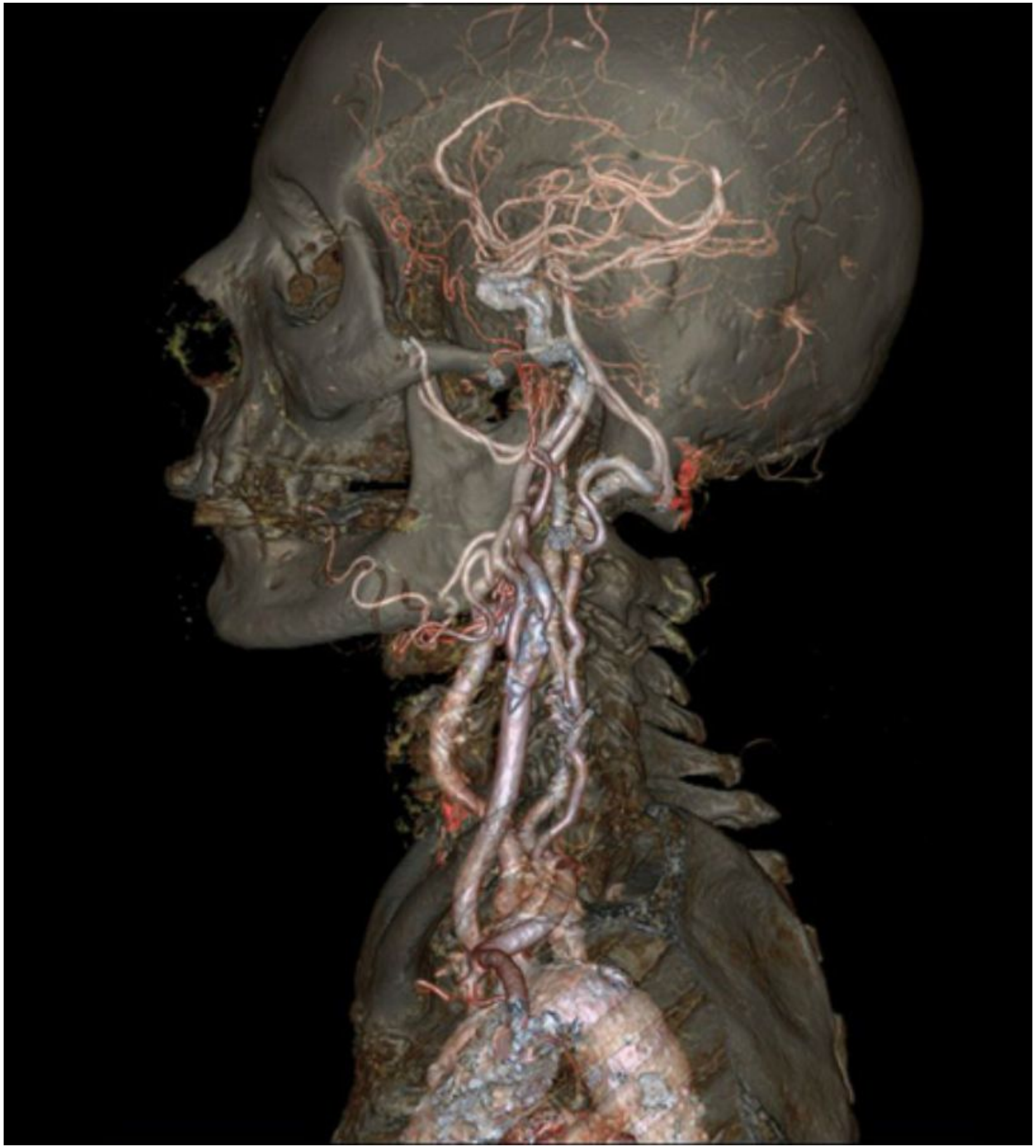
Volume Visualization



http://gizmodo.com/ges-new-fast-ct-scanner-captures-insane-images-in-a-he-1482904872
http://www3.gehealthcare.com/en/Products/Categories/Computed_Tomography/Revolution_CT

