Volume Visualization

Part 3 (out of 3)

Hardware-Volume Visualization

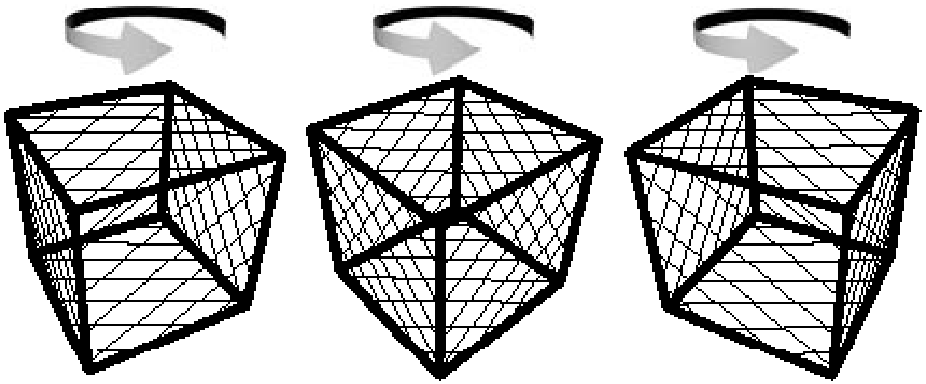
Faster with Hardware?!

Two Approaches

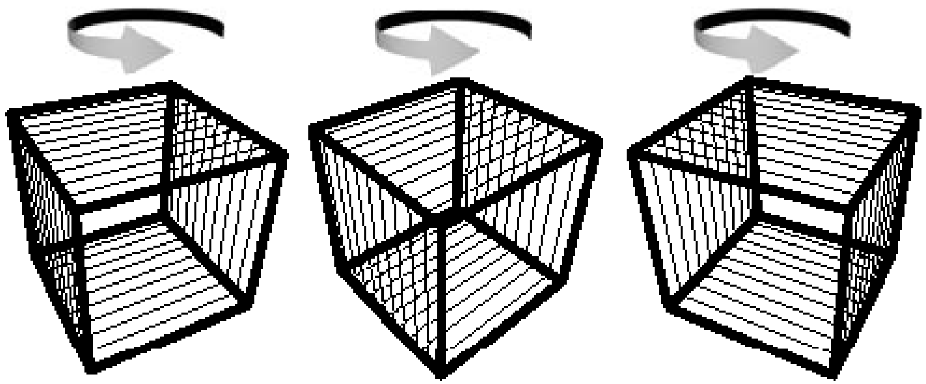
- 3D-textures:
  - Volume data stored in 3D-texture
  - Proxy geometry (slices) parallel to image plane, are interpolated tri-linearly
  - Back-to-front compositing
- 2D-textures:
  - 3 stacks of slices (x-, y- & z-axis), slices are interpolated bi-linearly
  - Select stack (most “parallel” to image 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)

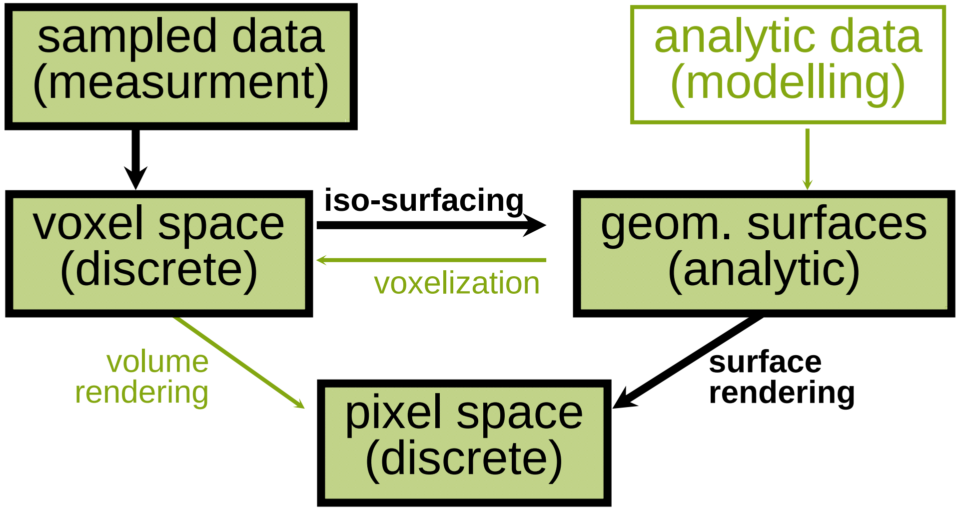
Iso-Surface-Display

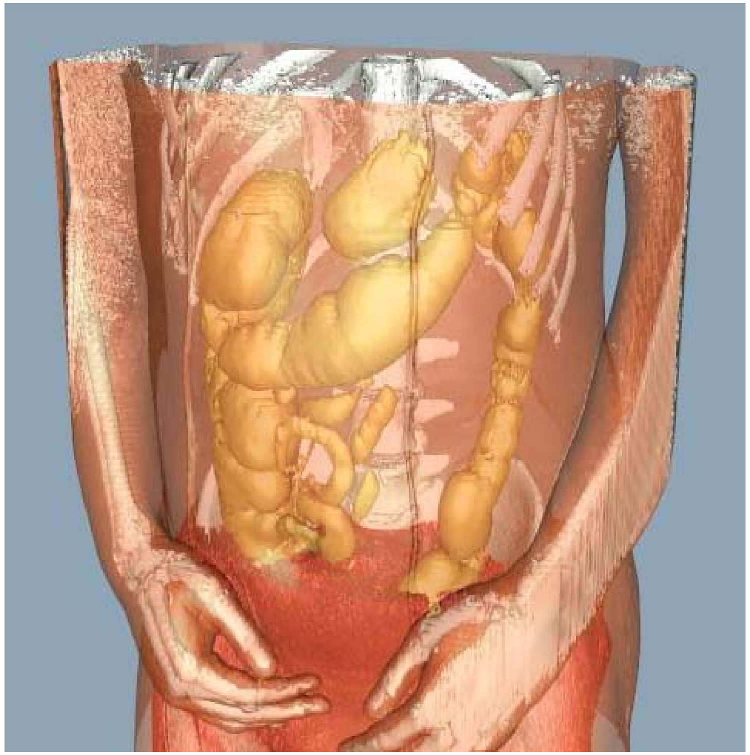
Repetition: Volume vs. Surface Rendering

- 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

Concepts and Terms

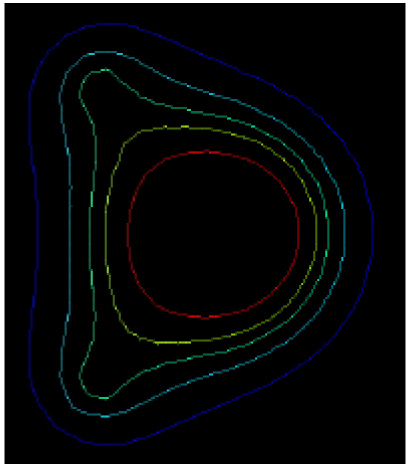
- Example 1:
  - CT measurement
  - Iso-stack-conversion
  - Iso-surface-calculation (marching cubes)
  - Surface rendering (OpenGL)

