CSCI 4550/6550 Interactive Visualization

https://www.cs.rpi.edu/~cutler/classes/visualization/S24/

Lecture 15: Volume Visualization

https://www.vox.com/2015/1/12/7533155/ge-ct-scans

Today

- Homework 7: Volume Visualization: What do we want to visualize?
- Isocontours & Implicit Surfaces
  - Surface/Triangle Mesh → Signed Distance Field: Fast Marching Method
- Voxels: Volumetric Elements / Data
  - Signed Distance Field → Surface/Triangle Mesh: Marching Cubes
- Papers for Today (& an extra paper)
  - "A Survey of Algorithms for Volume Visualization"
  - "Intuitive Exploration of Volumetric Data Using Dynamic Galleries"
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  - "Anisotropic Ambient Volume Shading"
- Readings for Tuesday

Homework 7: Volume Visualization Using Paraview

- *The last non-final project assignment*
- Download and experiment with Paraview
  - Based on VTK: The Visualization Toolkit from Kitware, an open-source software company *in Clifton Park, NY (with lots of RPI alums!)*
- Start with the Paraview Tutorial & sample datasets
- Experiment with settings, take screenshots
- Try your hand at creating your own input dataset
  - generated input is probably easiest
  - or construct a real-world dataset!
- Write a short review of the tool

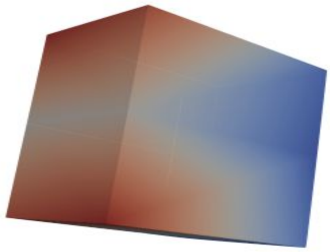


Figure 1: Frame 17 of the visualization

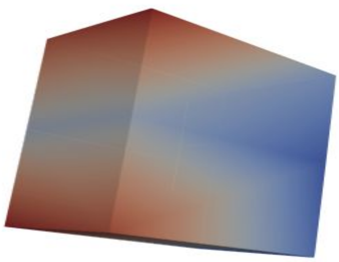


Figure 2: Frame 18 of the visualization

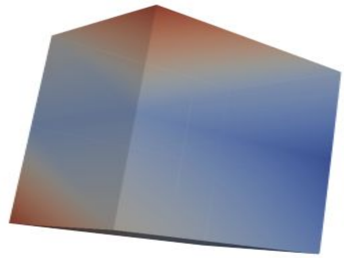


Figure 3: Frame 19 of the visualization

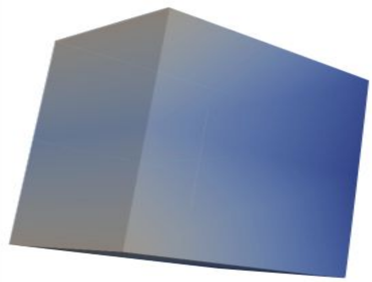
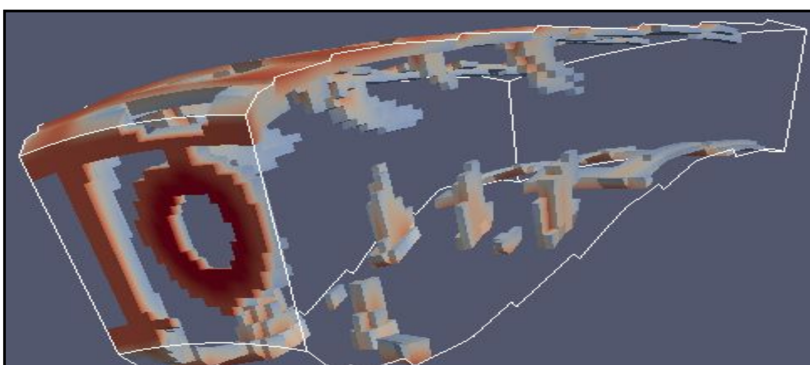