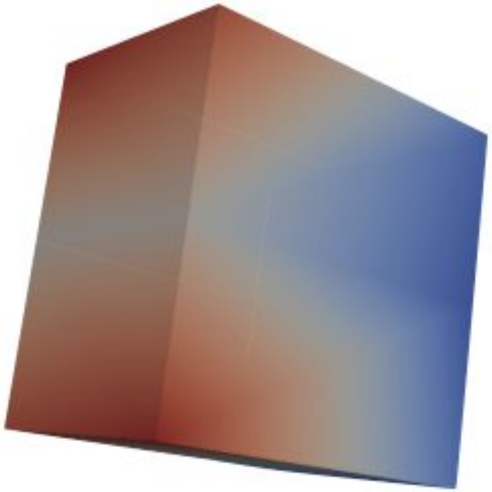


Figure 1: Frame 17 of the visualization

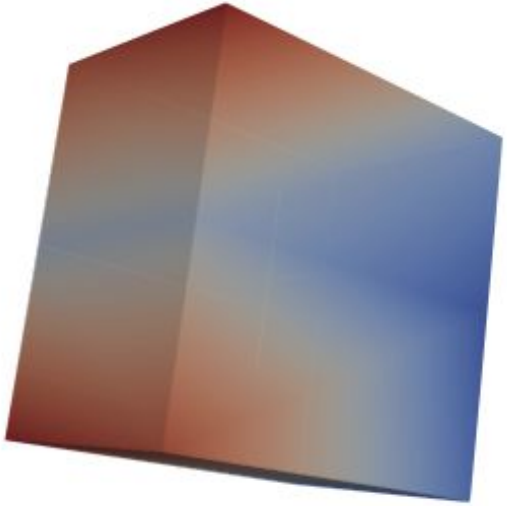


Figure 2: Frame 18 of the visualization

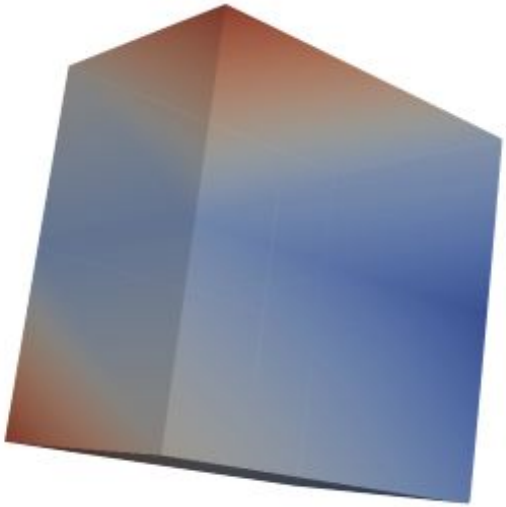


Figure 3: Frame 19 of the visualization

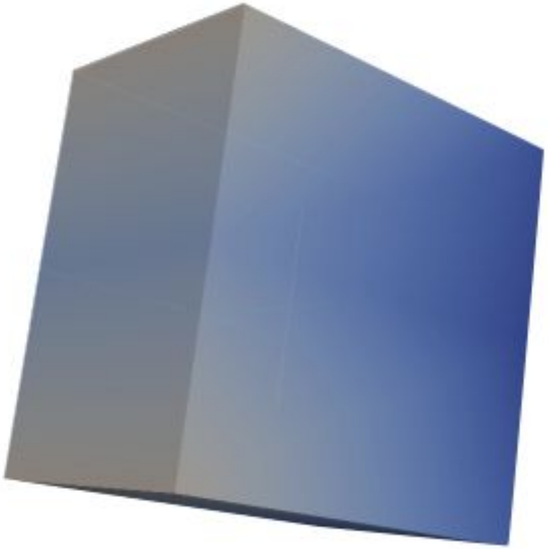
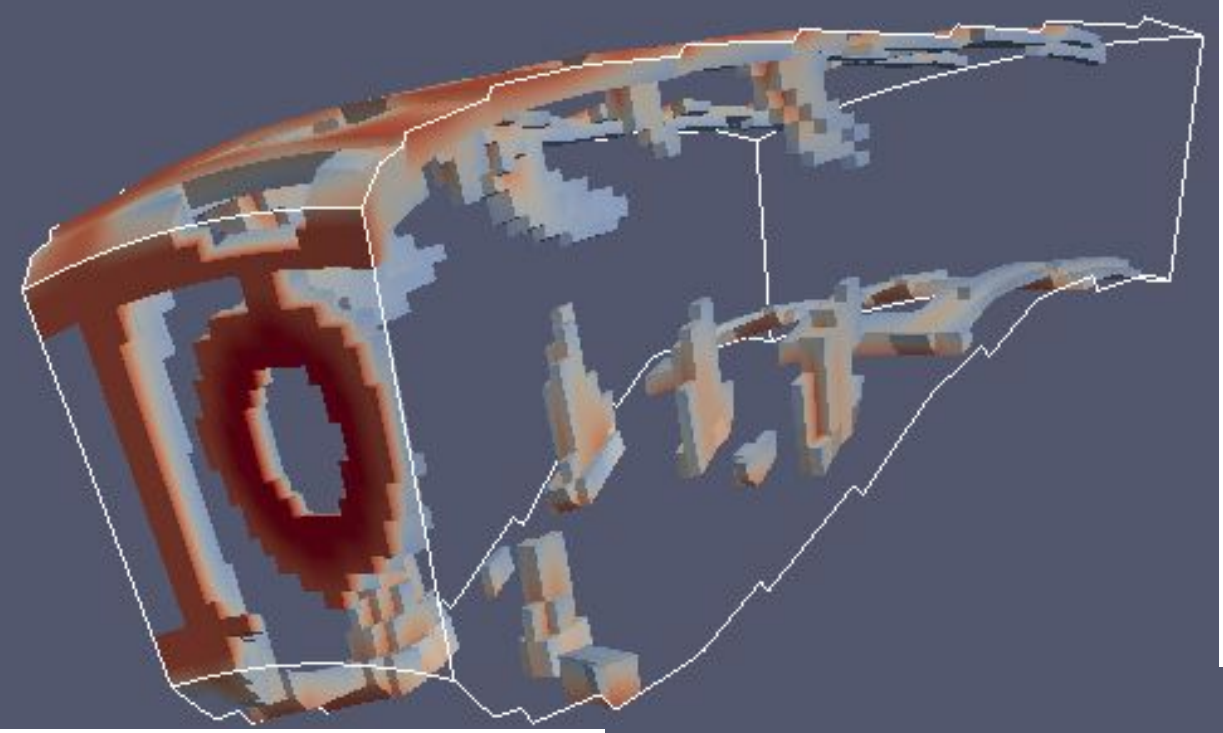