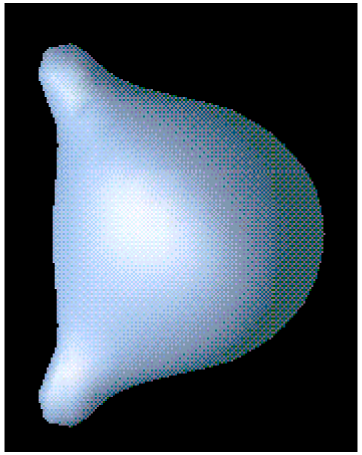




Iso-Surfaces

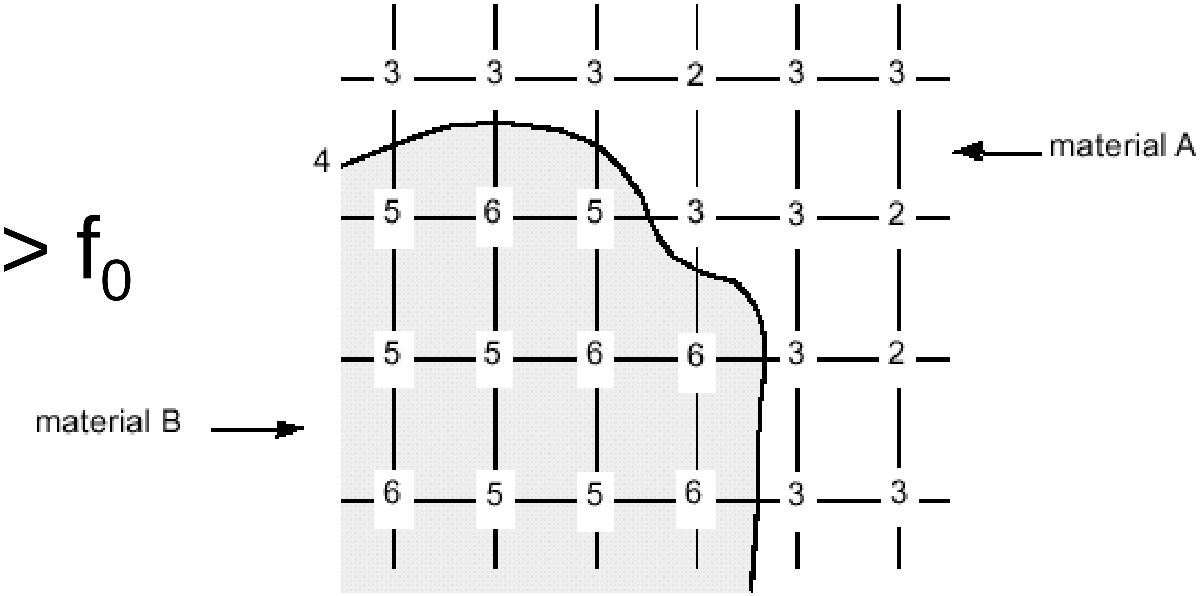
- Intermediate representation
- Aspects:
  - Preconditions:
    - expressive Iso-value,
      Iso-value separates materials
    - Interest: in transitions
  - Very selective (binary selection / omission)
  - Uses traditional hardware
  - shading ⇒ 3D-impression!





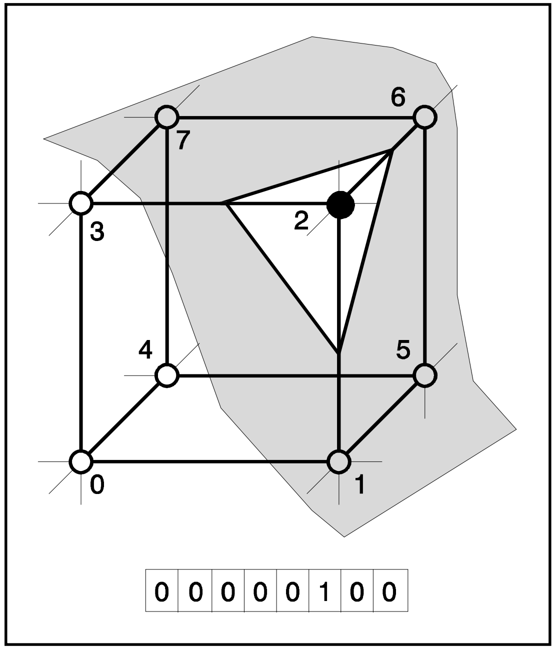
Volume Data ⇔ Iso-Surfaces

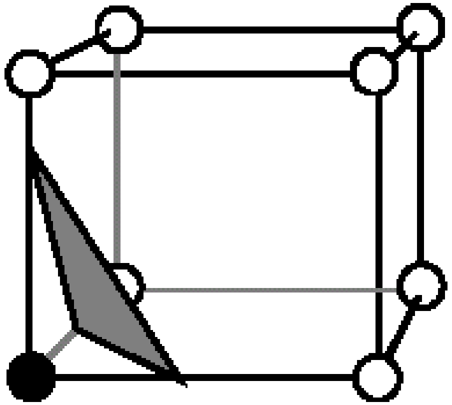
- Iso-Surface:
  - Iso-value f_0
  - separates values > f_0 from values ≤ f_0
  - Often not known →
  - Can only be approximated from samples!
  - Shape / position dependent on type of reconstruction