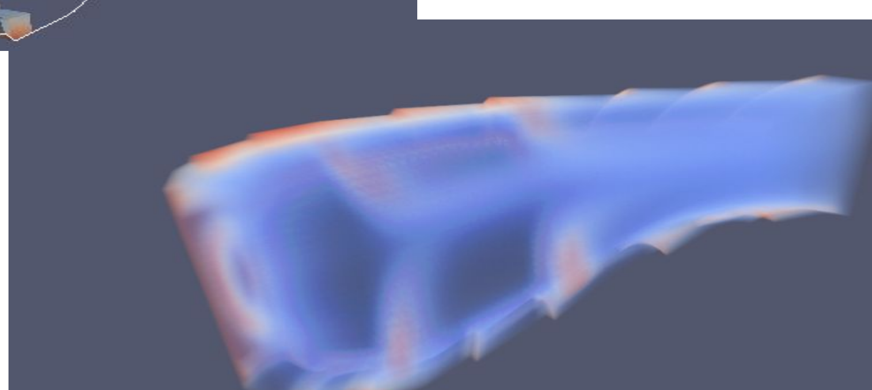
Figure 4: Frame 20 of the visualization

Visualize data values on the surface of a volume

Using VTK HW - Elsa

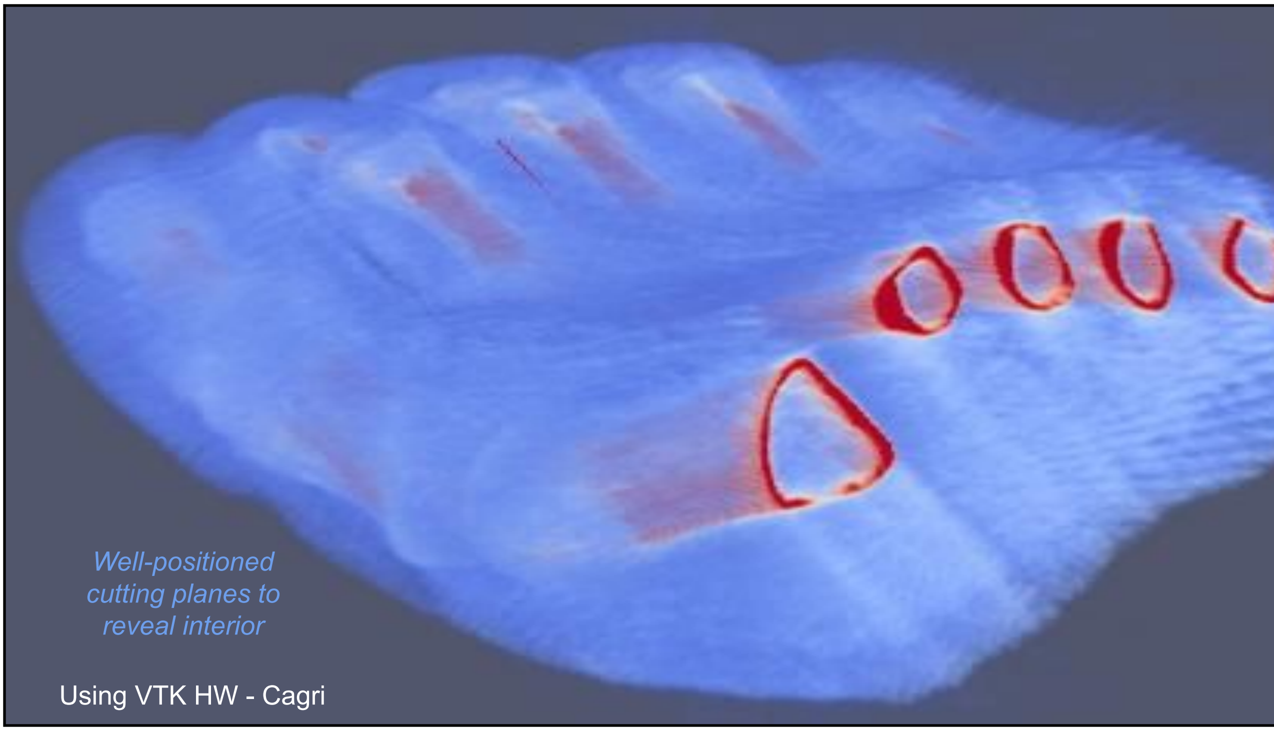


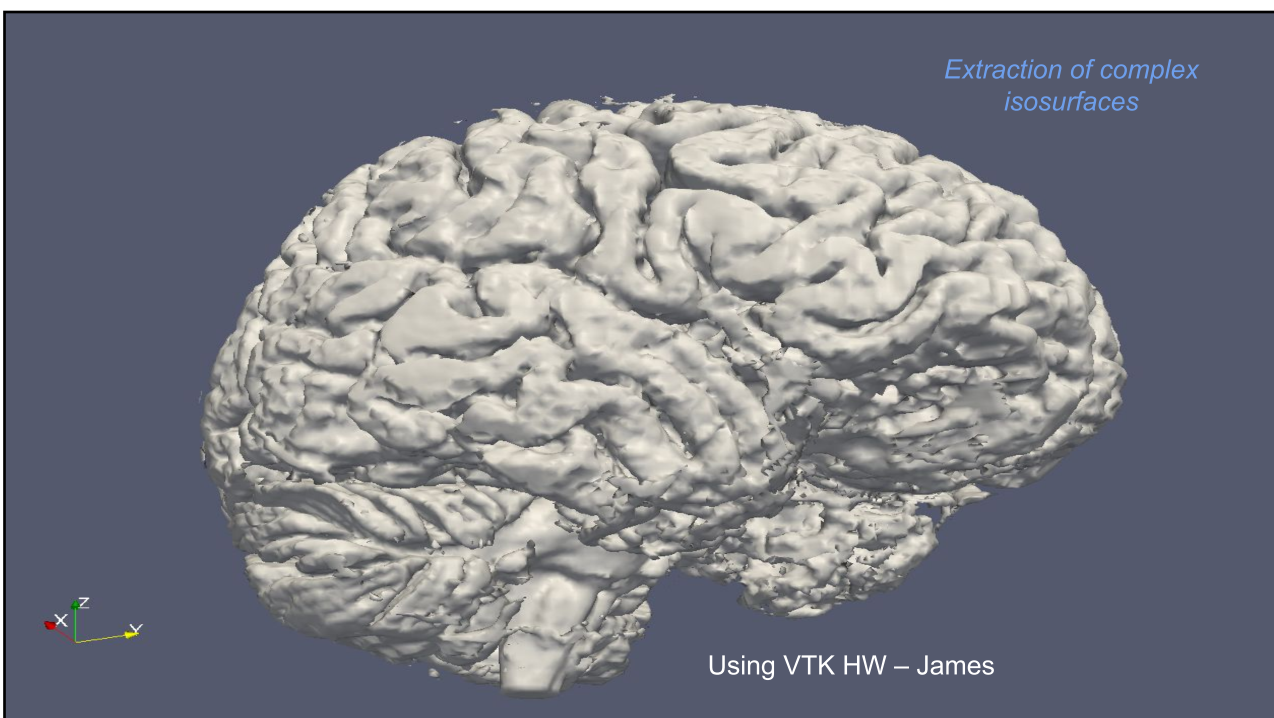
Threshold and show/hide cells

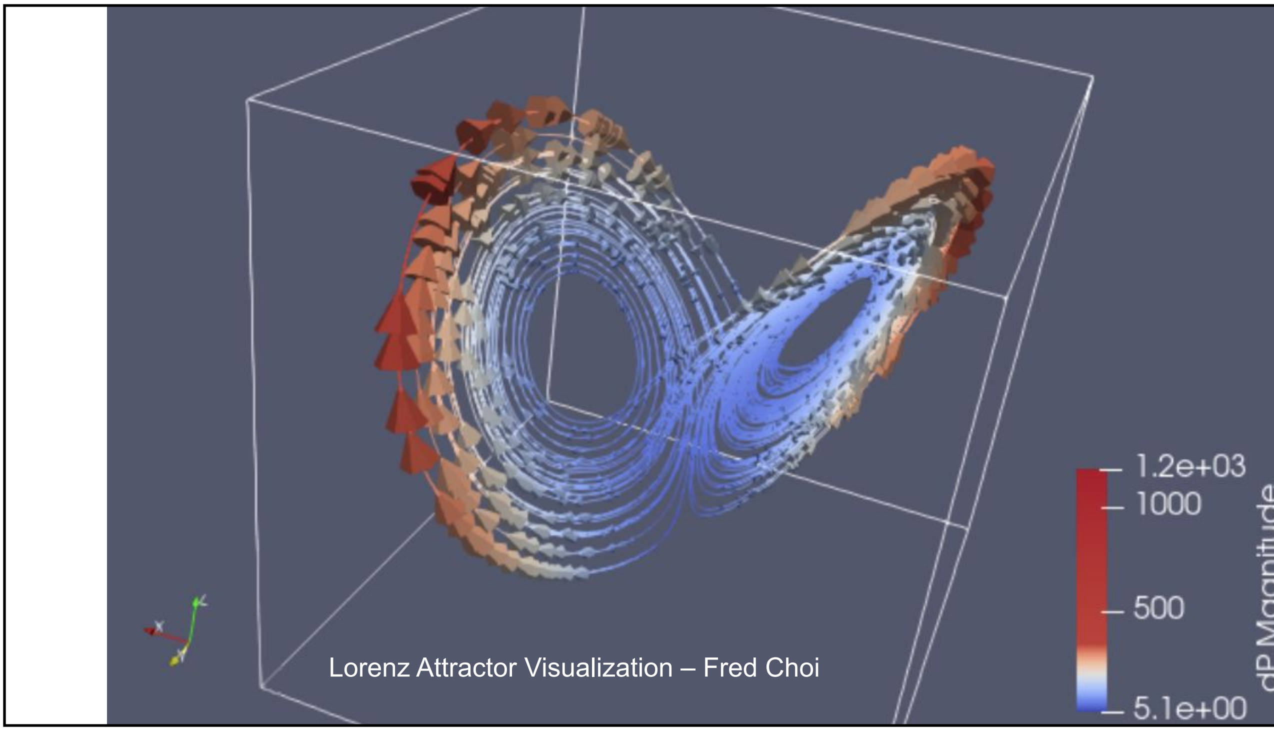


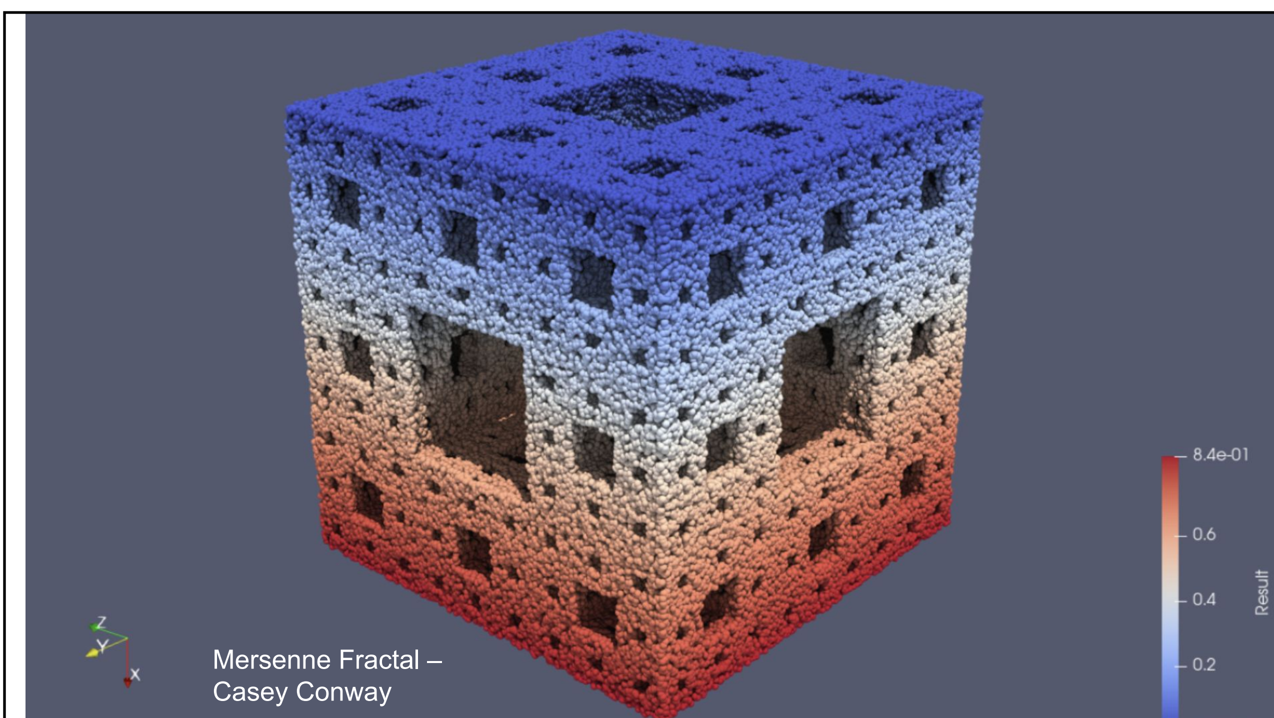
Transparency

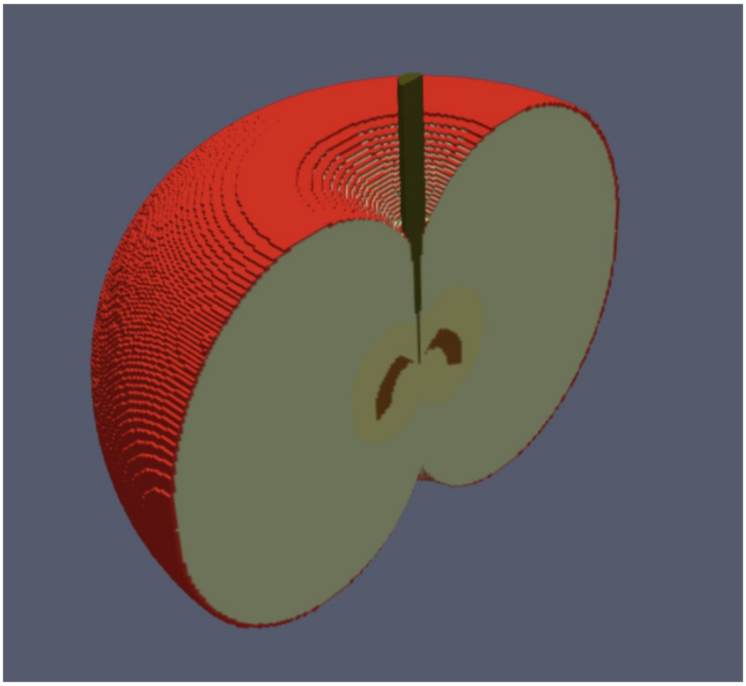
Using VTK HW - Artem

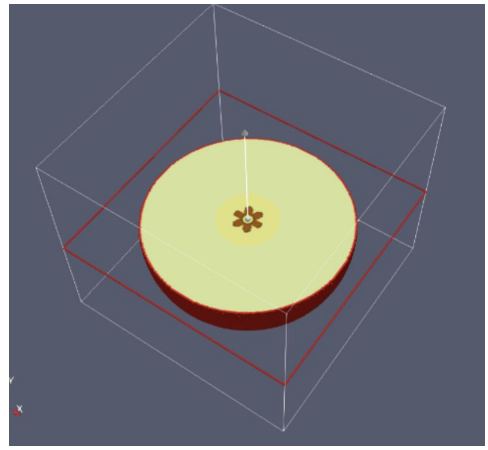

Well-positioned cutting planes to reveal interior
Using VTK HW - Cagri


Extraction of complex isosurfaces
Z
X
Y
Using VTK HW – James


1.2e+03
1000
500
5.1e+00
dP Magnitude
Lorenz Attractor Visualization – Fred Choi


8.4e-01
0.6
0.4
0.2
Result
Mersenne Fractal –
Casey Conway





Kevin MacKenzie

