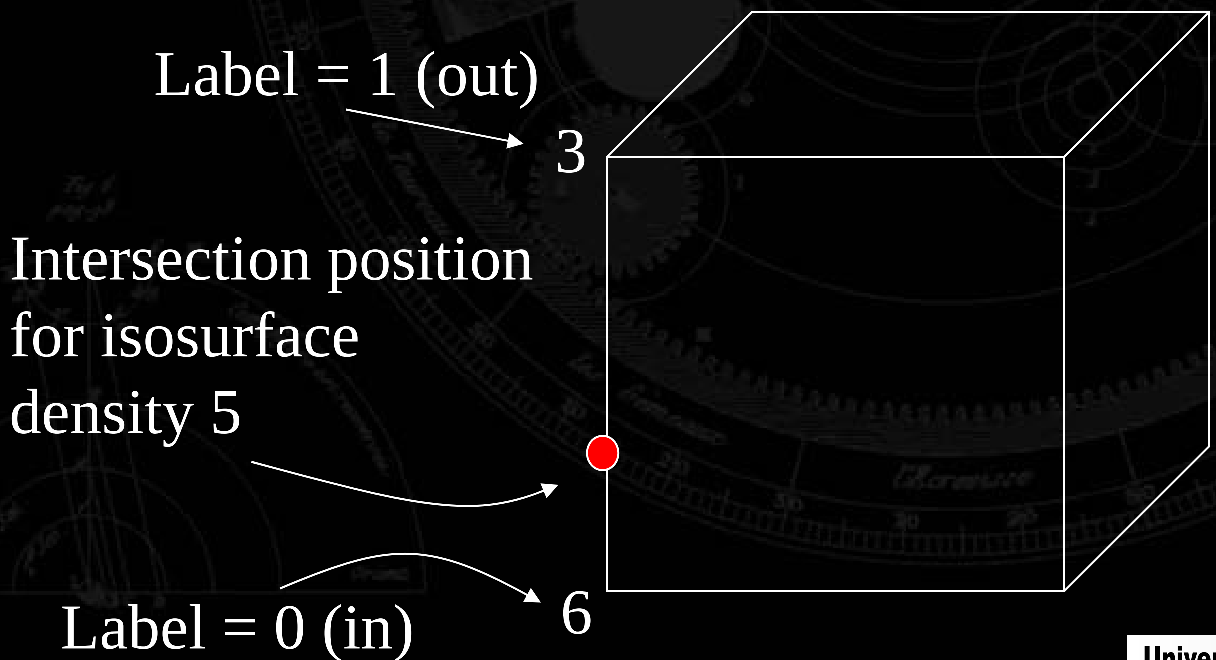
- Linear interpolation of density values at corners



Geometry calculations

Edge intersection positions

- Linear interpolation of density values at corners



Geometry Calculations

Vertex normals

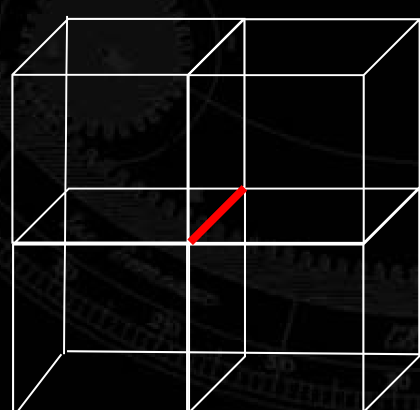
- Want to set to normal to iso-surface
- Gradient direction = normal direction for iso-surfaces
- Calculate gradient at each corner
  - Look at 6 neighbors
- Interpolate to edge intersections

Efficiency

Internal cube edges shared

- 12 edges/cube
- 4 cubes/edge

} 3 new edges per internal cube



Booleans

Boolean evaluation also uses in/out labeling (and on)

- Implement Booleans on cube index
- Use truth tables to combine 0, 255, “in-between”
- For in-between/in-between, clip triangles