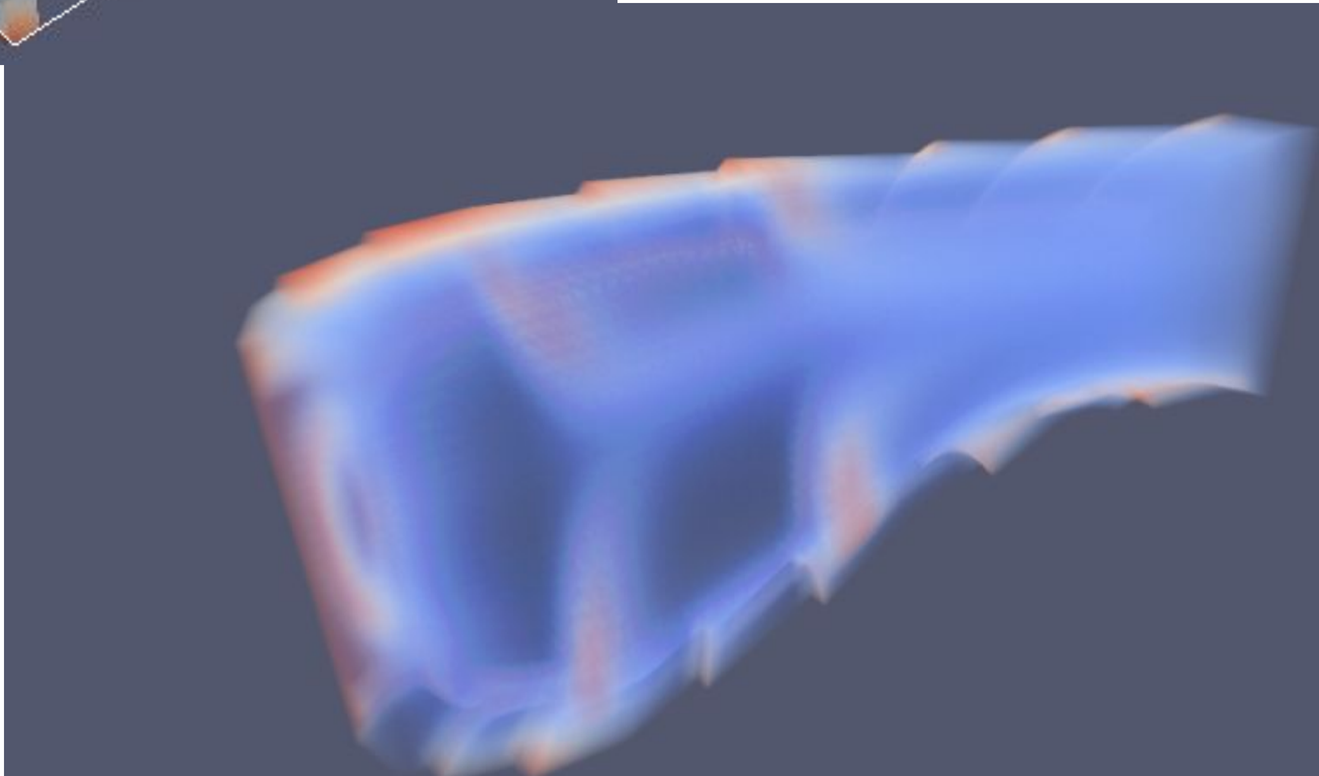
Figure 4: Frame 20 of the visualization

Visualize data values on the surface of a volume

Using VTK HW - Elsa

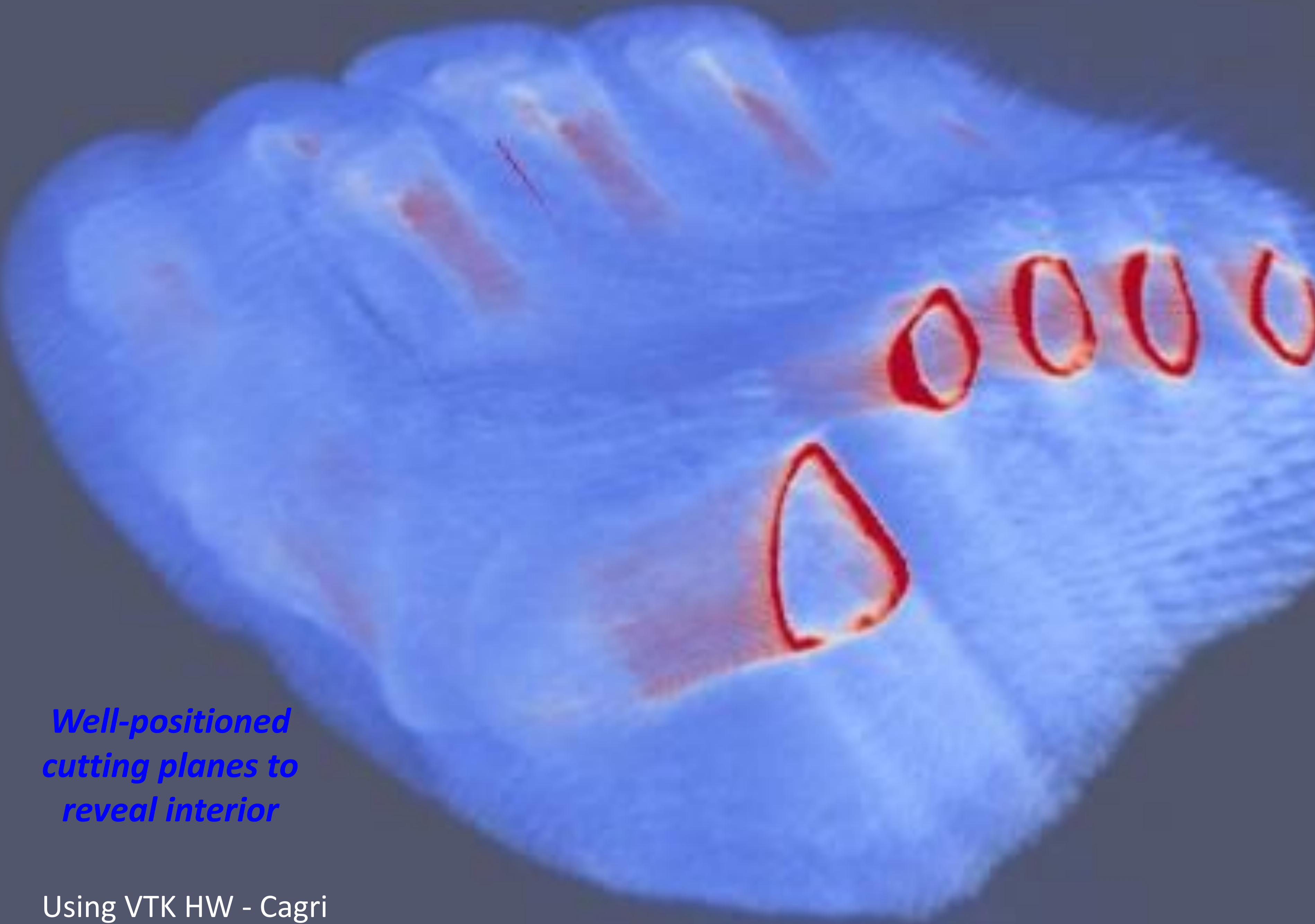


Threshold and show/hide cells



Transparency

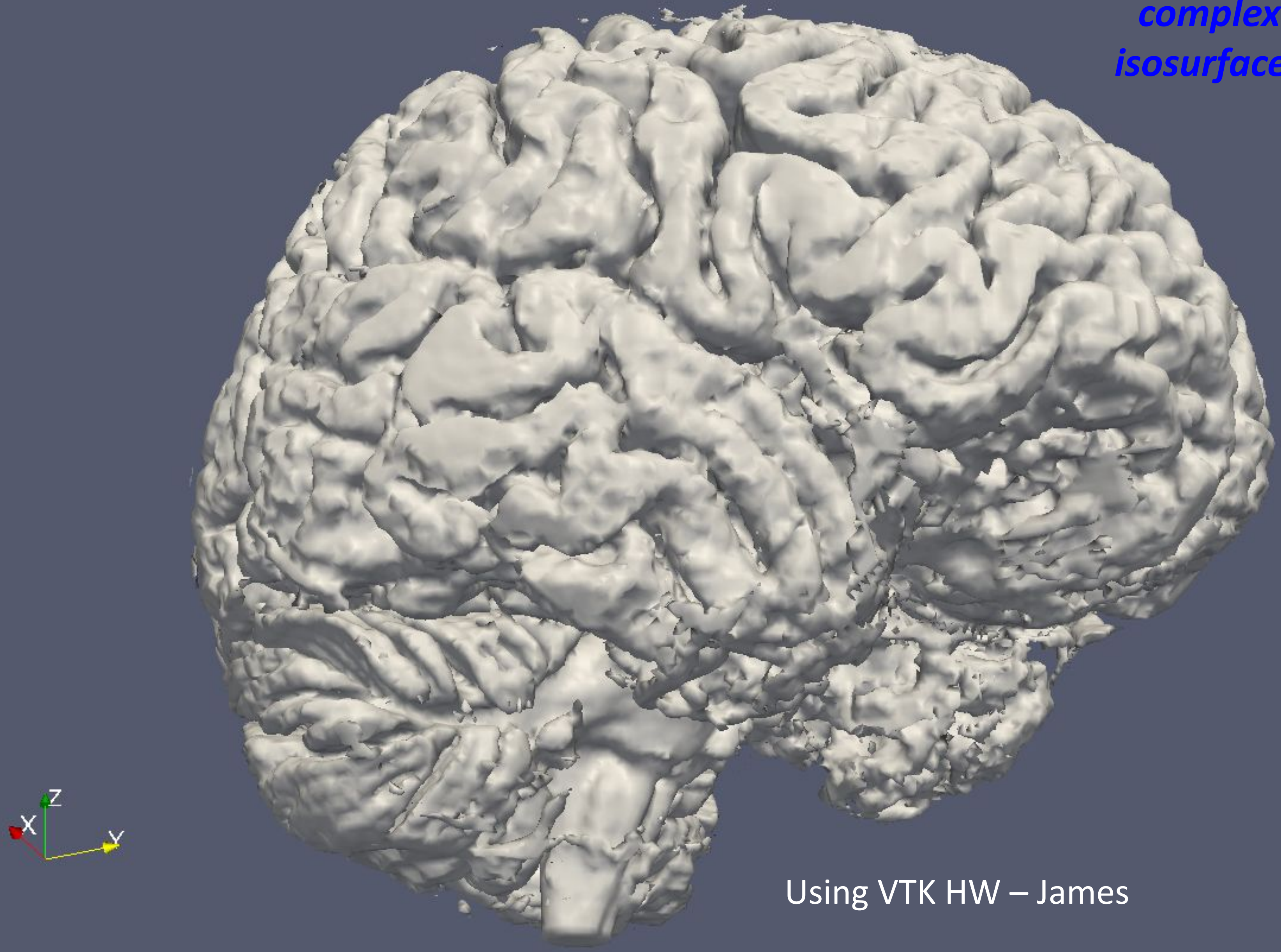
Using VTK HW - Artem



Well-positioned cutting planes to reveal interior

Using VTK HW - Cagri

Extraction of complex isosurfaces



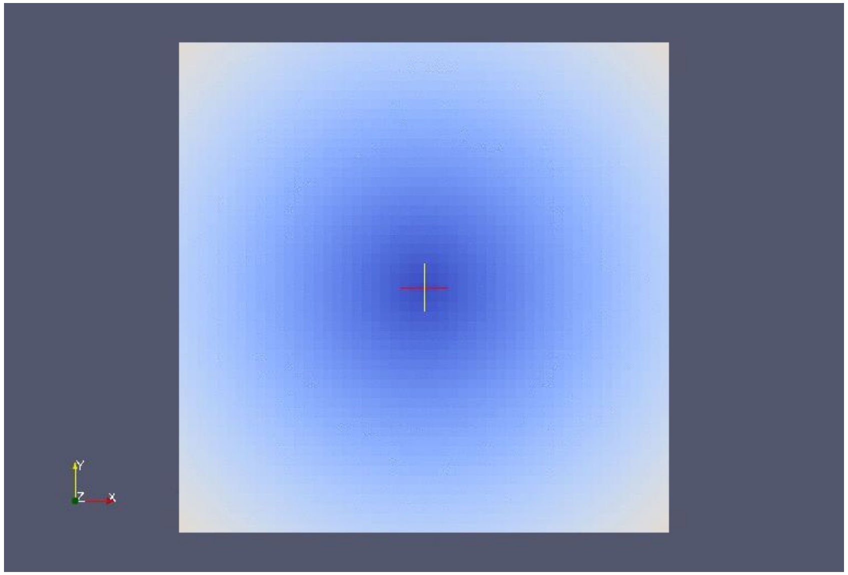
Using VTK HW – James

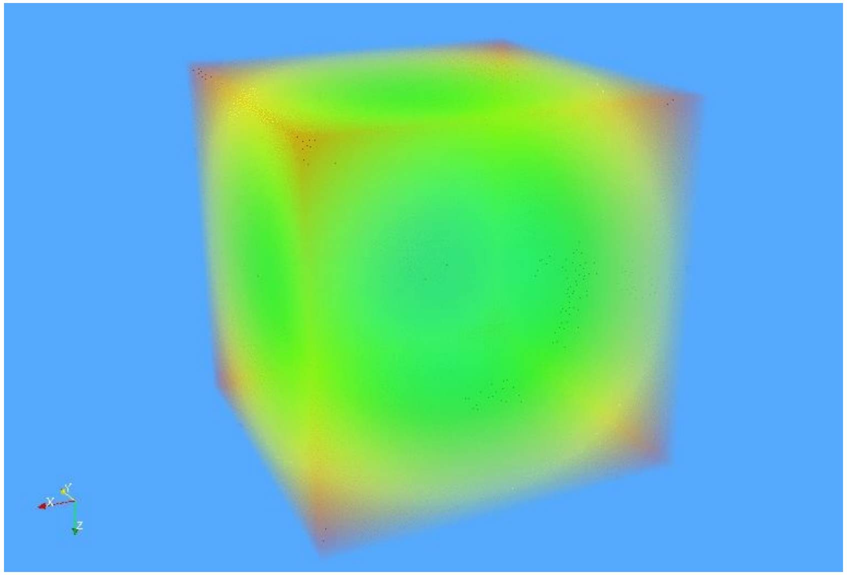
Today

- Homework 8: 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 (& a couple others)
  - “A Survey of Algorithms for Volume Visualization”
  - “Intuitive Exploration of Volumetric Data Using Dynamic Galleries”
  - “Interactive Dynamic Volume Illumination with Refraction and Caustics”
  - "Anisotropic Ambient Volume Shading"
- Readings for Friday