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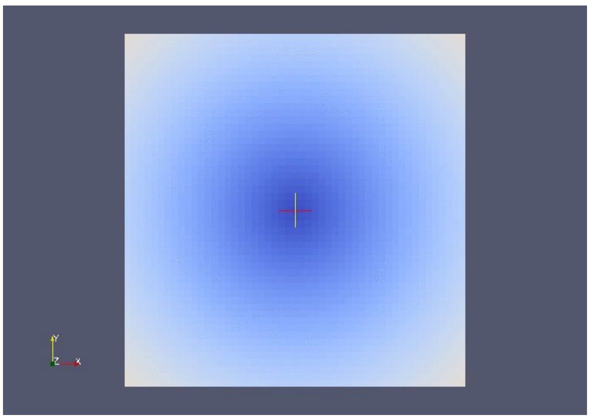
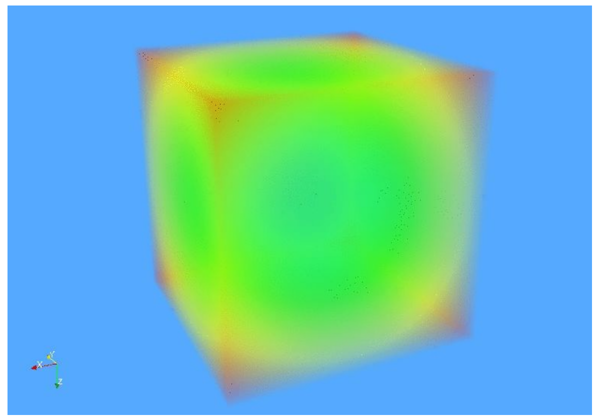
Isocontours / Isosurfaces

- "iso-" (from Greek word meaning 'equal')
- Determine everywhere in a data set that the data equals a specified value

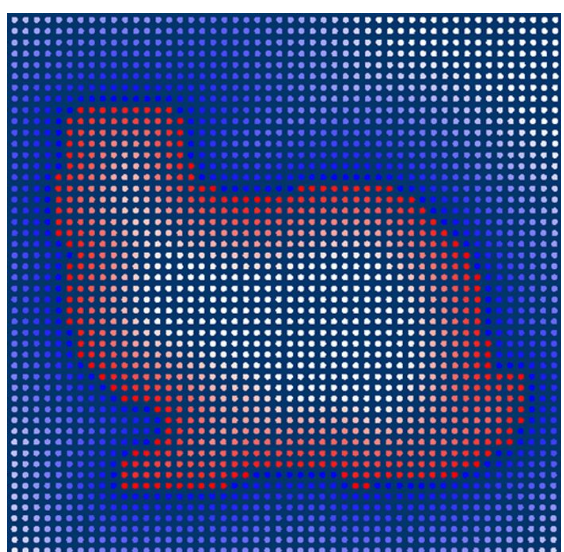




Implicit Surfaces

Normally we focus on modeling surfaces with triangle meshes separating "inside" from "outside"

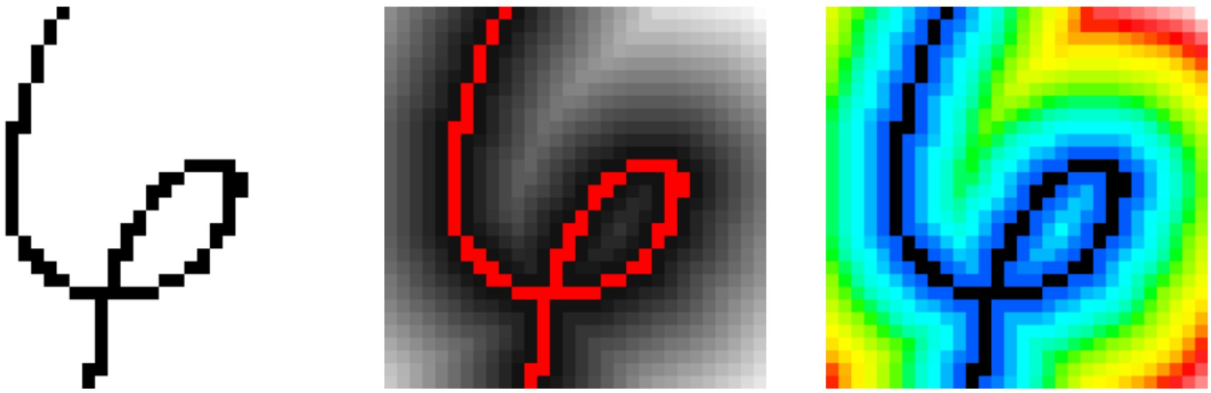
- For a sphere:
  $H(x,y,z) = x^2 + y^2 + z^2 - r^2$
- If $H(x,y,z) = 0$, on surface
- If $H(x,y,z) > 0$, outside surface
- If $H(x,y,z) < 0$, inside surface



Computing a Signed Distance Field

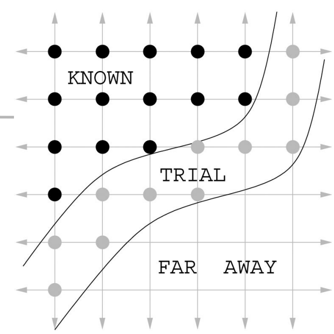
- Given a shape/surface
- Cost to compute shortest distance to original shape for each point (on a grid) in the volume?