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





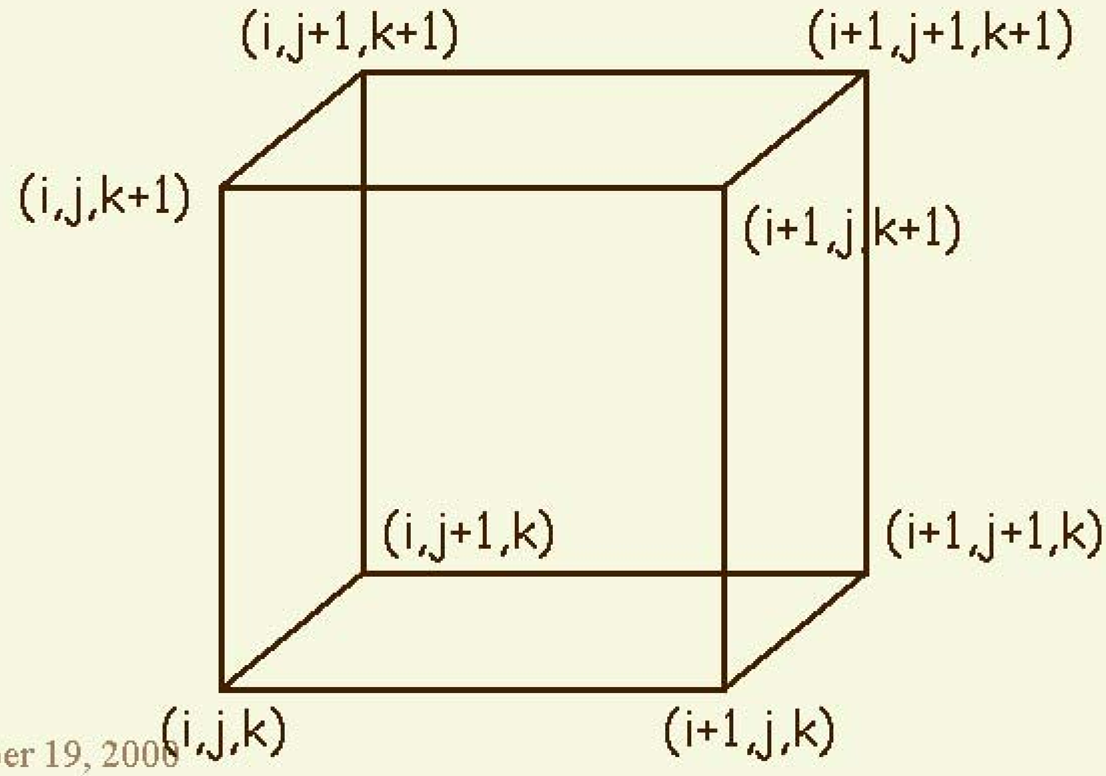
Marching Cubes

✓ 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

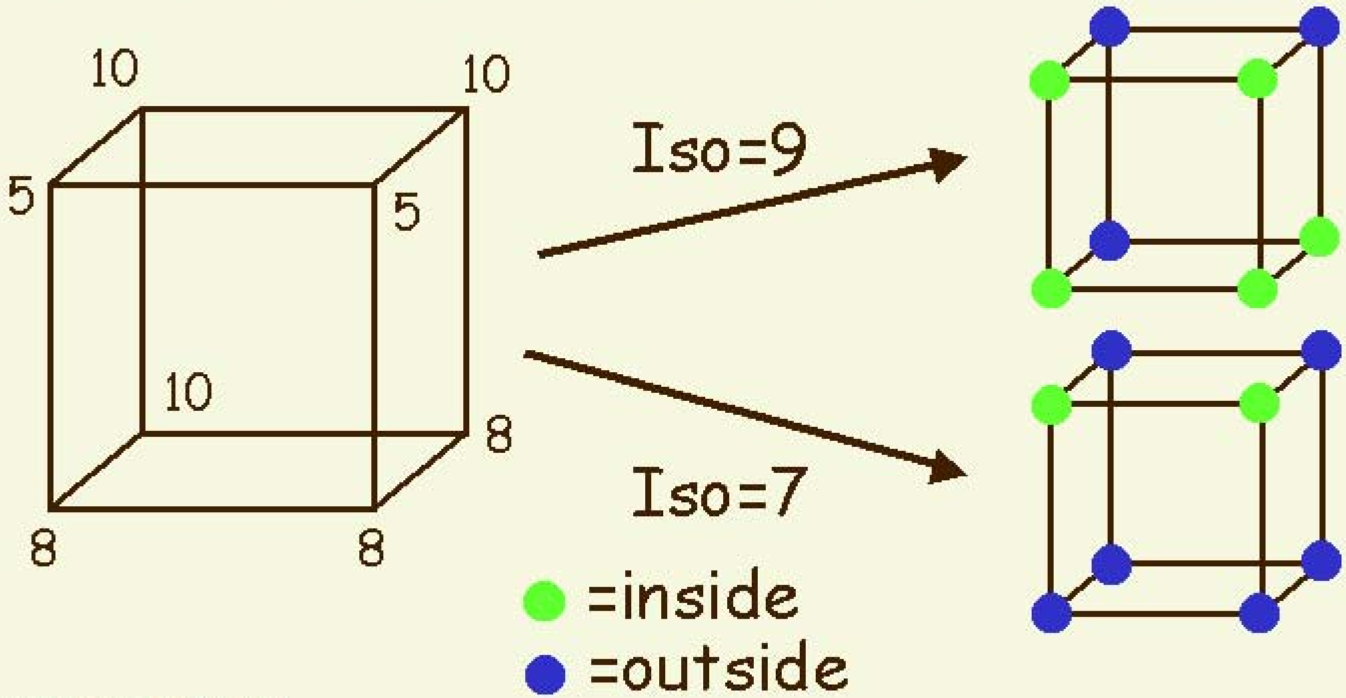
MC 1: Create a Cube

- ✓ Consider a Cube defined by eight data values:



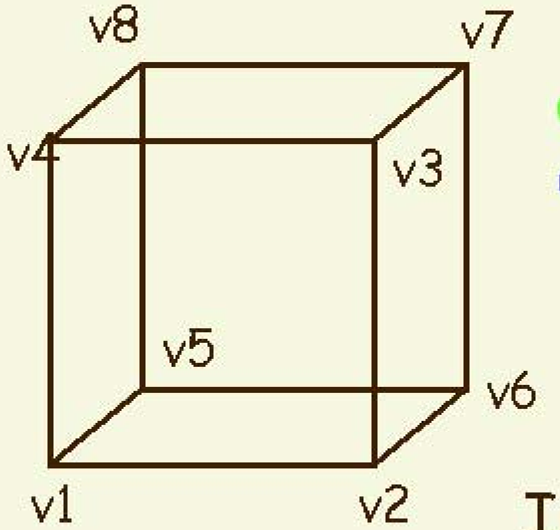
MC 2: Classify Each Voxel

- ✓ Classify each voxel according to whether it lies outside the surface (value > iso-surface value) inside the surface (value <= iso-surface value)

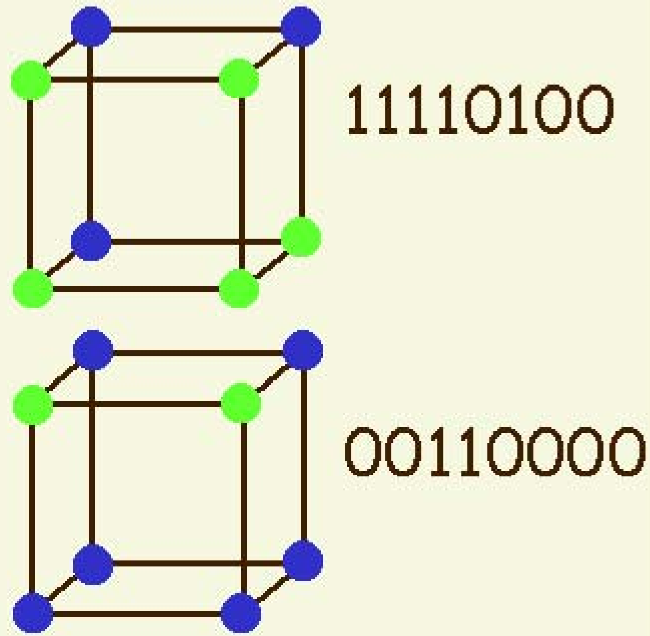


MC 3: Build An Index

- ✓ Use the binary labeling of each voxel to create an index



● inside =1
● outside=0

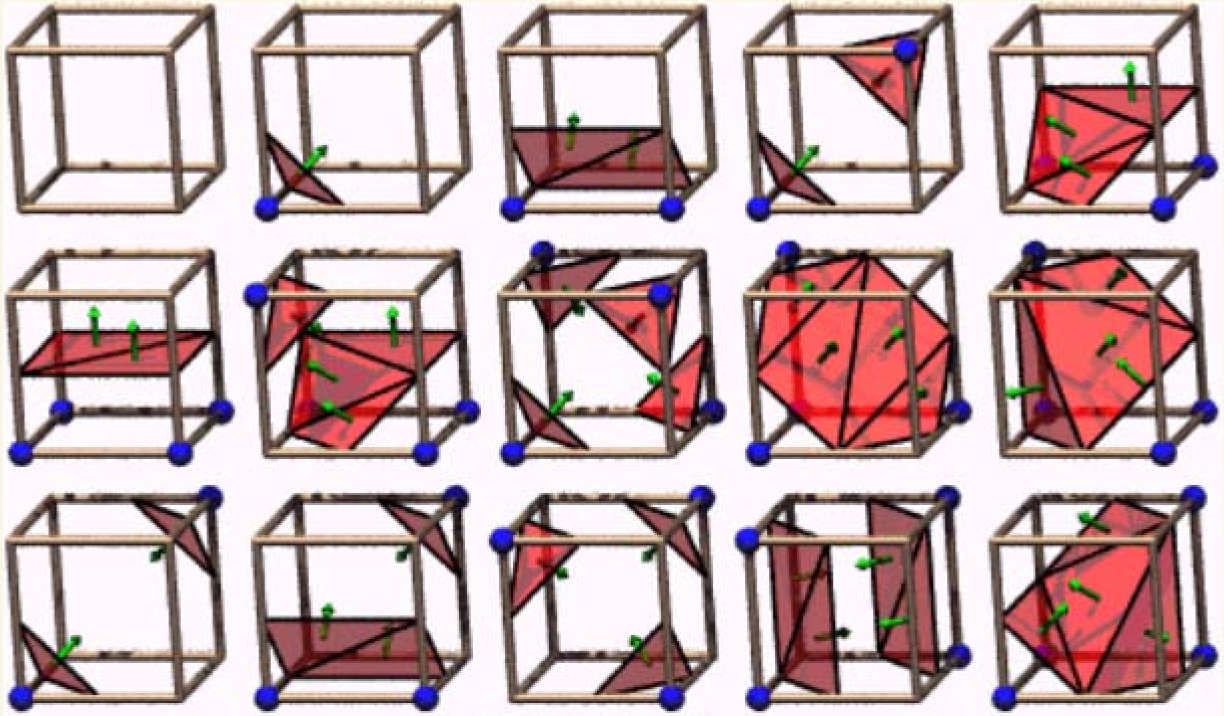


Index:

v1	v2	v3	v4	v5	v6	v7	v8

MC 4: Lookup Edge List

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

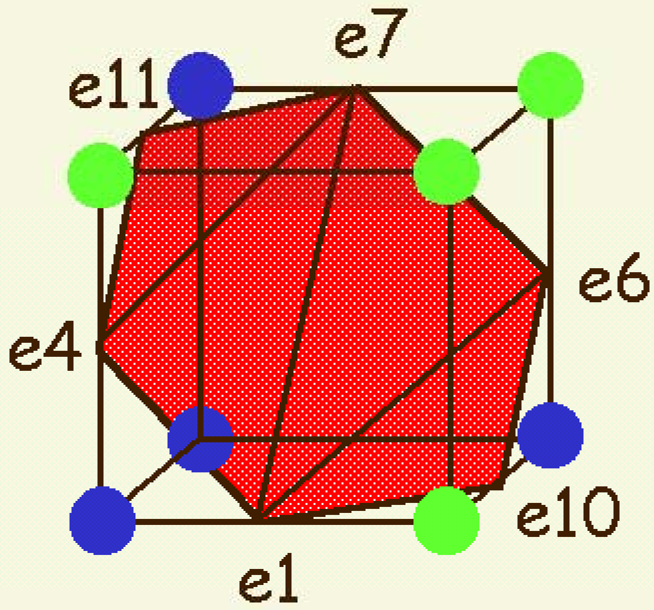


The 15 Cube Combinations

- all 256 cases can be derived from 15 base cases

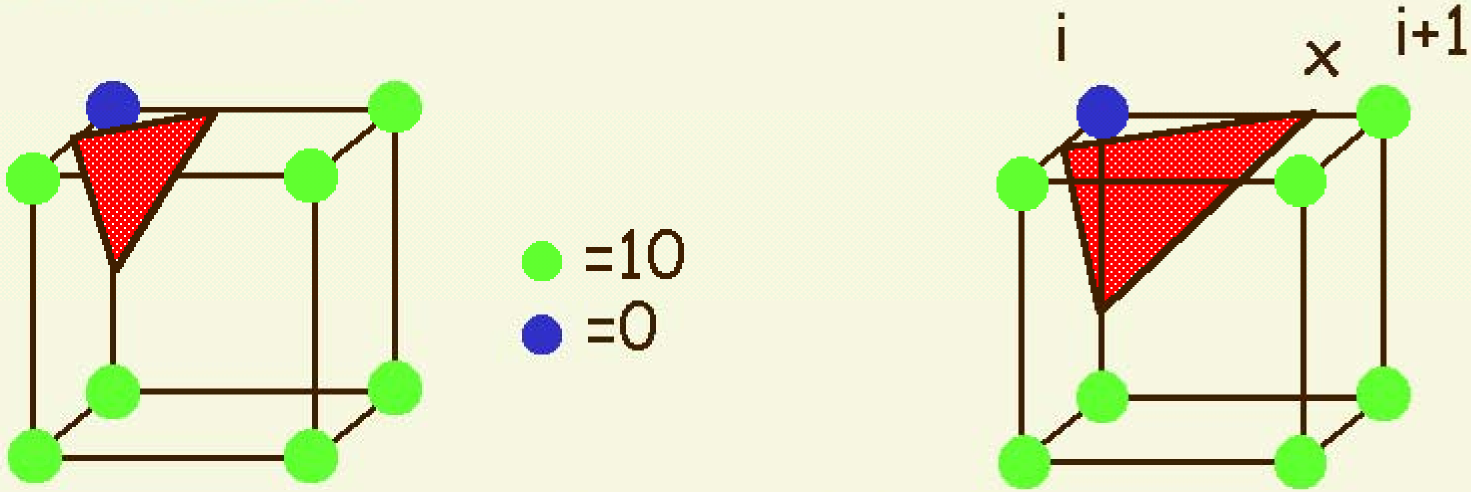
MC 5: Example

- ✓ 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



T=5

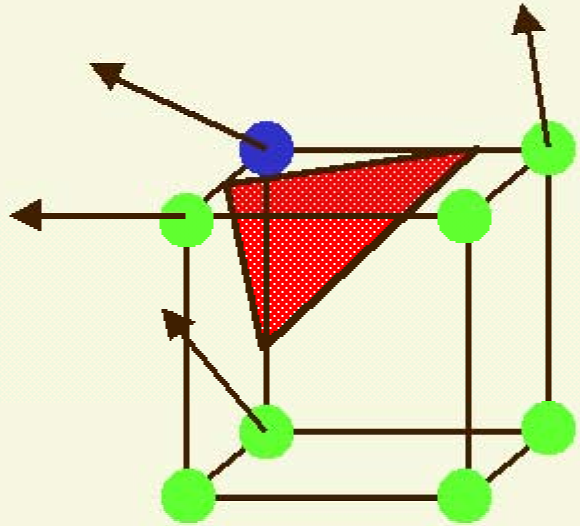
$$x = i + \left(\frac{T - v[i]}{v[i+1] - v[i]} \right)$$

T=8

MC 7: Compute Normals

- Calculate the normal at each cube vertex

$$G_x = V_{x-1,y,z} - V_{x+1,y,z}$$
$$G_y = V_{x,y-1,z} - V_{x,y+1,z}$$
$$G_z = V_{x,y,z-1} - V_{x,y,z+1}$$