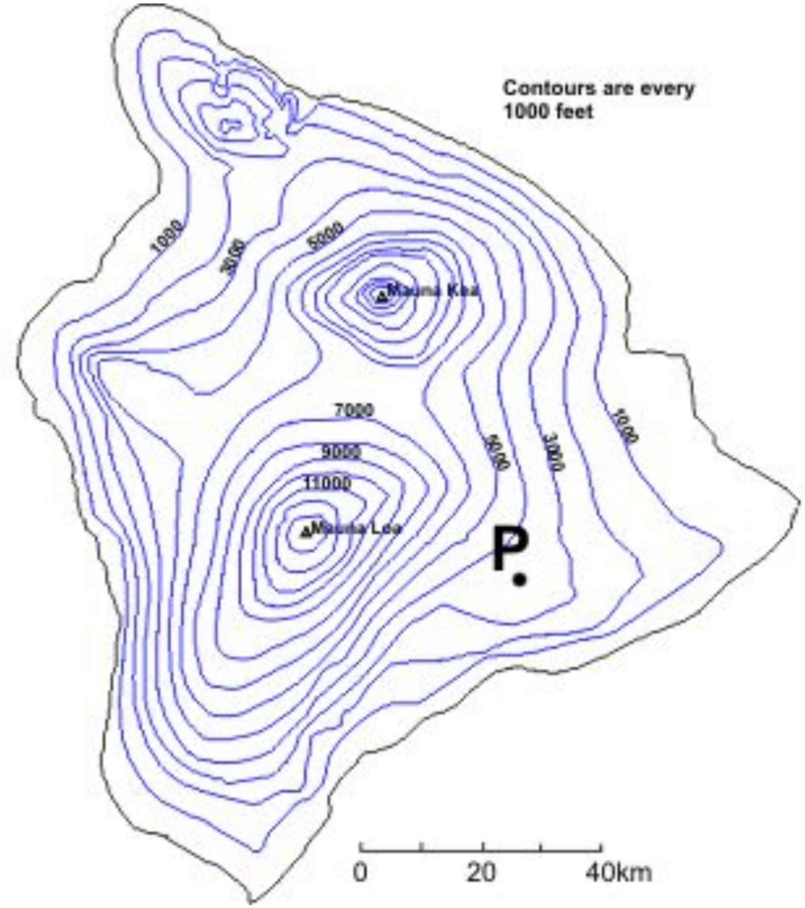
Isocontours / Isosurfaces

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





Contour Map



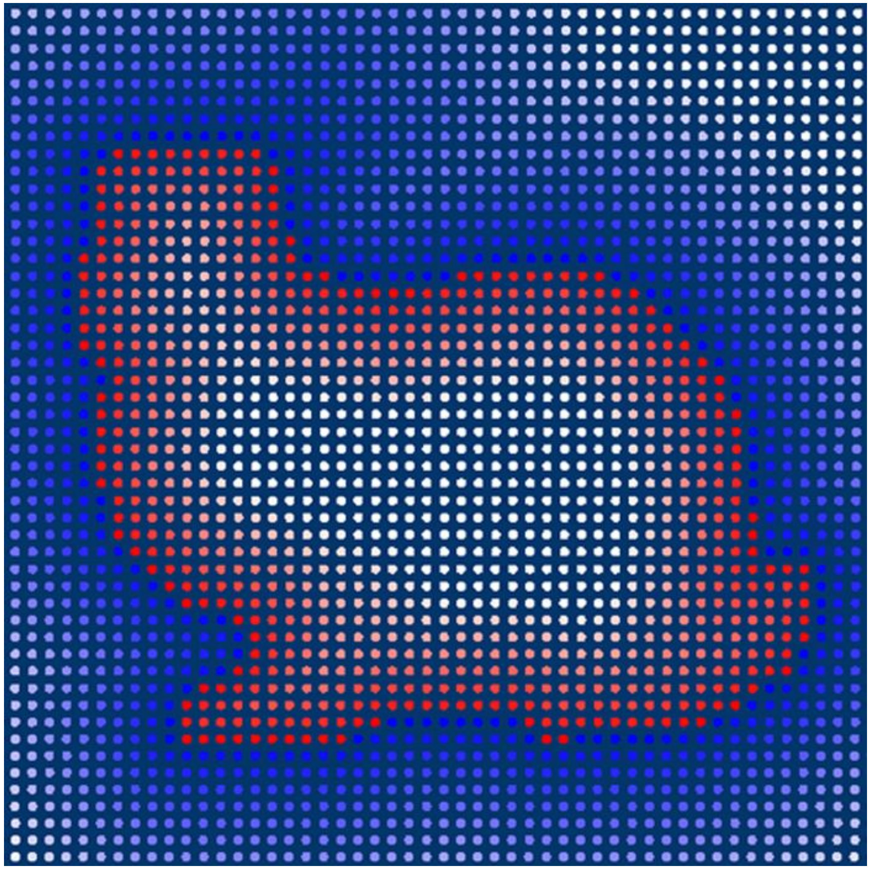
https://www.e-education.psu.edu/meteo3/l1_p10.html

Implicit Surfaces

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

- For a sphere:
  $H(x,y,z) = x^2 + y^2 + z^2 - r^2$

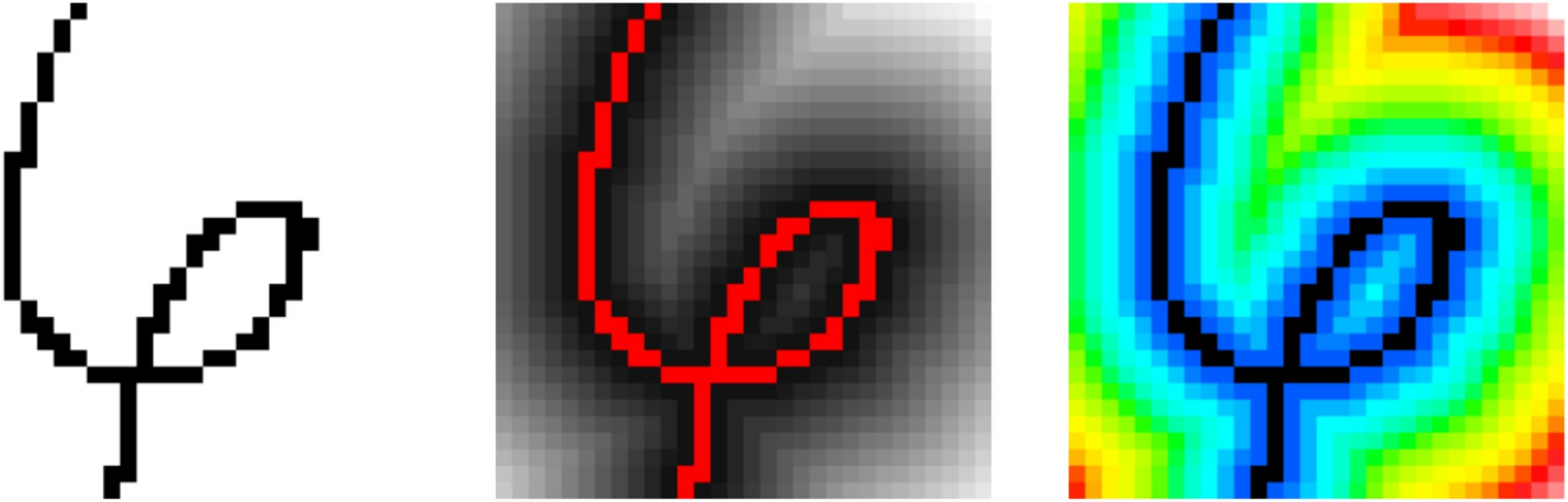
- If $H(x,y,z) = 0$, on surface
- If $H(x,y,z) > 0$, outside surface
- If $H(x,y,z) < 0$, inside surface



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?