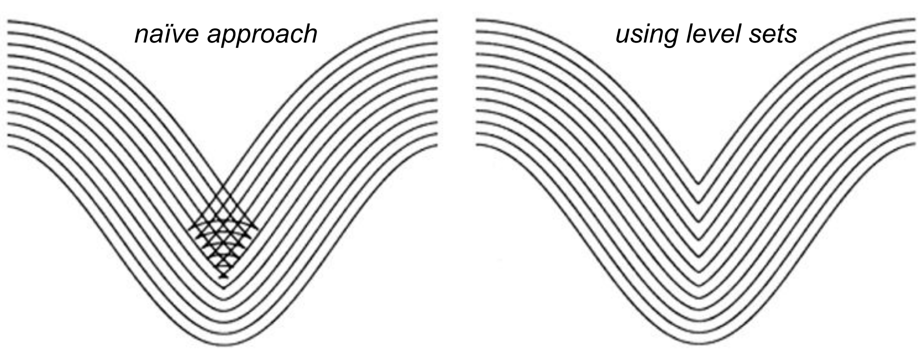
*Naive: O(# of volume grid samples * # of surface elements)*
$w*h * w*h = O(w^2h^2)$!!



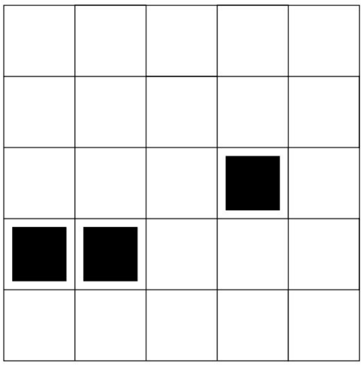
Level Sets

- *Level Set Methods and Fast Marching Methods*, Sethian, 1999
- *Efficient method for computing signed distance field*

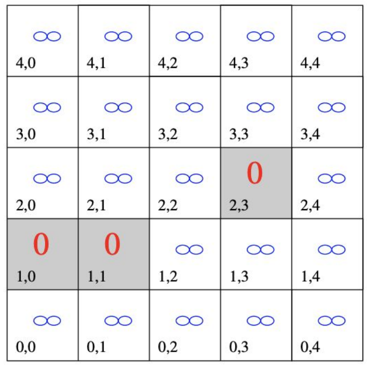




A Data Structures Homework



input image

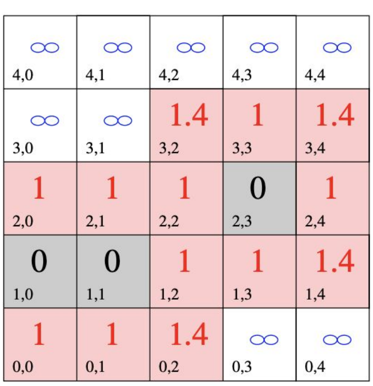


initialization of the signed distance field

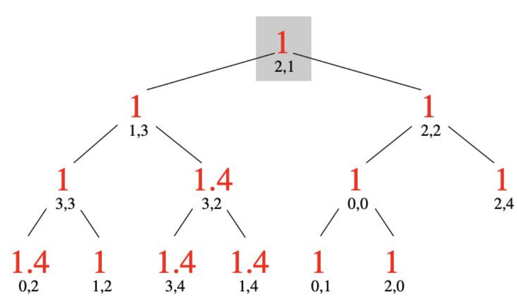
Initially, only the surface pixels are "known" to have distance = 0

https://www.cs.rpi.edu/academics/courses/fall18/csci1200/hw/10_level_sets/hw.pdf

A Data Structures Homework



propagating initial values



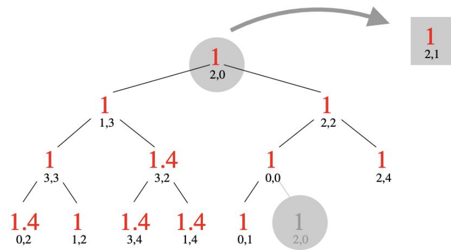
initial priority queue of pixels

We compute the distance of all neighbors of these "known" pixels

Put all these new pixels in a priority queue, ordered by distance

A Data Structures Homework

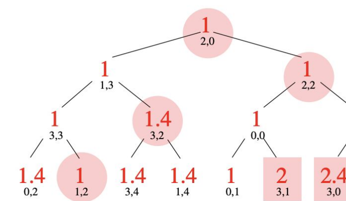
Grab the top item from the priority queue...



after popping & fixing the top value, grab the last leaf & percolate down

∞ 4,0	∞ 4,1	∞ 4,2	∞ 4,3	∞ 4,4
2.4 3,0	2 3,1	1.4 3,2	1 3,3	1.4 3,4
1 2,0	1 2,1	1 2,2	0 2,3	1 2,4
0 1,0	0 1,1	1 1,2	1 1,3	1.4 1,4
1 0,0	1 0,1	1.4 0,2	∞ 0,3	∞ 0,4

propagate fixed value to neighbors



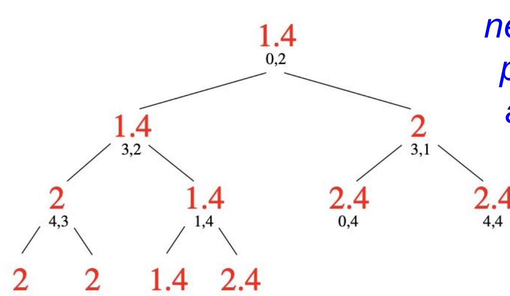
adjust existing values & add new values to the priority queue

Lock its value, and update its immediate neighbors

A Data Structures Homework

∞ 4,0	∞ 4,1	2.4 4,2	2 4,3	2.4 4,4
2 3,0	2 3,1	1.4 3,2	1 3,3	1.4 3,4
1 2,0	1 2,1	1 2,2	0 2,3	1 2,4
0 1,0	0 1,1	1 1,2	1 1,3	1.4 1,4
1 0,0	1 0,1	1.4 0,2	2 0,3	2.4 0,4

after fixing all pixels <= 1



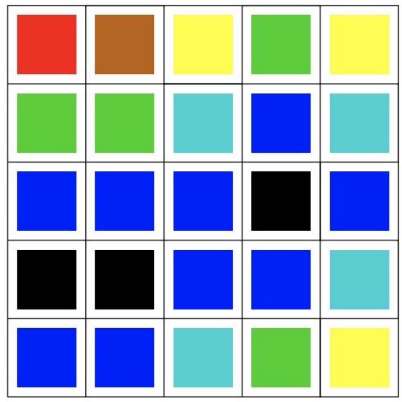
priority queue after fixing all pixels <= 1

Grab the next pixel in the priority queue and repeat…

A Data Structures Homework

3 (4,0)	2.8 (4,1)	2.4 (4,2)	2 (4,3)	2.4 (4,4)
2 (3,0)	2 (3,1)	1.4 (3,2)	1 (3,3)	1.4 (3,4)
1 (2,0)	1 (2,1)	1 (2,2)	0 (2,3)	1 (2,4)
0 (1,0)	0 (1,1)	1 (1,2)	1 (1,3)	1.4 (1,4)
1 (0,0)	1 (0,1)	1.4 (0,2)	2 (0,3)	2.4 (0,4)

final distance field



output image

Final result: Every pixel stores the (approximate) shortest distance to the original surface (black pixels)

Fast Marching Method:
*O(# of volume grid samples * log (# of surface elements))*
*O(wh*log(w*h))*