Memory Usage

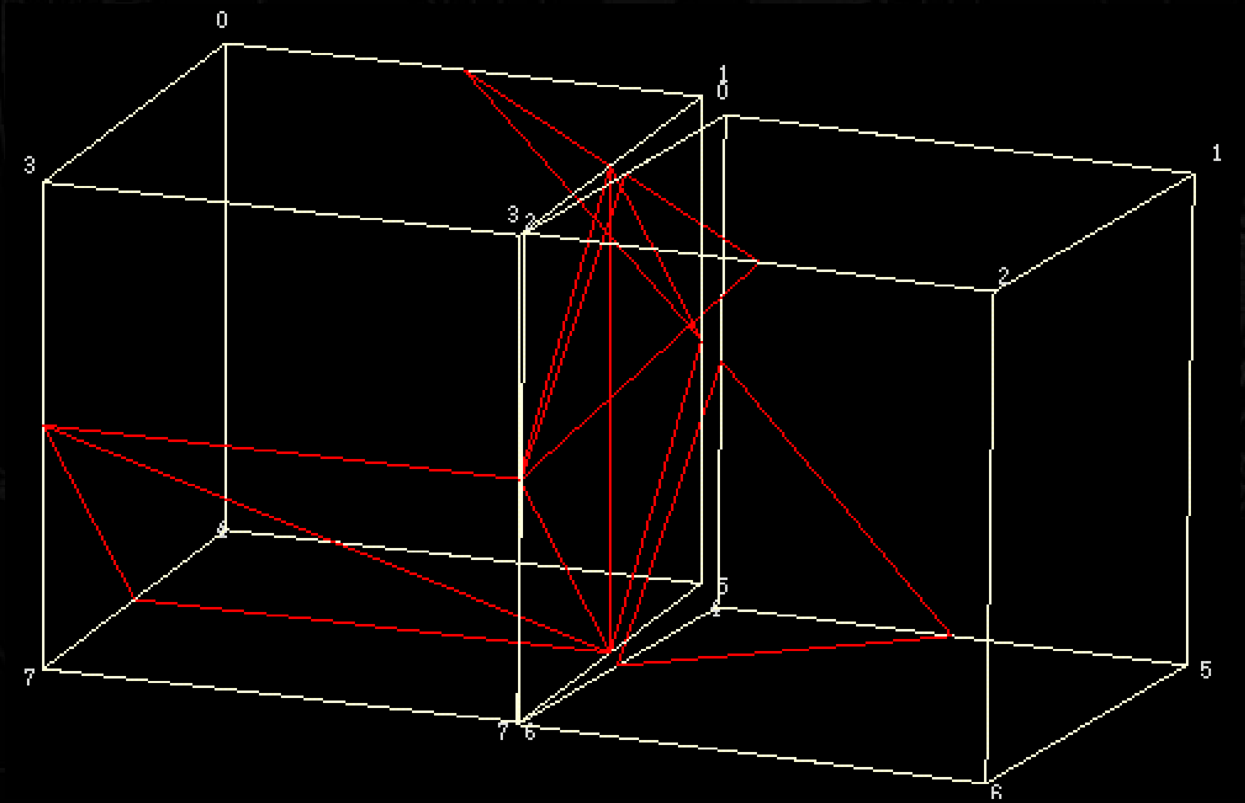
Just need four slices of data in memory

- No problem for normal data sets

Small memory footprint good indicator of possible parallelism

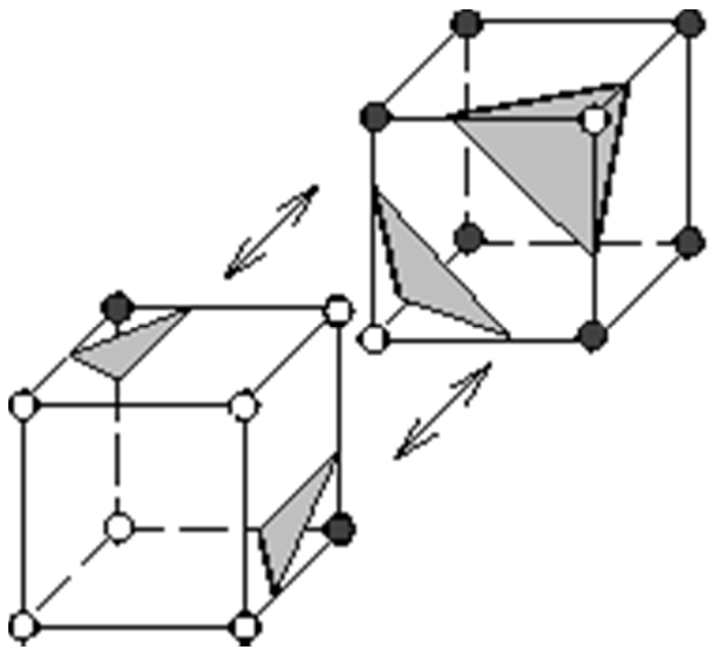
Topology Problems

E.g. non-manifold output



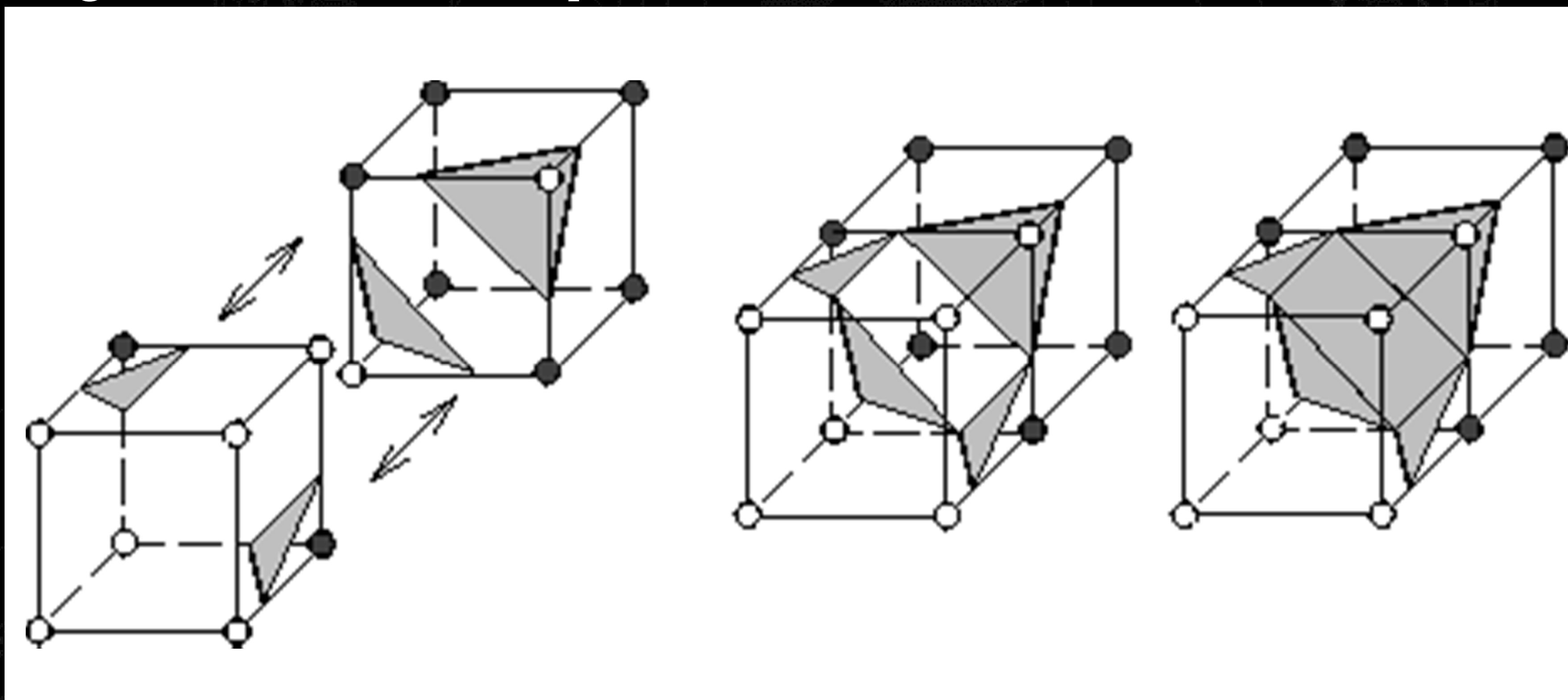
Topology Problems

E.g. holes in output



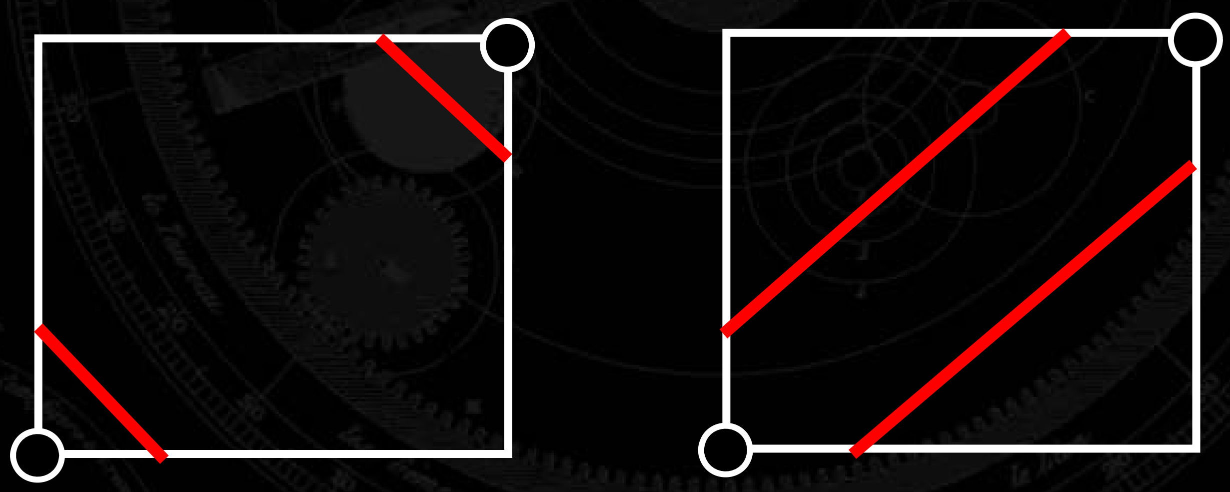
Topology Problems

E.g. holes in output



Ambiguity of configurations

2D Example



Fixes

Simple approaches

- Consider adjacent cubes
  - Helps some, not all cases
- Divide into Tetrahedra
  - Make consistent with adjacent elements
  - Correctness not guaranteed

Fixes

Interpolation approaches
calculate additional vertices or values

- Add center point & tetrahedralize
- Subdivision
  - Down to pixel resolution, e.g.
  - Dividing Cubes [Cline et al. 1988]
- Fit higher order curves
  - Curve orientation disambiguates

Questions?