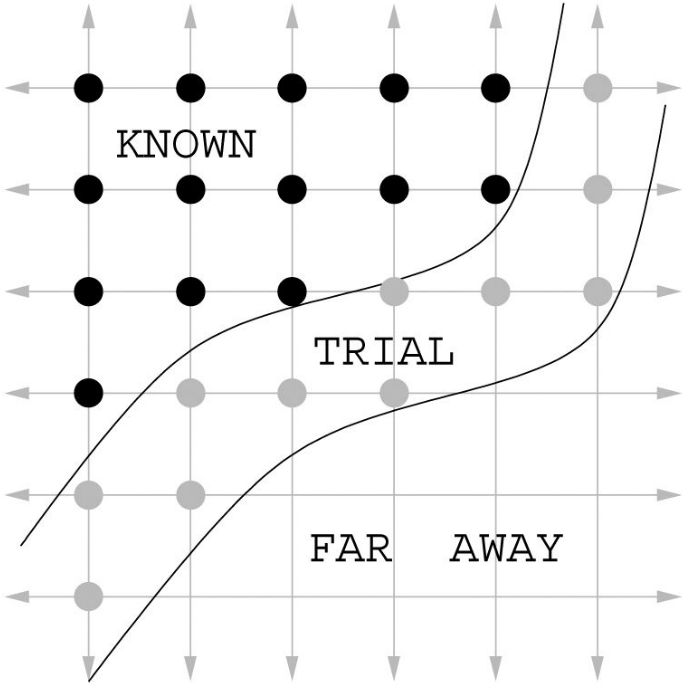
Naive: O(# of volume grid samples * # of surface elements)

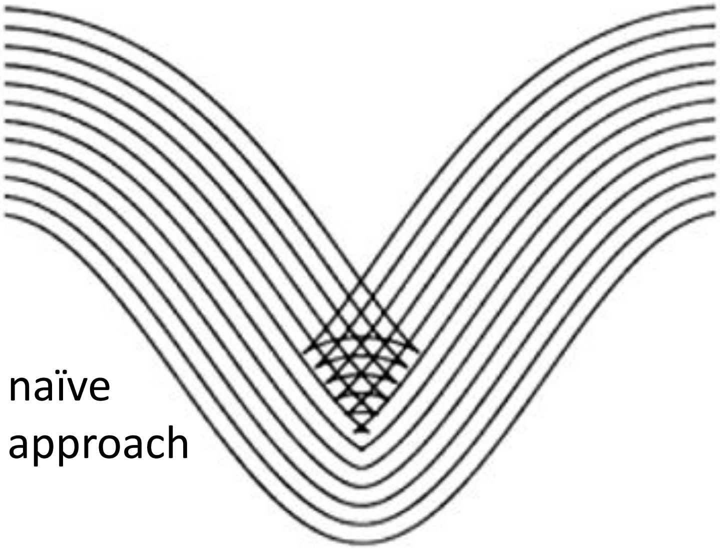


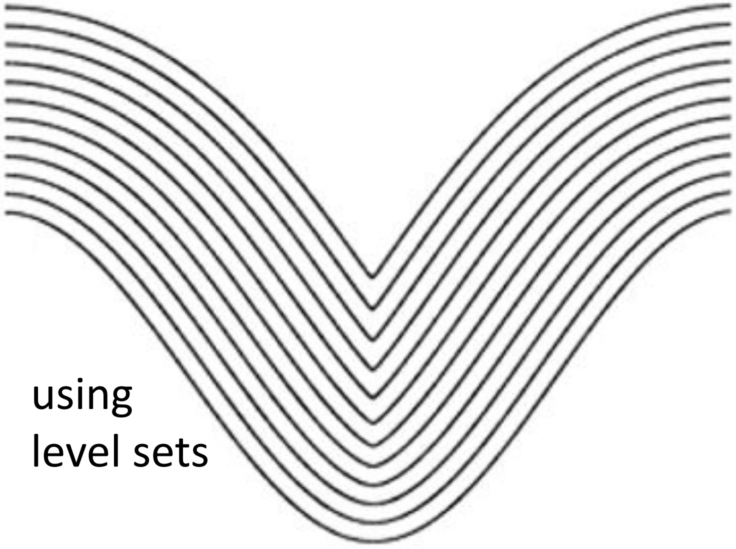
Level Sets

- Efficient method for computing signed distance field

Level Set Methods and Fast Marching Methods, Sethian, 1999

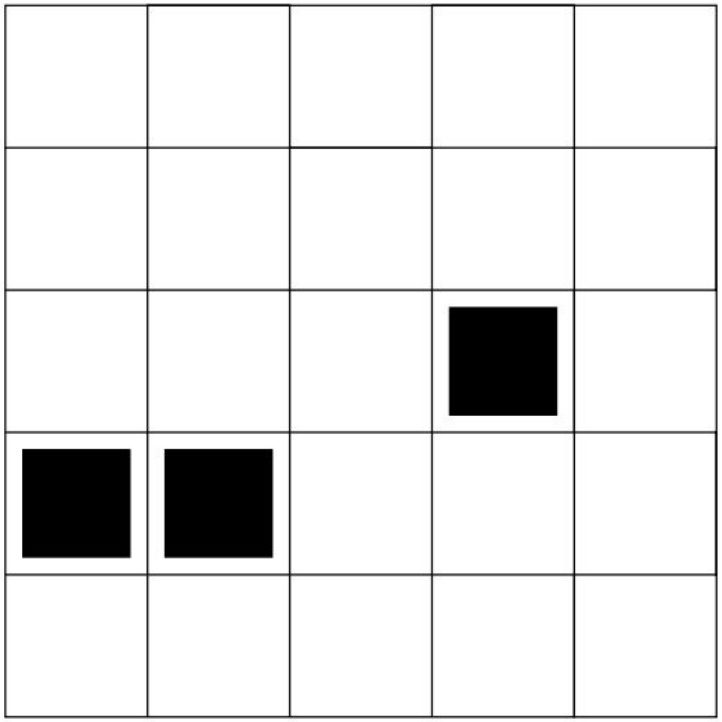




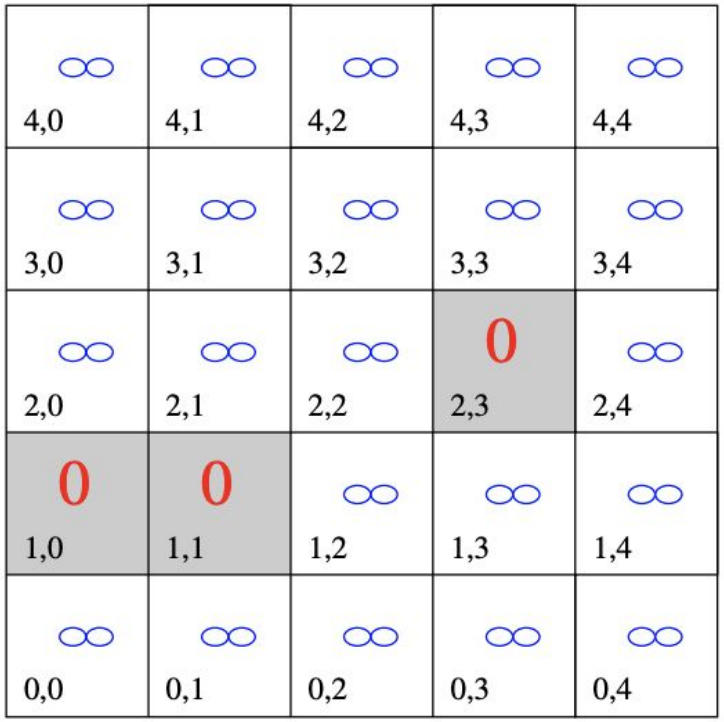


A Data Structures Homework

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



input image



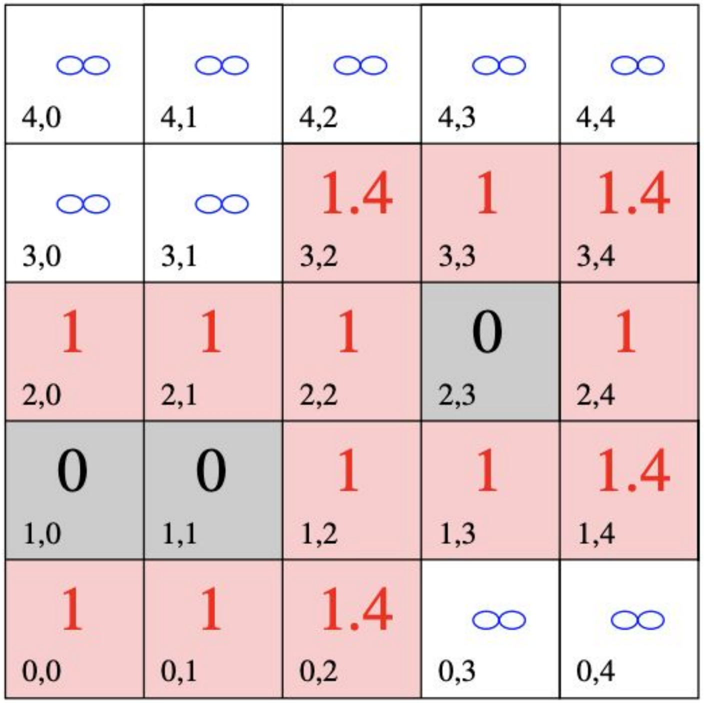
∞ 4,0	∞ 4,1	∞ 4,2	∞ 4,3	∞ 4,4
∞ 3,0	∞ 3,1	∞ 3,2	∞ 3,3	∞ 3,4
∞ 2,0	∞ 2,1	∞ 2,2	0 2,3	∞ 2,4
0 1,0	0 1,1	∞ 1,2	∞ 1,3	∞ 1,4
∞ 0,0	∞ 0,1	∞ 0,2	∞ 0,3	∞ 0,4