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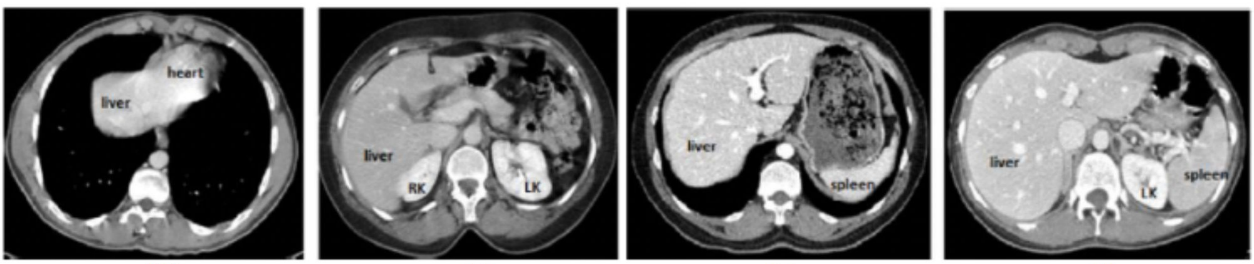
Application: Medical Imaging

- Input: a stack of 2D images, closely spaced parallel "slices" of the 3D object
- Step 1: Segment the different regions (by density / color / texture)
- Step 2: *Marching Cubes!*

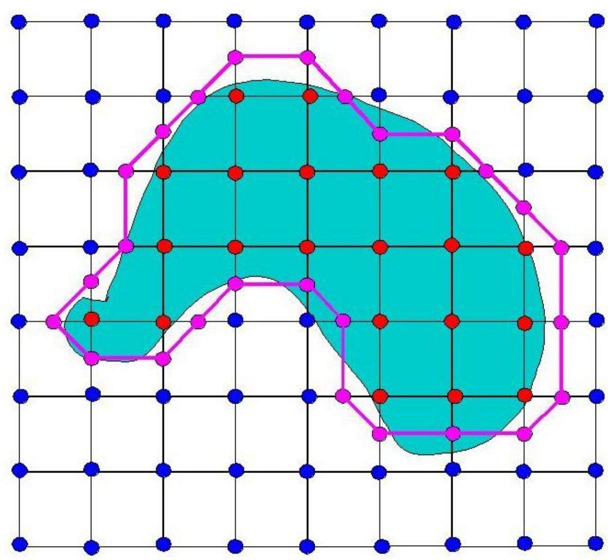


(a) (b) (c) (d)

https://chaos.grand-challenge.org/Data/

Marching Cubes

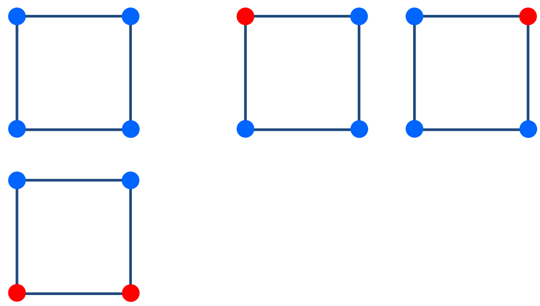
- Each point in the 3D grid is labeled "inside" (red dots) or "outside" (blue dots) the unknown surface.
- Any cell in the grid that has at least one red vertex and at least one blue vertex, must be crossed by the unknown surface.
- We can piecewise construct an approximation of the surface.



http://www.cs.carleton.edu/cs_comps/0405/shape/marching_cubes.html

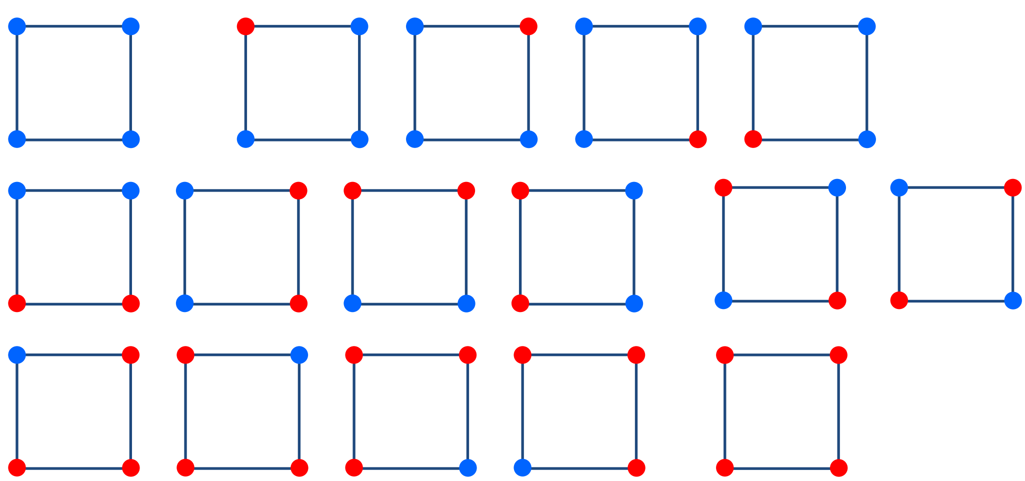
Enumerate Cases in 2D?

- How many cases?
- How many unique cases (excluding rotations)?



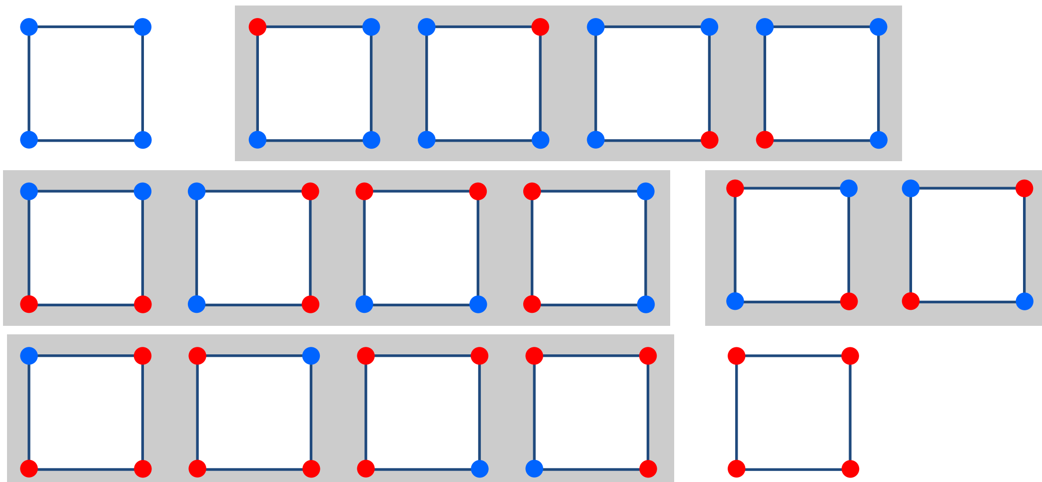
Enumerate Cases in 2D?

- How many cases? **$2^4 = 16$**
- How many unique cases (excluding rotations)?



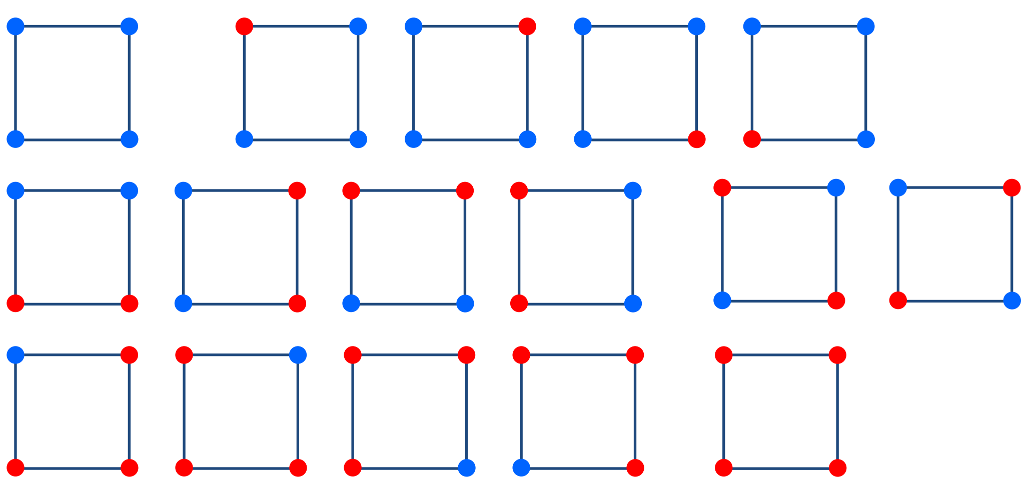
Enumerate Cases in 2D?