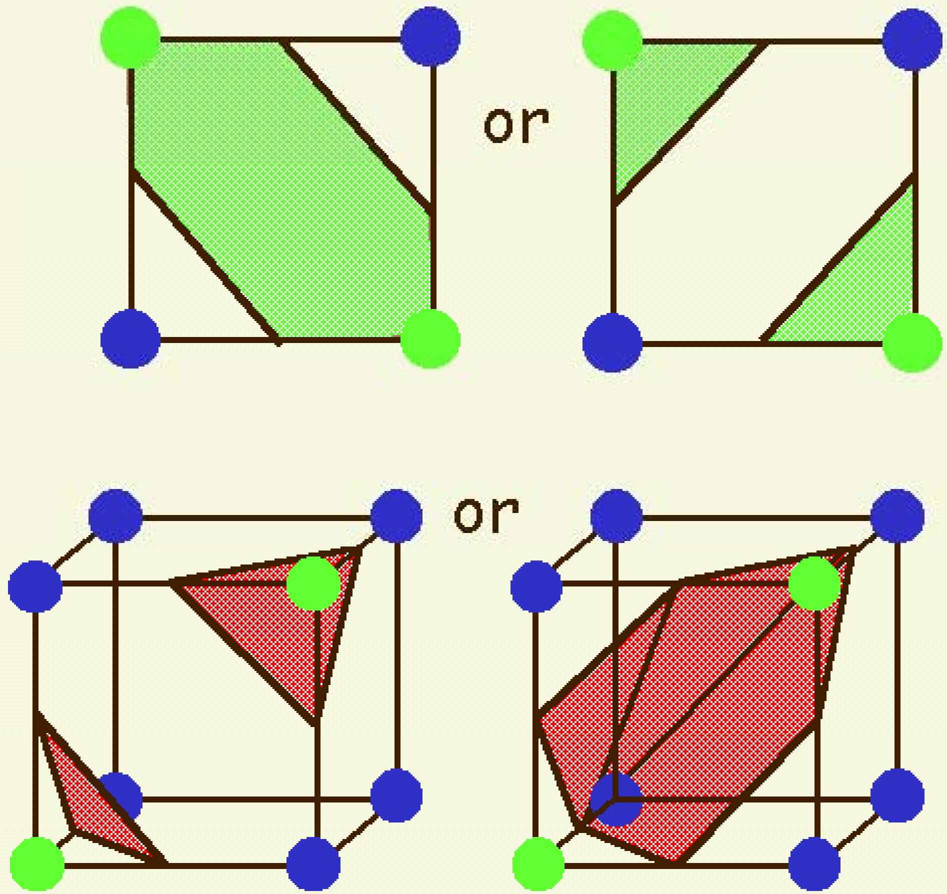


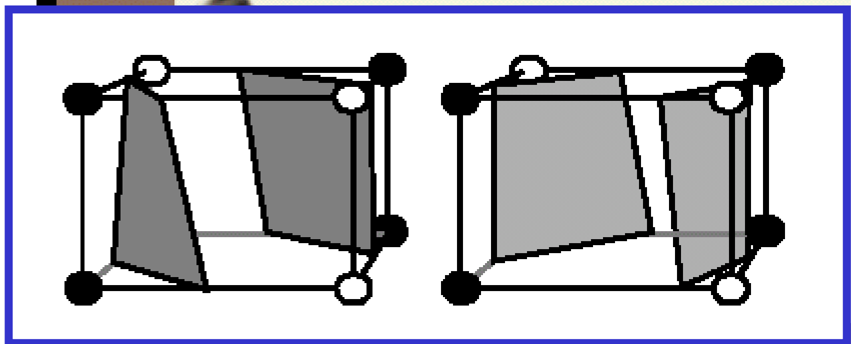
$$\vec{N} = \frac{\vec{G}}{|\vec{G}|}$$

- Use linear interpolation to compute the polygon vertex normal

MC 8: Ambiguous Cases

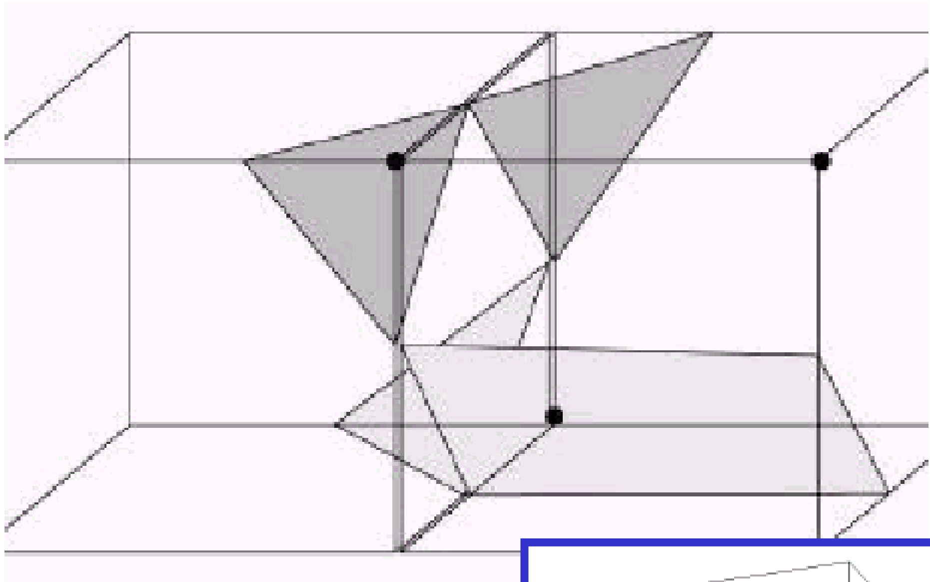
- Ambiguous cases: 3, 6, 7, 10, 12, 13
- Adjacent vertices: different states
- Diagonal vertices: same state
- Resolution: decide for one case

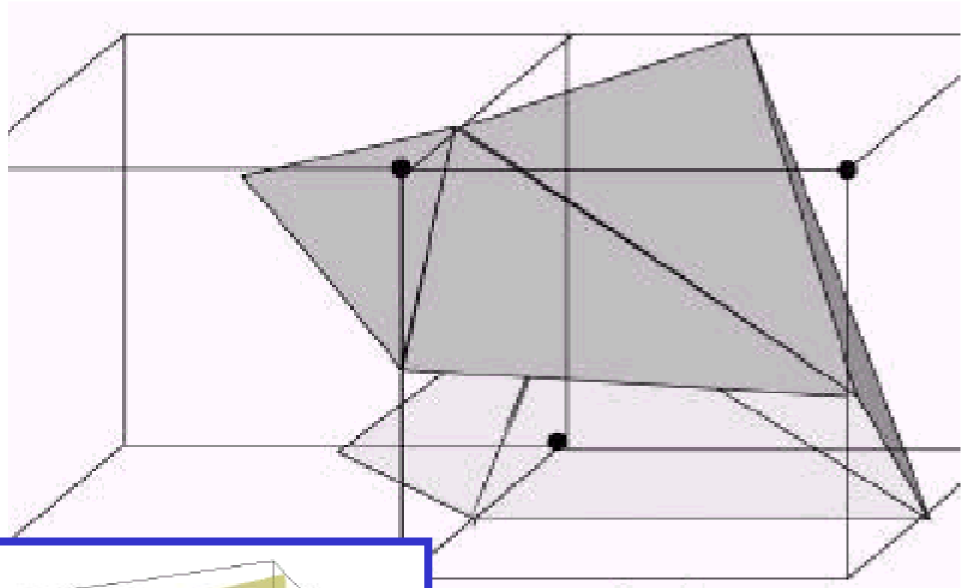




Danger: Holes!

- Wrong vs. correct classification!





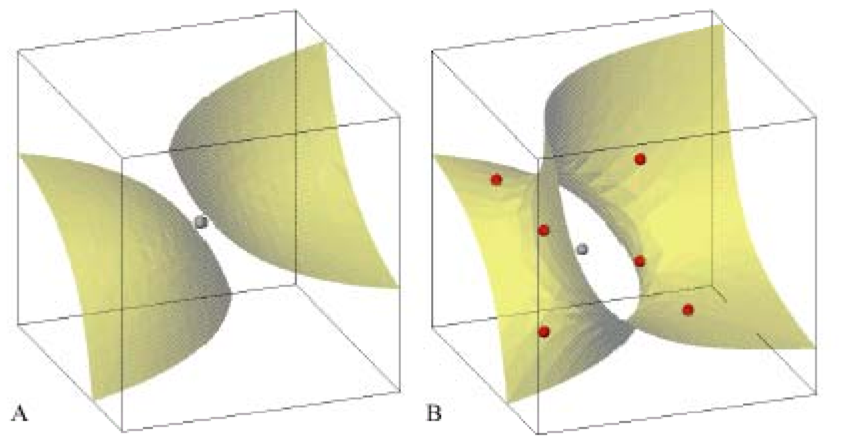
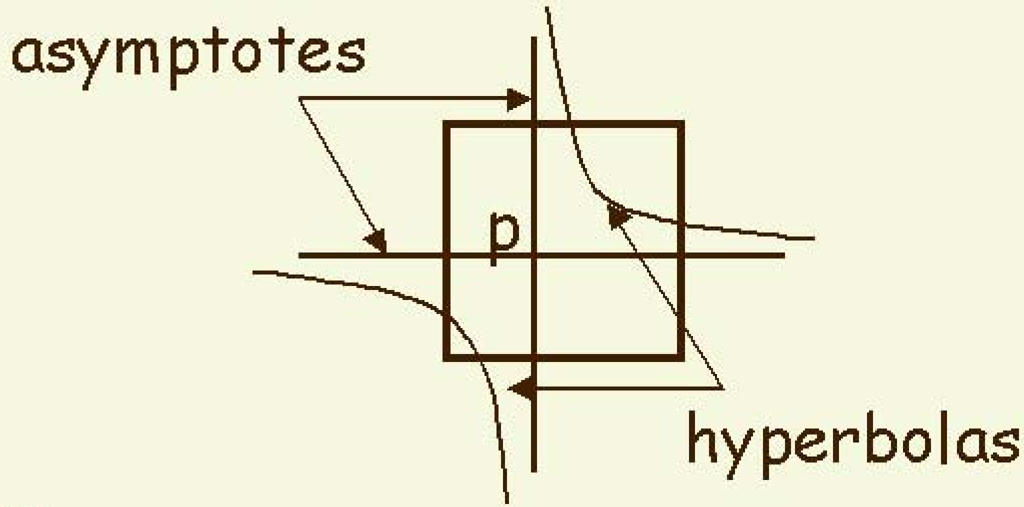