initialization of the signed distance field

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

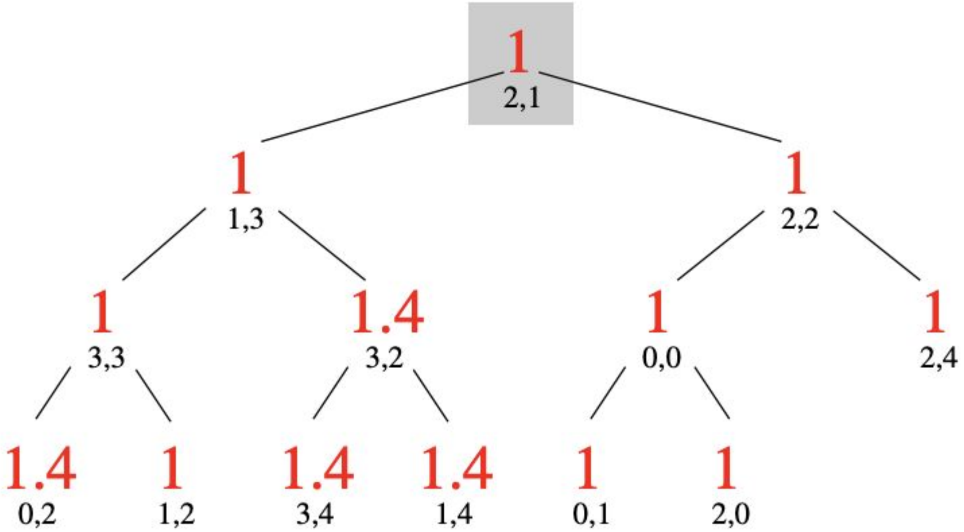
A Data Structures Homework

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



∞ 4,0	∞ 4,1	∞ 4,2	∞ 4,3	∞ 4,4
∞ 3,0	∞ 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

propagating initial values

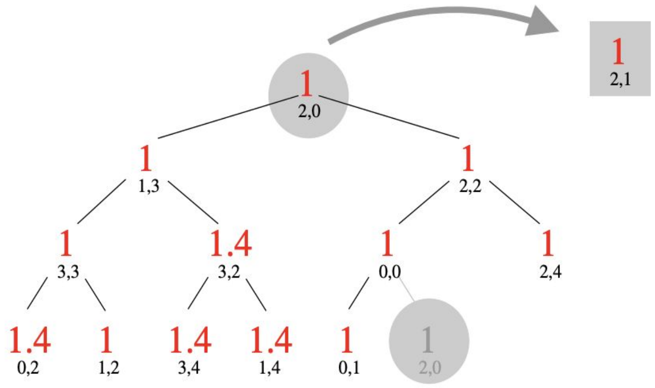


initial priority queue of pixels

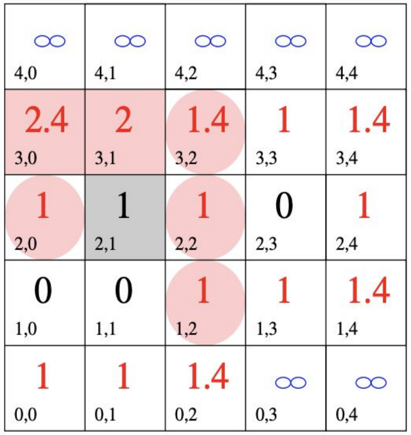
Put all these new pixels in a priority queue, ordered by distance

A Data Structures Homework

Grab the top item from the priority queue...

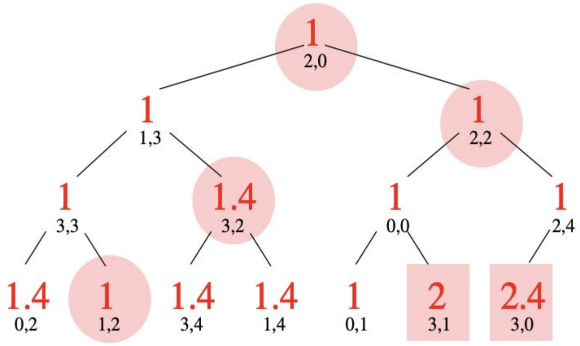


after popping & fixing the top value,
grab the last leaf & percolate down



∞ 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

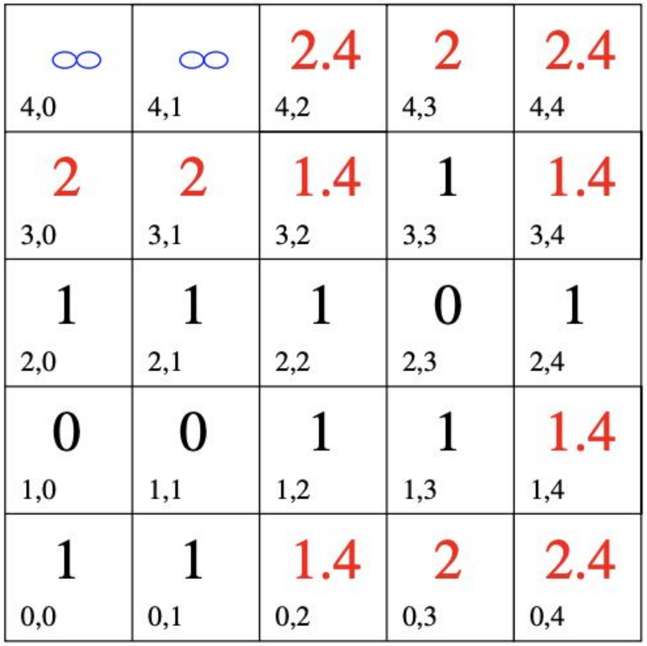


adjust existing values & add
new values to the priority queue

Lock its value, and update its immediate neighbors

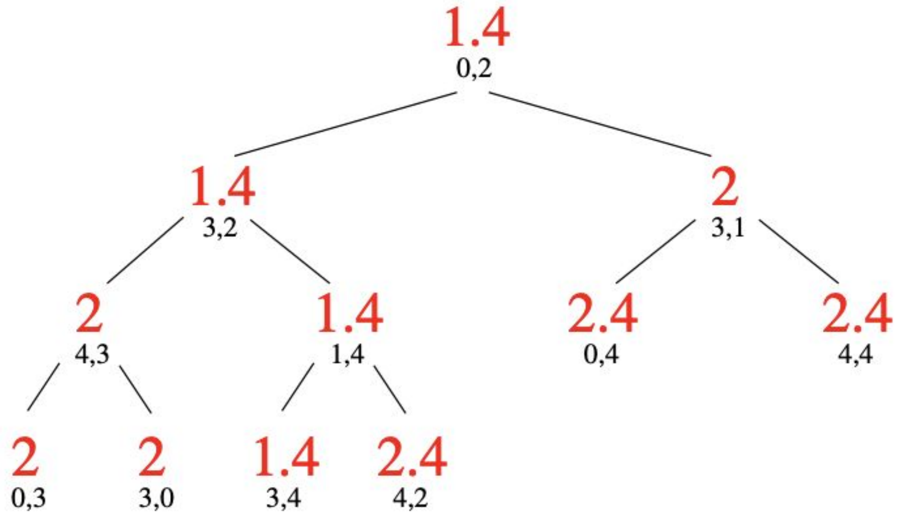
A Data Structures Homework

Grab the next pixel in the priority queue and repeat….