- How many cases? **$2^4 = 16$**
- How many unique cases (excluding rotations)? **6**



2D Marching Cubes Volume & Surface

- What portion of the cell is inside of the object?
- Where is the surface separating inside from outside?



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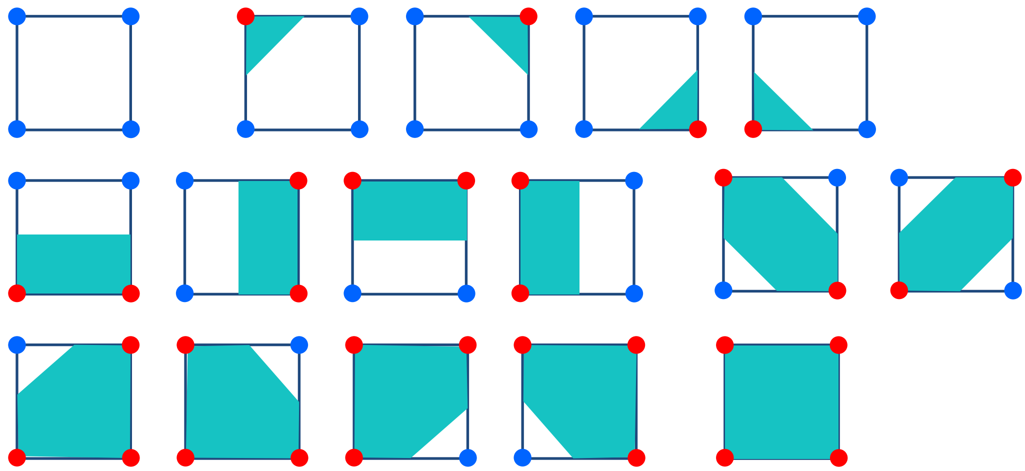
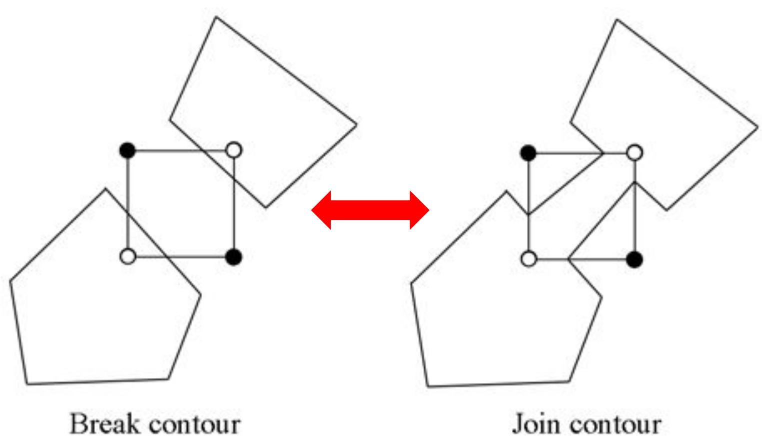


Ambiguity in Marching Cubes

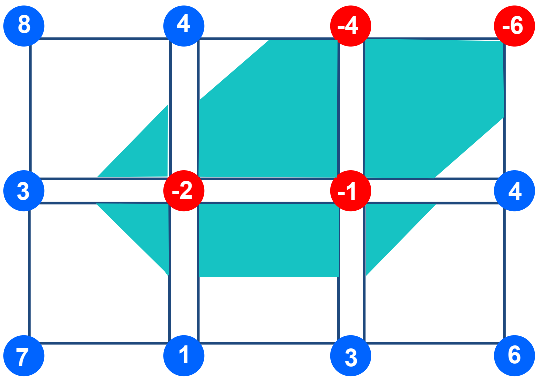
- *An implementation headache:*
- *Both are valid, but…*
- *The choice will affect the global topology of the surface and its connectedness!*

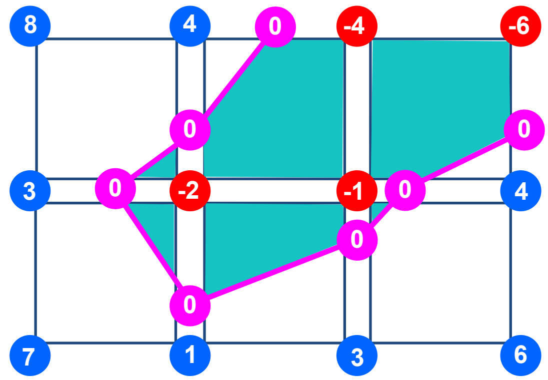


http://users.polytech.unice.fr/~lingrand/MarchingCubes/algo.html

More than Binary – Use Signed Distance Data!

- NOTE: We don't place vertices at the midpoints of cell edges, but at the estimated (interpolated) position of the level set!





… Hint: This will be the Worksheet for Next Week

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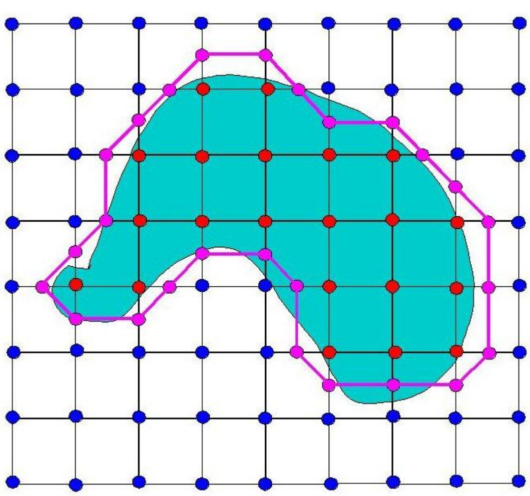
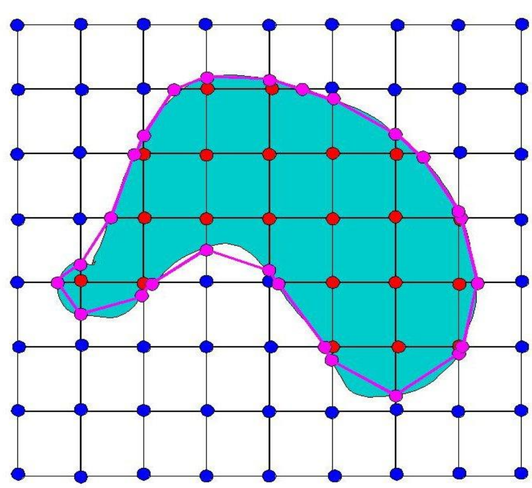


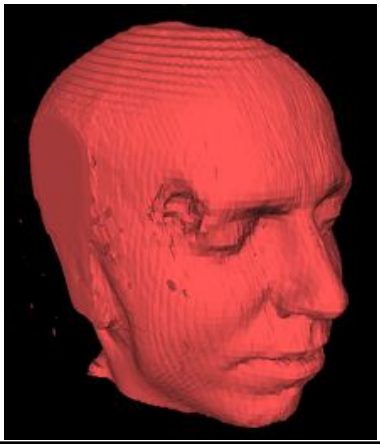


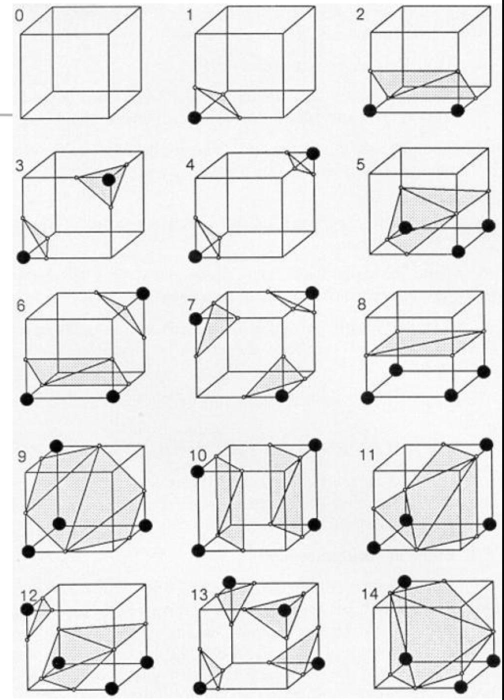
http://www.cs.carleton.edu/cs_comps/0405/shape/marching_cubes.html