Figure 4: *Two internal configurations for the Marching Cubes configuration 5*

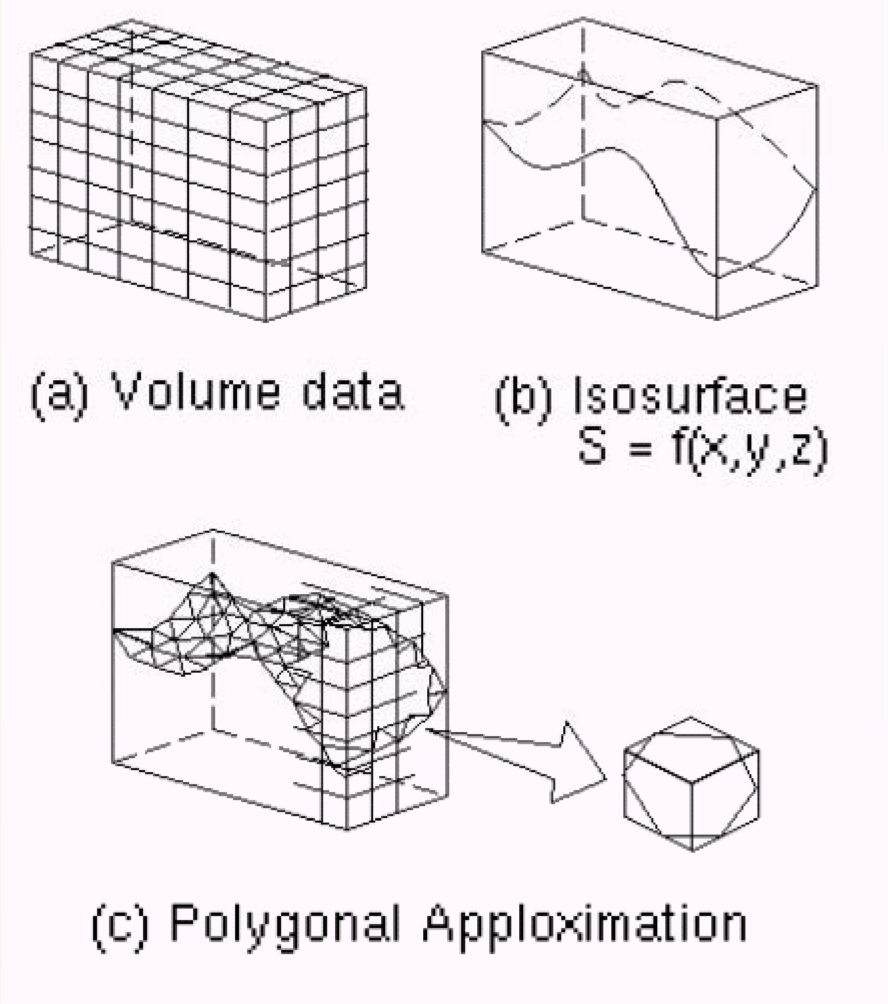
MC 9: Asymptotic Decider

- ✓ 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



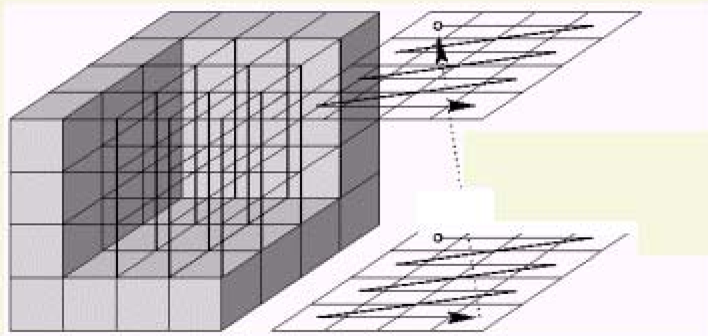
Marching Cubes - Summary 1

- 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.