∞ 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



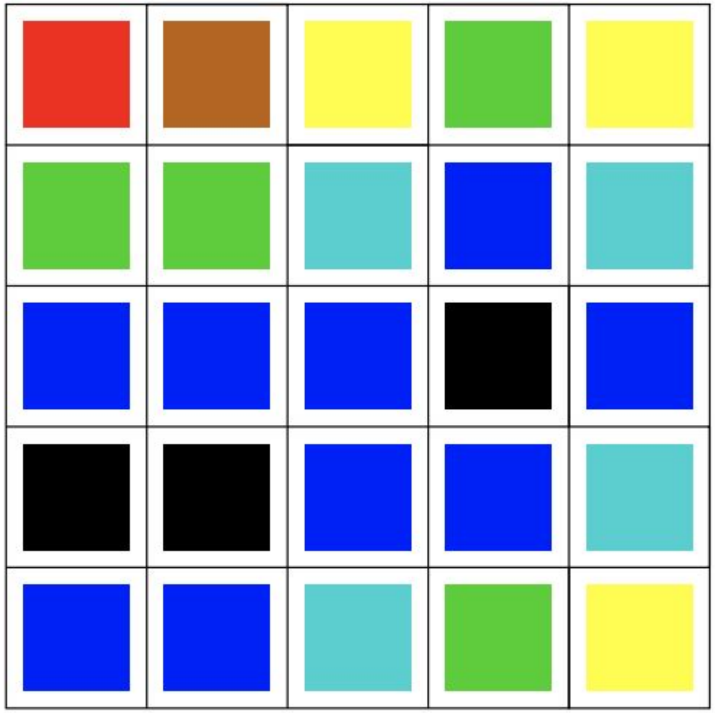
priority queue after fixing all pixels <= 1

A Data Structures Homework

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

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

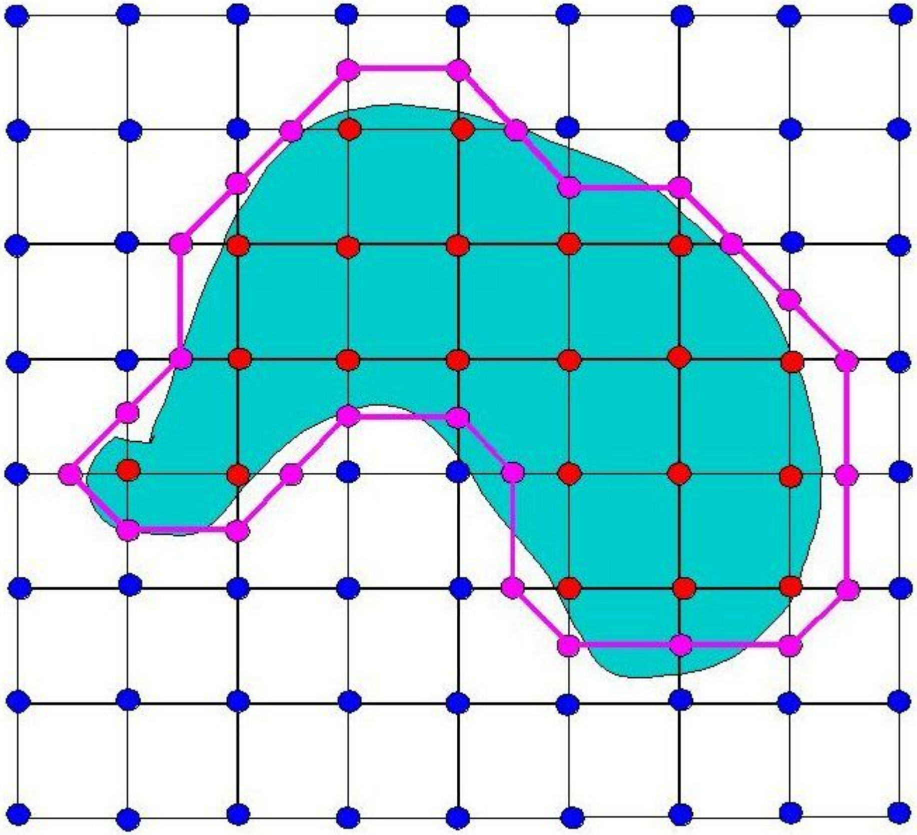


output image

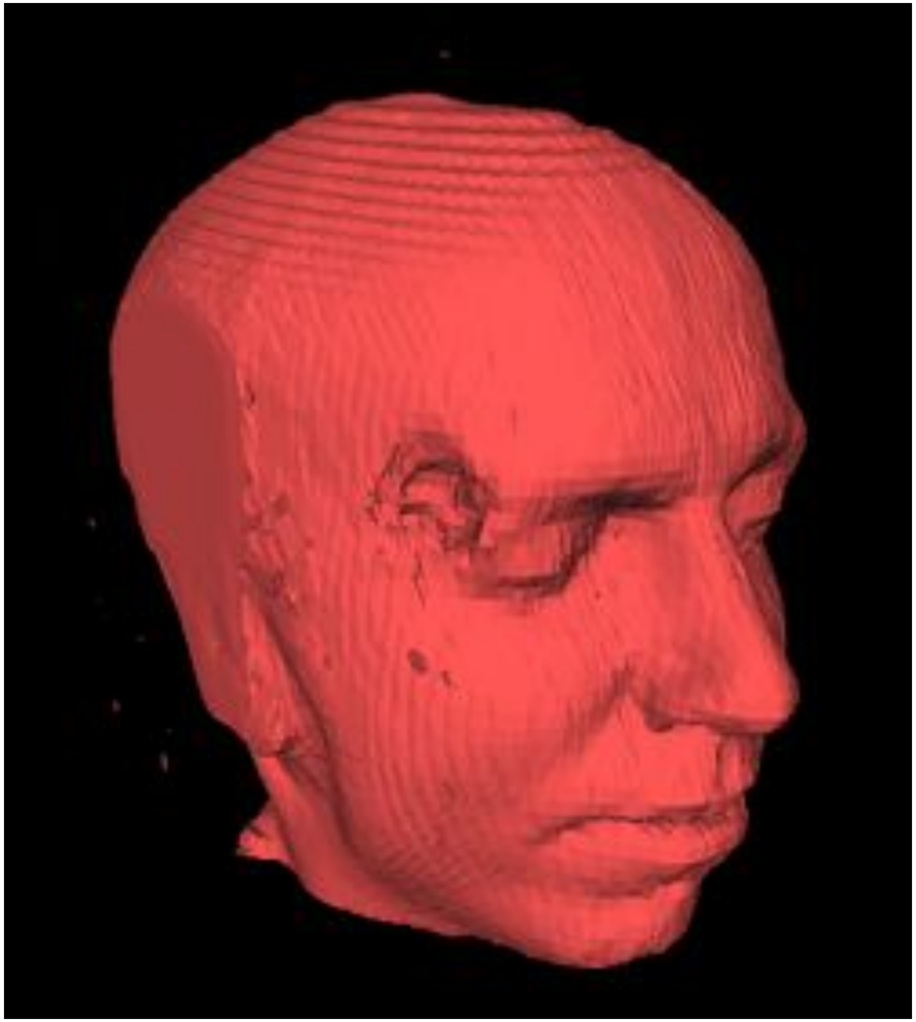
Today

- Homework 8: 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 (& a couple others)
  - “A Survey of Algorithms for Volume Visualization”
  - “Intuitive Exploration of Volumetric Data Using Dynamic Galleries”
  - “Interactive Dynamic Volume Illumination with Refraction and Caustics”
  - "Anisotropic Ambient Volume Shading"
- Readings for Friday