3D Marching Cubes

- "Marching Cubes: A High Resolution 3D Surface Construction Algorithm", Lorensen and Cline, SIGGRAPH '87.
- 256 possible inside/outside labelings of each grid cube.
- 15 unique cases to implement

http://en.wikipedia.org/wiki/Marching_cubes





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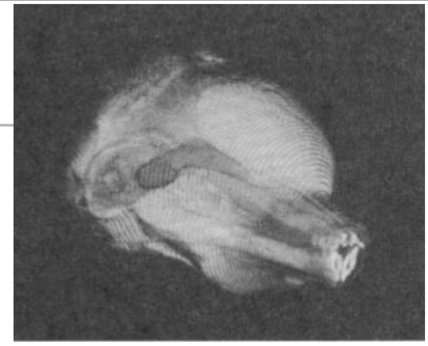
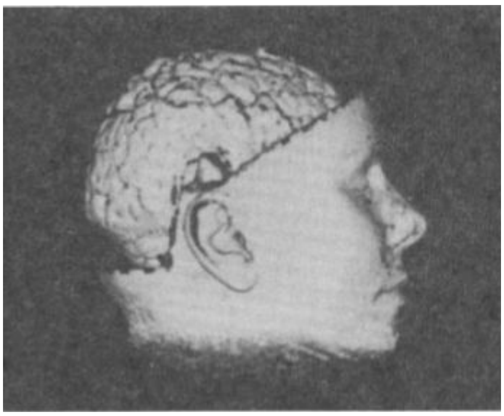
A Reading From Past Terms...

- "A survey of algorithms for volume visualization", T. Todd Elvins, 1992





- Applications in: Geoscience, astrophysics, chemistry, microscopy, mechanical engineering, non-destructive testing
- Types of data: Density, pressure, temperature, electrostatic charge, velocity
- Sources of data: MRI, CT, PET, Sonogram, Laser scan confocal & other microscopes, simulation, created by-hand
- Data is on a 3D lattice, with 1 or more values at each grid point
- Animation is critical: from a static 2D image, it is hard to understand 3D information
- "... in 10 years, all rendering will be volume rendering"
  Jim Kajiya at SIGGRAPH 1991

- Steps in all volume visualization methods
  - Data acquisition
  - Slice pre-processing (adjust contrast, etc)
  - Resample/interpolate (as needed) to proportional 3D volume/grid
  - Data classification (a.k.a. thresholding)
  - Add external elements (e.g., radiation treatment plan, etc.)
  - Mapping to geometric or display primitives
    The key difference between volume visualization algorithms
  - Store, manipulate, transform, shade, display to screen
- Traversal orders: image order (scanline) and
  object order (front-to-back or back-to-front)
- Orthographic (better for DVR) vs perspective
- Photorealism?

Challenges

- Choosing appropriate threshold values &
  Choosing appropriate color & opacity tables
  - Highly dependent on dataset!
    Examine data, choose initial values, visualize, adjust values,
    & repeat as needed
- Avoid rendering artifacts/errors that mislead to incorrect medical diagnoses
- Resolution vs. rendering speed vs. accuracy/errors
- Future work: parallelization, automate data classification, make real-time

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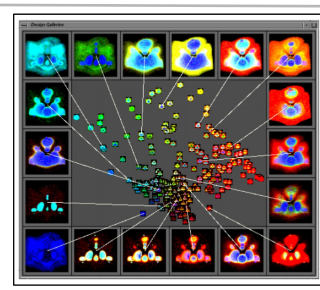
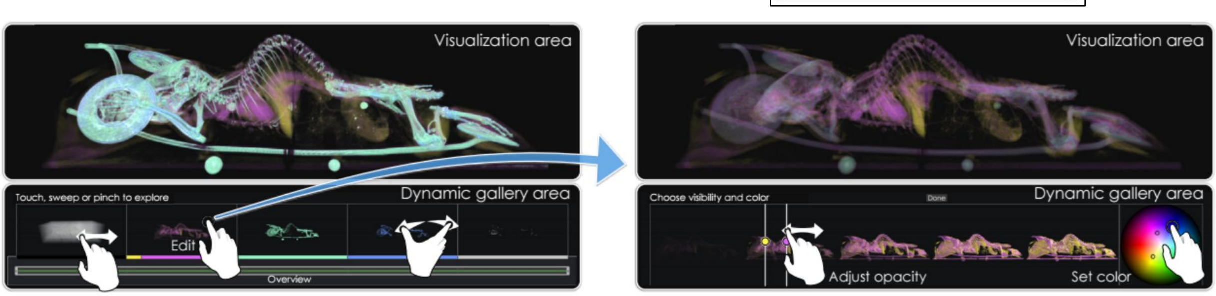
- “Intuitive Exploration of Volumetric Data Using Dynamic Galleries”
  Jönsson, Falk, & Ynnerman
  IEEE Visualization 2015





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  - "Anisotropic Ambient Volume Shading"
- Readings for Tuesday

Reading for Today

- "Interactive Dynamic Volume Illumination with Refraction and Caustics" Magnus & Bruckner, IEEE TVCG 2017

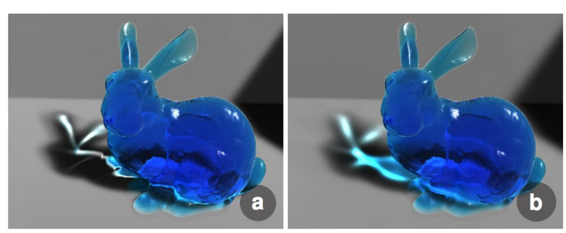


Fig. 3: Effects of light filtering. (a) No filtering. (b) Filtering of light and light direction.

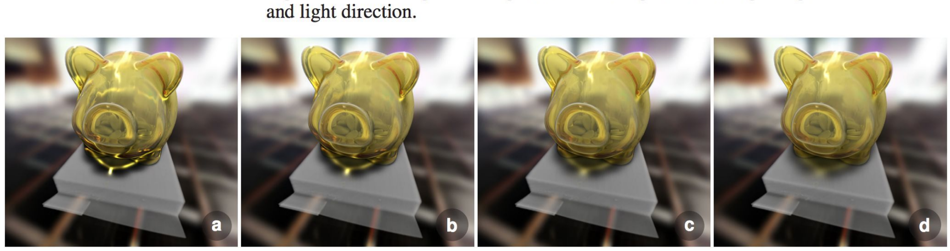


Fig. 7: CT scan of a piggy bank with refraction and combination of transmissive and reflective material properties and increasing light source softness from (a) to (d).

- Snell's law!
- The rendering equation!
- Wyman's GPU trick for approximate single object refraction…
- Parameters:
  - Medium color
  - density of reflective particles
- "... it is not our goal to accurately simulate light transport in participating media, but rather to achieve plausible results at interactive frame rates …"

Provides more choices/tools for the visualization designer: opacity vs. medium color