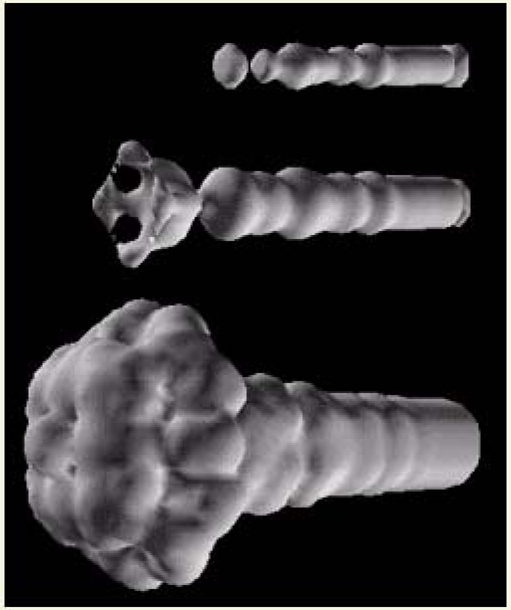
Marching Cubes - Summary 2

- ✓ 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

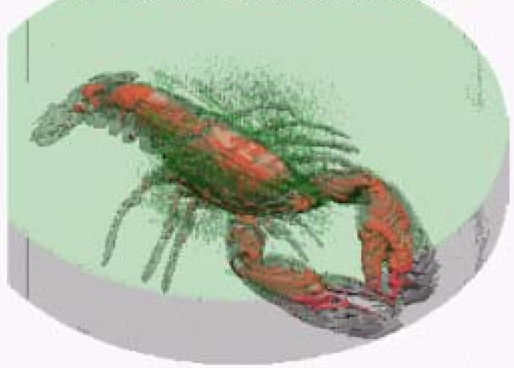


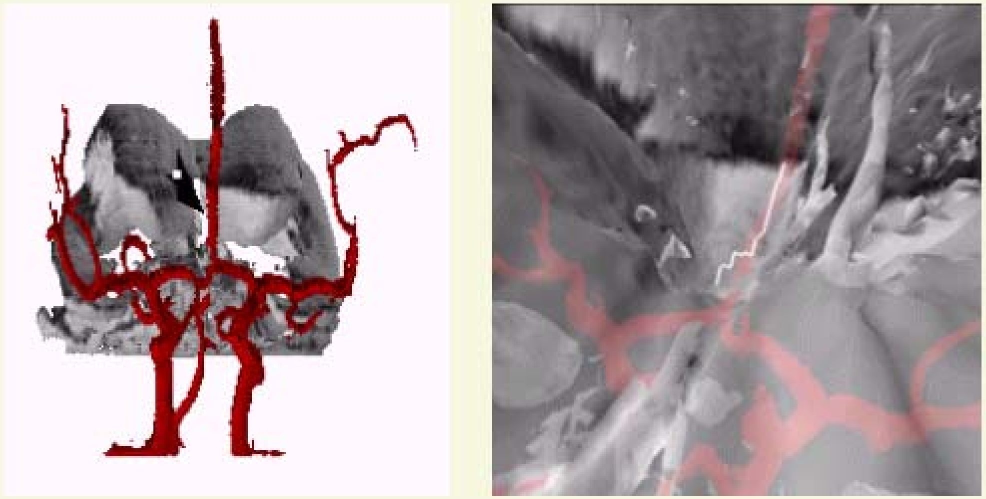
MC Examples

1 Iso-surface



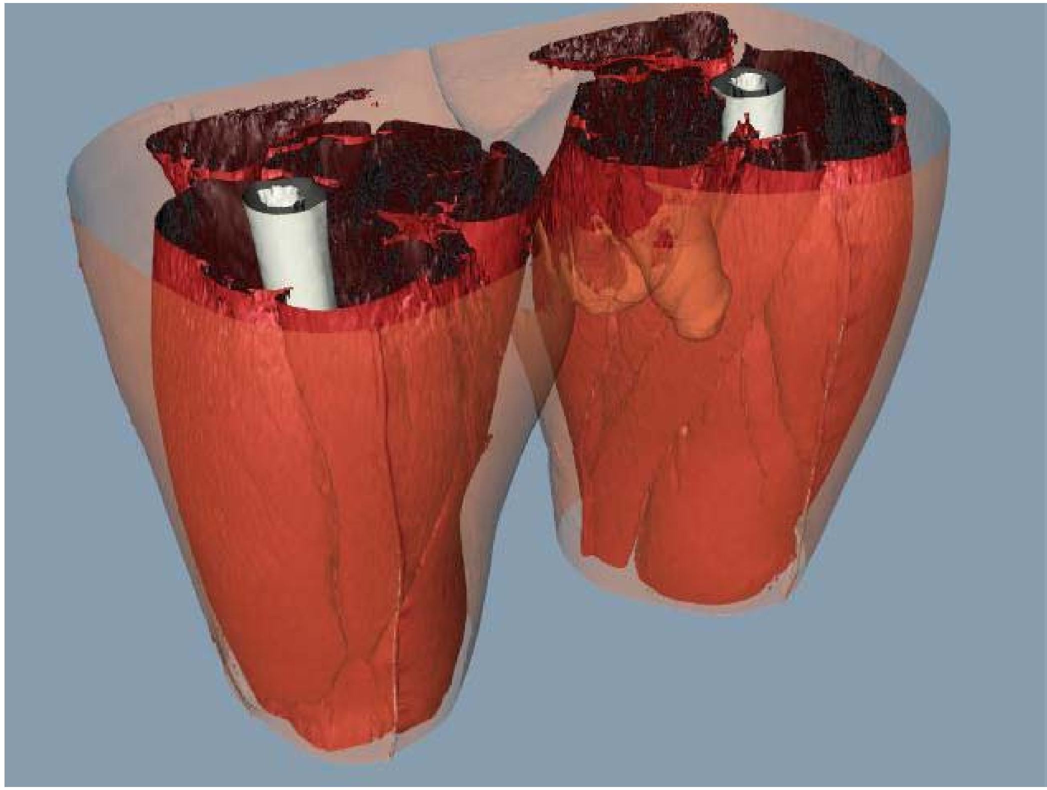
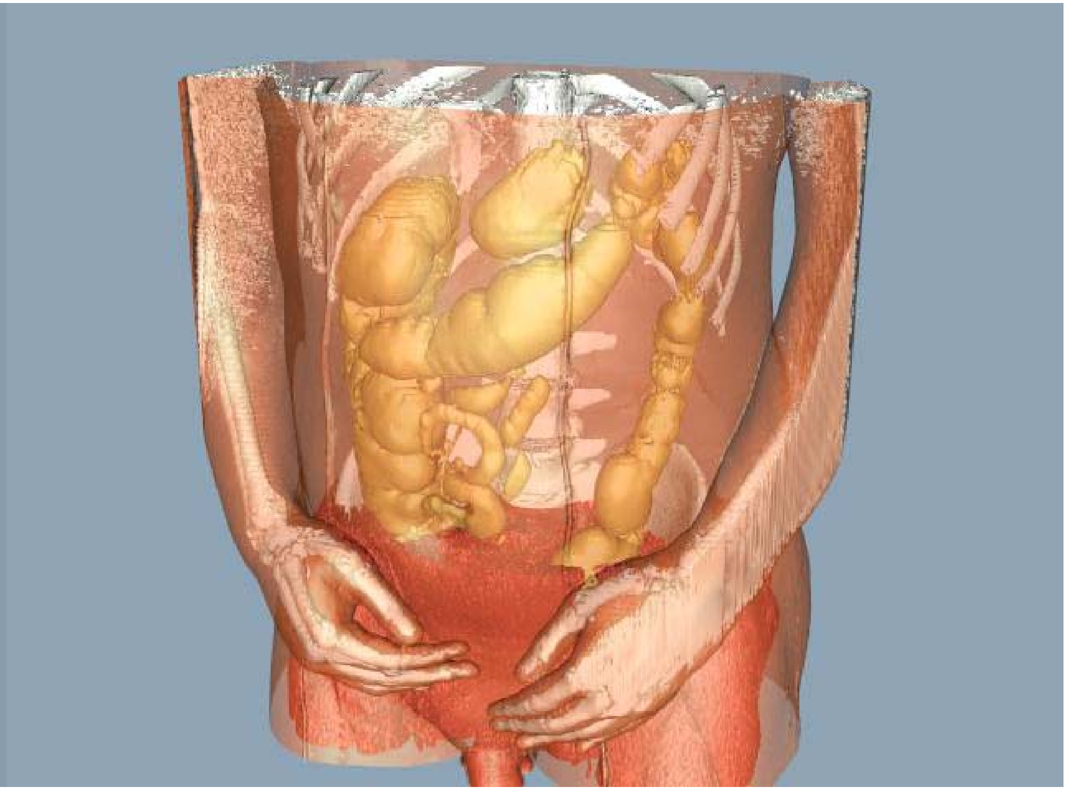
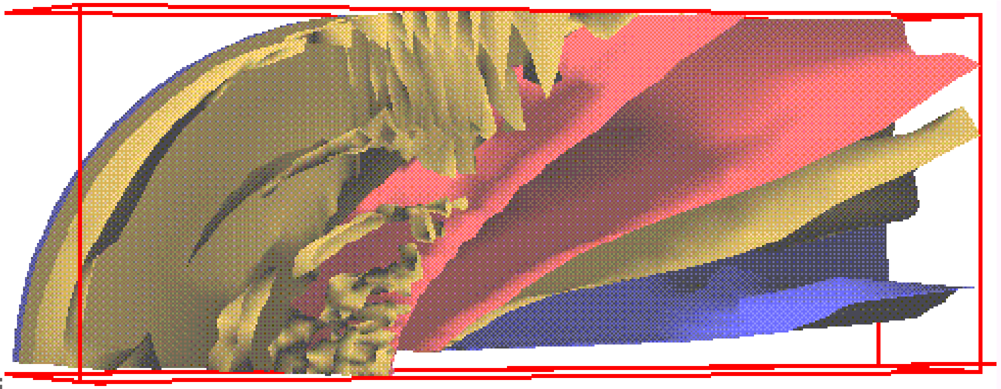
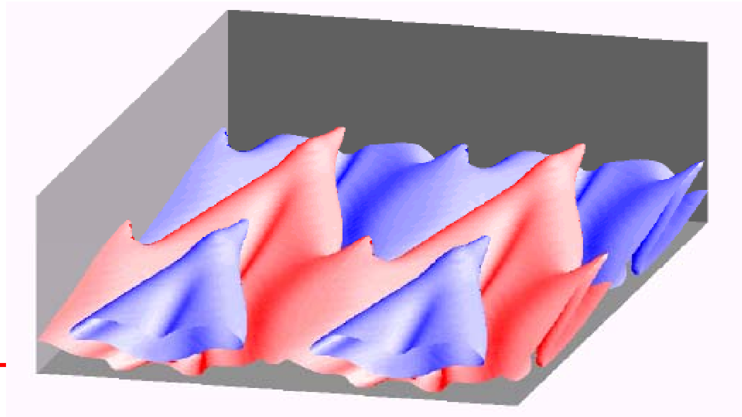
3 Iso-surfaces