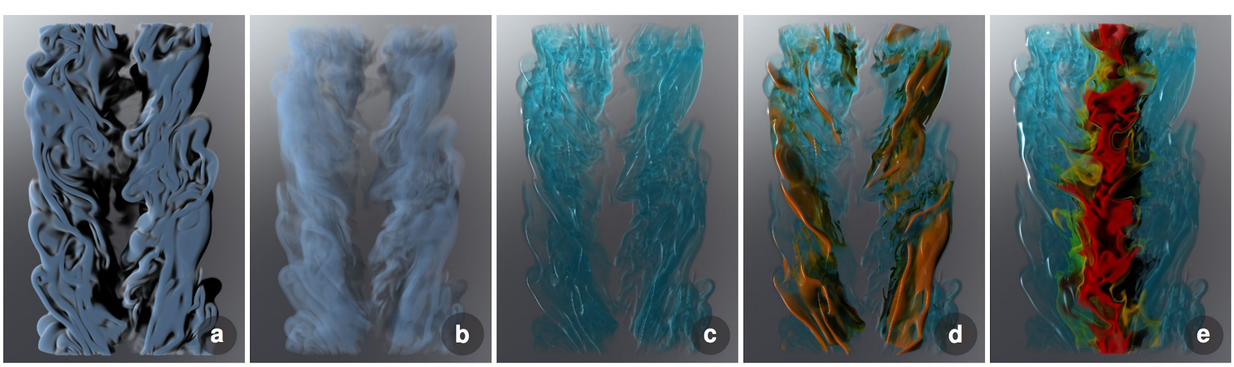
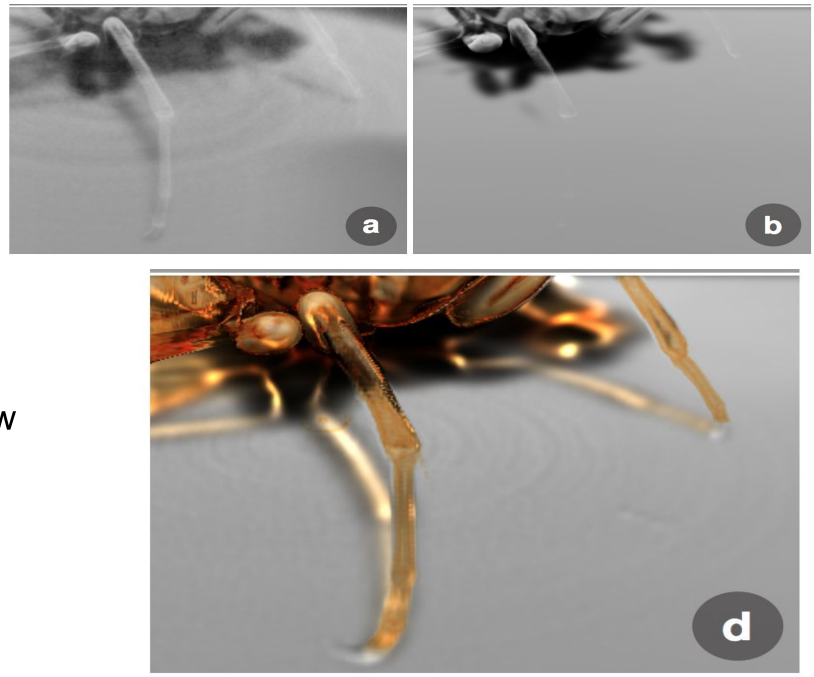


Fig. 12: A timestep of a combustion simulation. In (a) and (b), the chi variable is mapped to opacity, while in (c) the index of refraction is used instead, providing an overview visualization without introducing occlusion. (d) Reflective and refractive properties are combined to selectively highlight higher values. (e) Reflective properties are used to show the mixture fraction variable instead.

“For some visualization applications, the effects of refraction may be undesirable.”

“perception literature show that refractive effects can improve the perception of transparent structures”



Today

- Homework 7: Volume Visualization: What do we want to visualize?
- Isocontours & Implicit Surfaces
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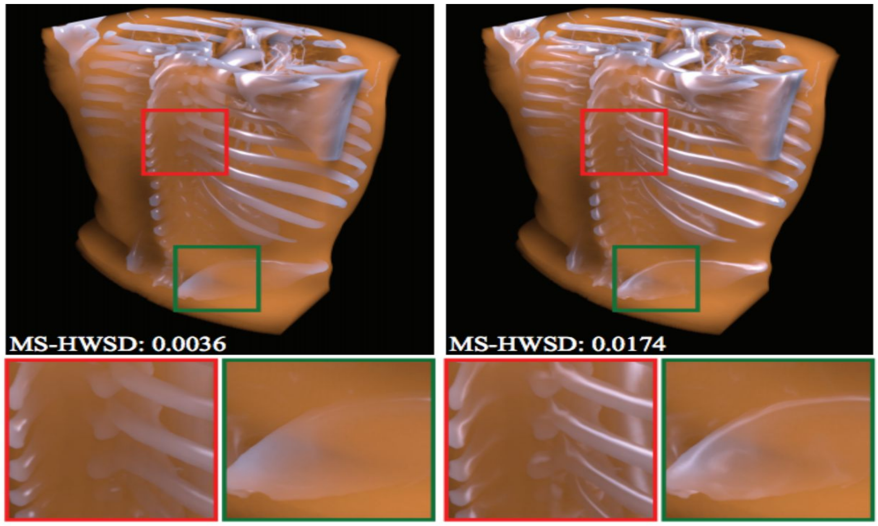
Reading for Today

- "Anisotropic Ambient Volume Shading" Ament & Dachsbacher, IEEE Visualization 2015



What is "Anisotropic"?

- *Isotropic*: is a property which does not depend on the direction.
- *Anisotropic*: is a property which is directionally dependent.
- Anisotropic Examples:
  - Physical simulation of the strength of wood (will splinter along grain)
  - Ray Tracing brushed metal (tiny parallel scratches reflect light differently based on orientation)

How to manipulate a "physically accurate" rendering to be a more useful visualization

- Search neighborhood for similar scalar values
- Use PCA to find eigenvectors (shape of this material in local neighborhood)
- Local illumination (highlights, darkening as surface bends away from light) helps understand shape
- Choose to use a more complex (expensive) lighting model than Phong to capture anisotropy of reflections

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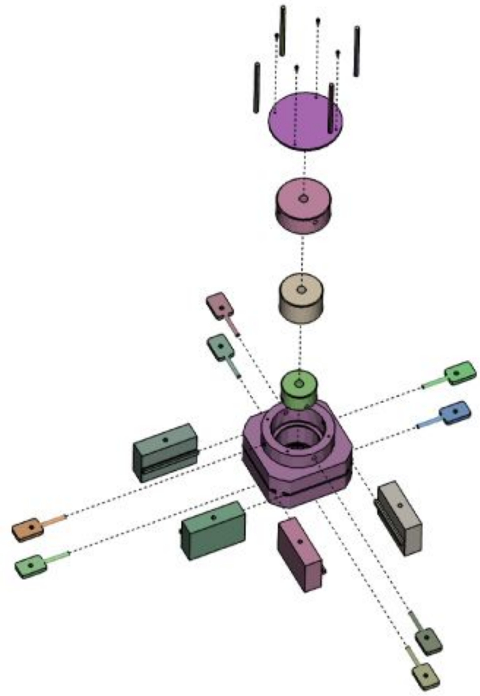
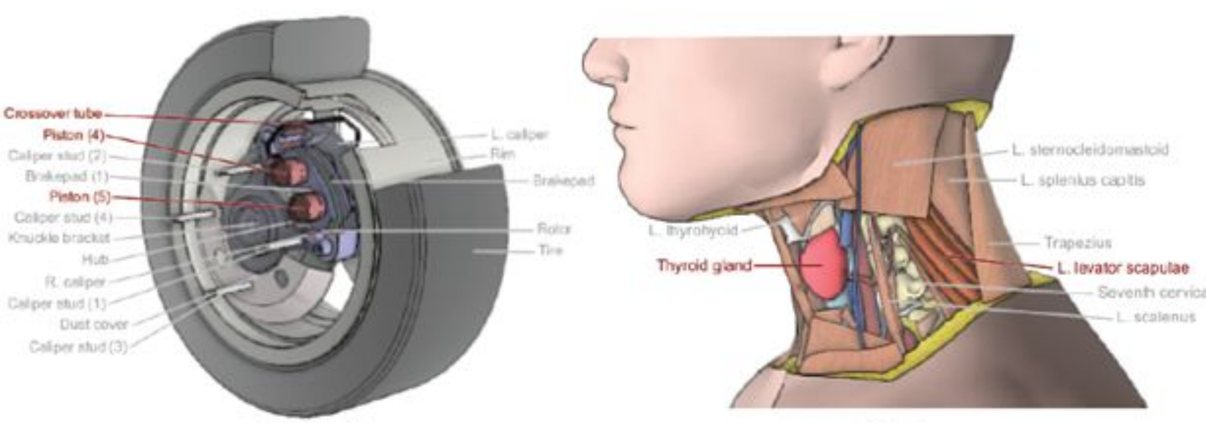
Reading for Tuesday *pick one*

- "Designing Effective Step-by-step Assembly Instructions"
  Agrawala, Phan, Heiser, Haymaker, Klingner, Hanrahan, & Tversky, SIGGRAPH 2003



Reading for Tuesday *pick one*

- "Interactive Cutaway Illustrations of Complex 3D Models", Li, Ritter, Agrawala, Curless, & Salesin, SIGGRAPH 2007



(a) Disk brake (b) Neck

Harvard's Glass Flowers

https://gardeninggonewild.com/glass-flowers-of-harvard/
https://hmnh.harvard.edu/glass-flowers