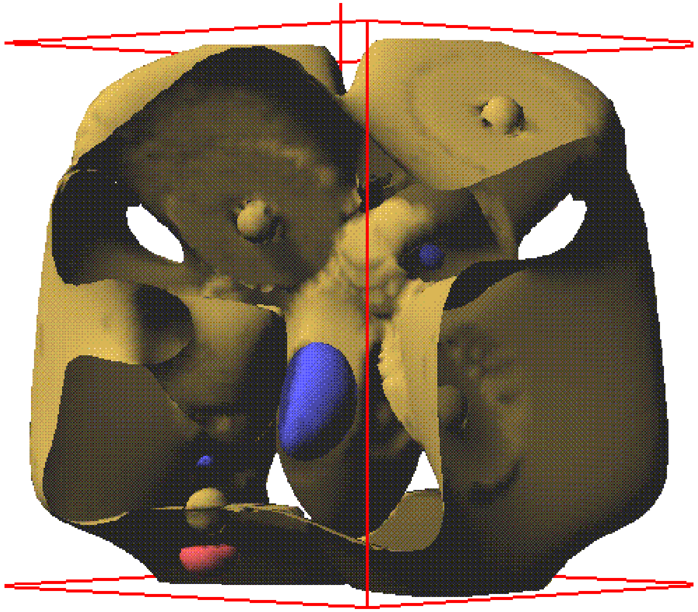


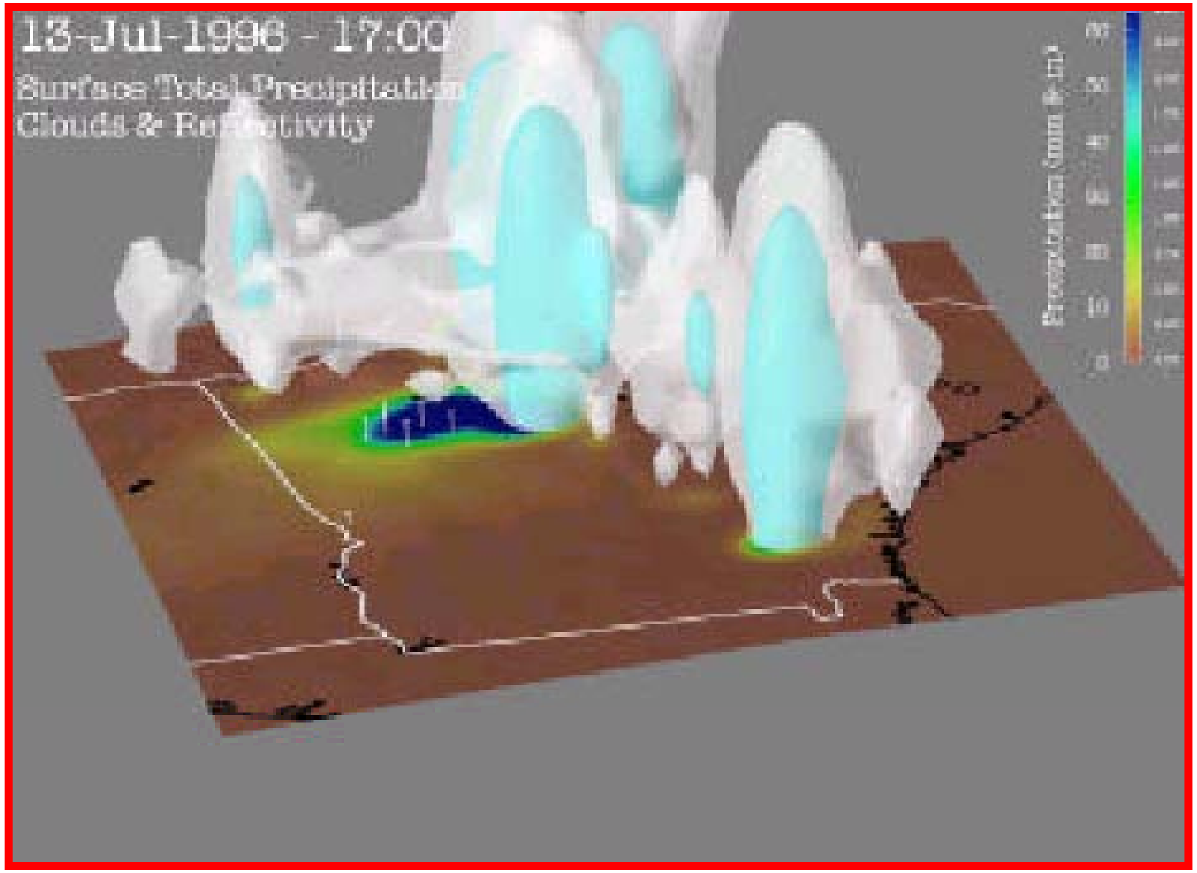
2 Iso-surfaces

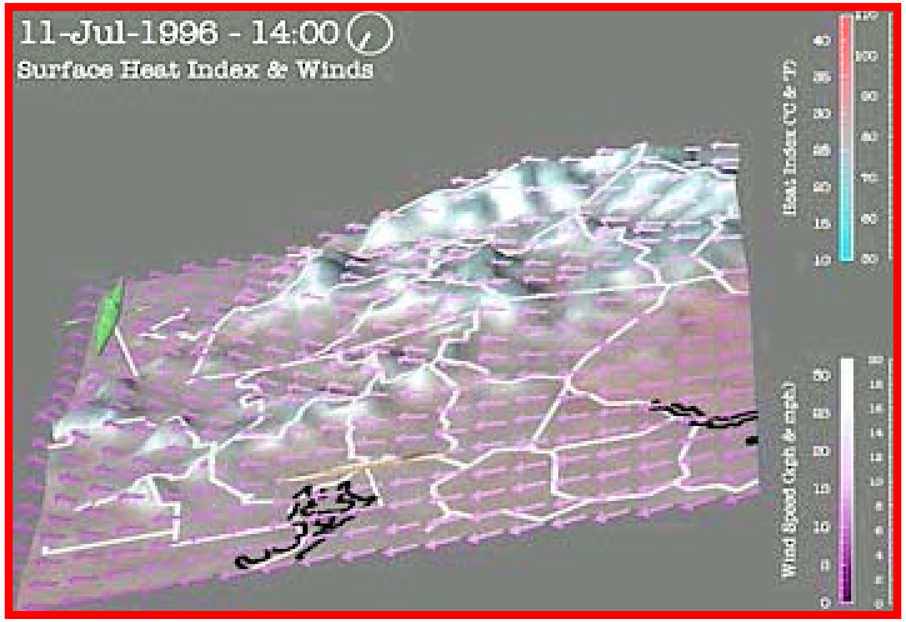
Further Examples

Even Further Examples







Literature

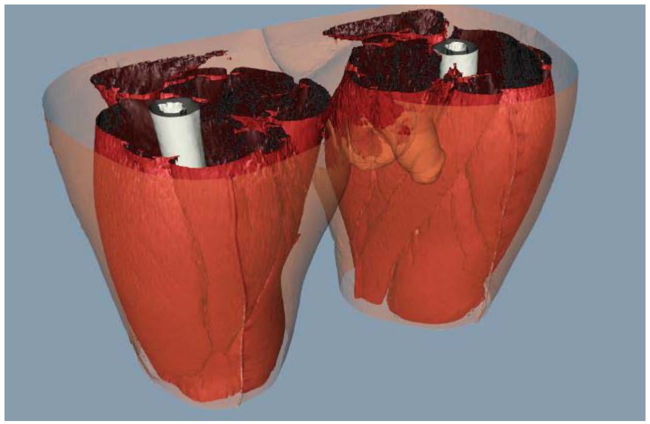
- Paper (more details):
  - W. Lorensen & H. Cline: "**Marching Cubes: A High Resolution 3D Surface Construction Algorithm**" in *Proceedings of ACM SIGRRAPH '87 = Computer Graphics*, Vol. 21, No. 24, July 1987

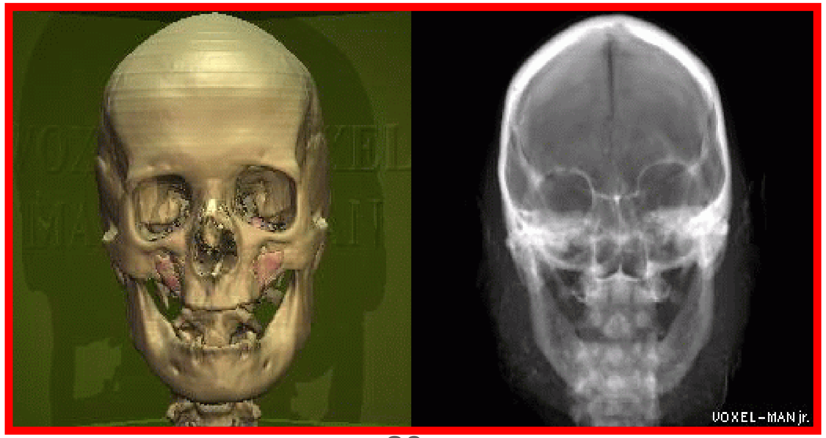
Conclusion
Volume Visualization

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





Conclusion VolVis

- Introduction ⇐ data, simple methods
  ⇐ DVR vs. surf. fitting
- Direct volume visualization
  - Ray casting ⇐ types of combinations
    ⇐ object-order vs. image-order
  - Splatting ⇐ speed vs. quality
  - Shear-warp factorization
  - Hardware-based VolVis
- Indirect VolVis
  ⇐ iso-value selection
  - Marching cubes (iso-surface-visualization)
- Conclusion

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