Marching Cubes



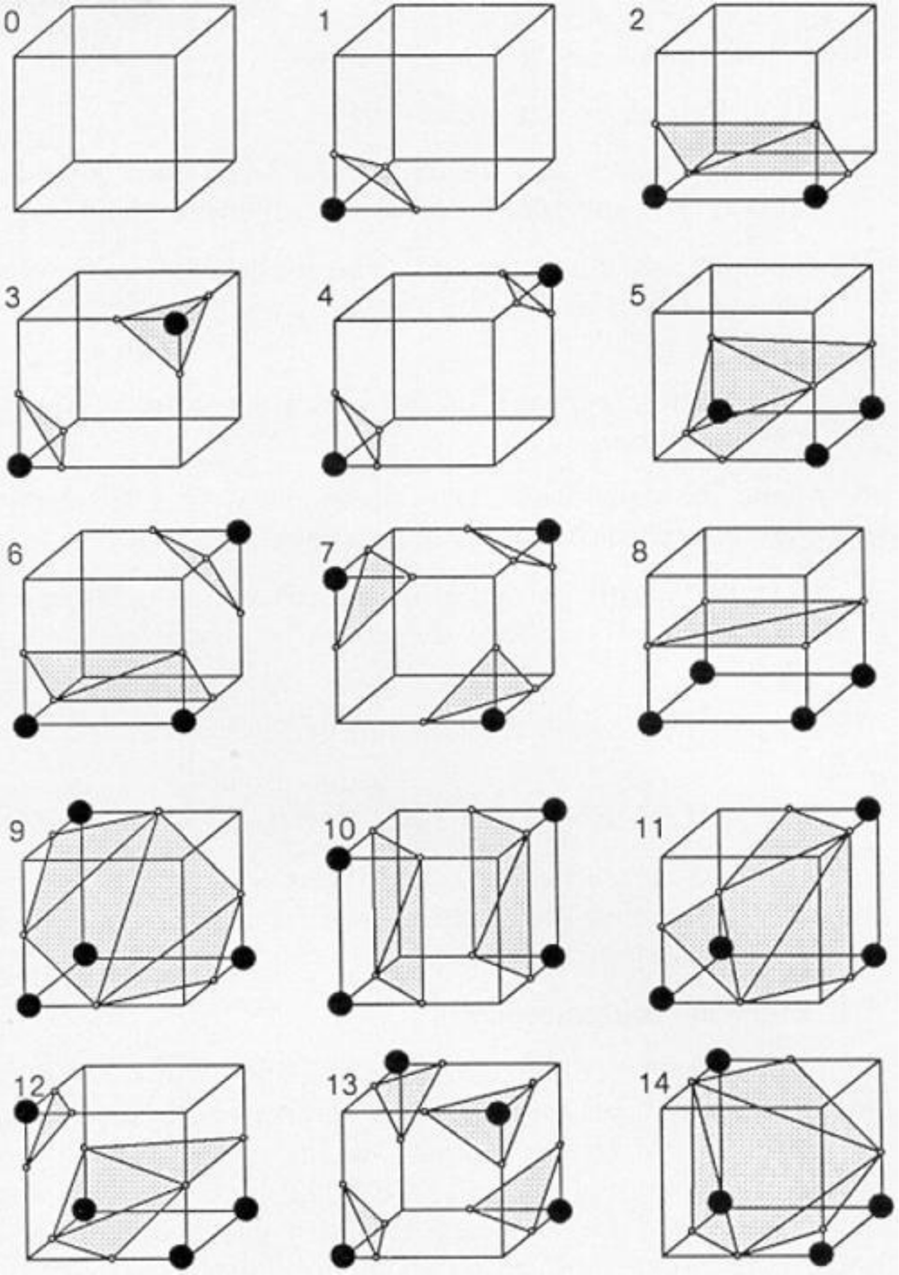
http://www.cs.carleton.edu/cs_comps/0405/shape/marching_cubes.html



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

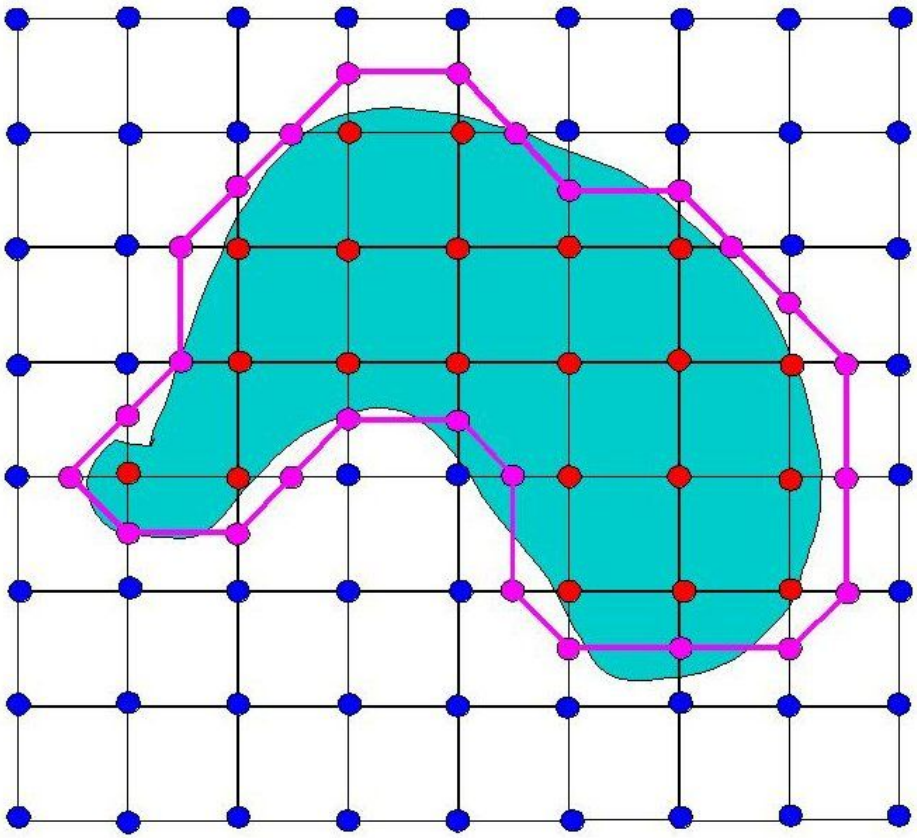
Marching Cubes

- Polygonization: extract triangle mesh from signed distance field



"Marching Cubes: A High Resolution 3D Surface Construction Algorithm", Lorensen and Cline, SIGGRAPH '87.

Note about Marching Cubes



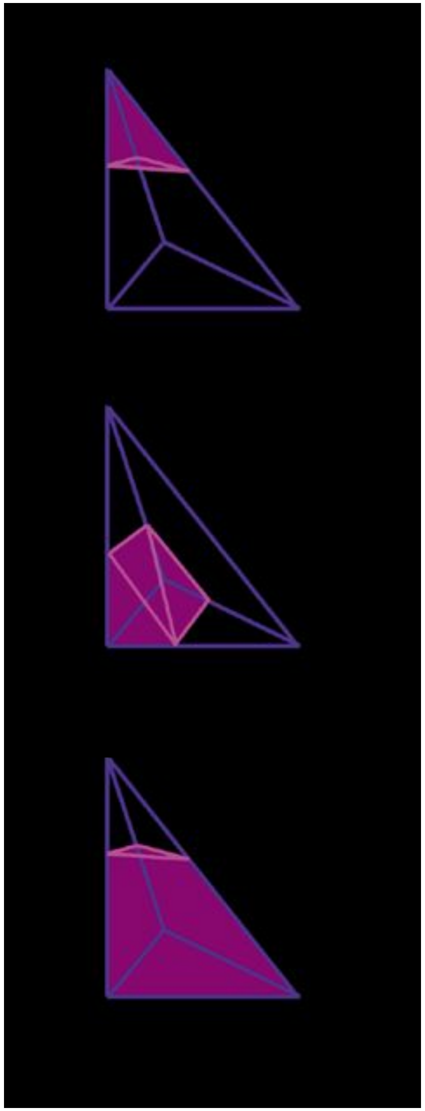
http://www.cs.carleton.edu/cs_comps/0405/shape/marching_cubes.html

- If the grid points are only boolean data, labeling “inside” vs. “outside” the marching cubes surface will simply bisect each cell boundary

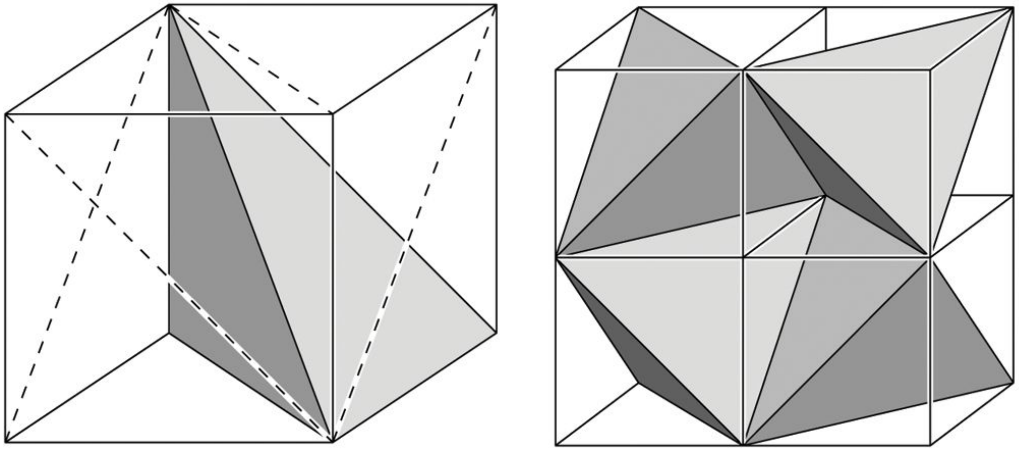
- If we have floating point “signed distance from surface” values, we can interpolate those values and position the iso-surface for a specific value more accurately

… Worksheet for Friday

“Marching Tetrahedra”

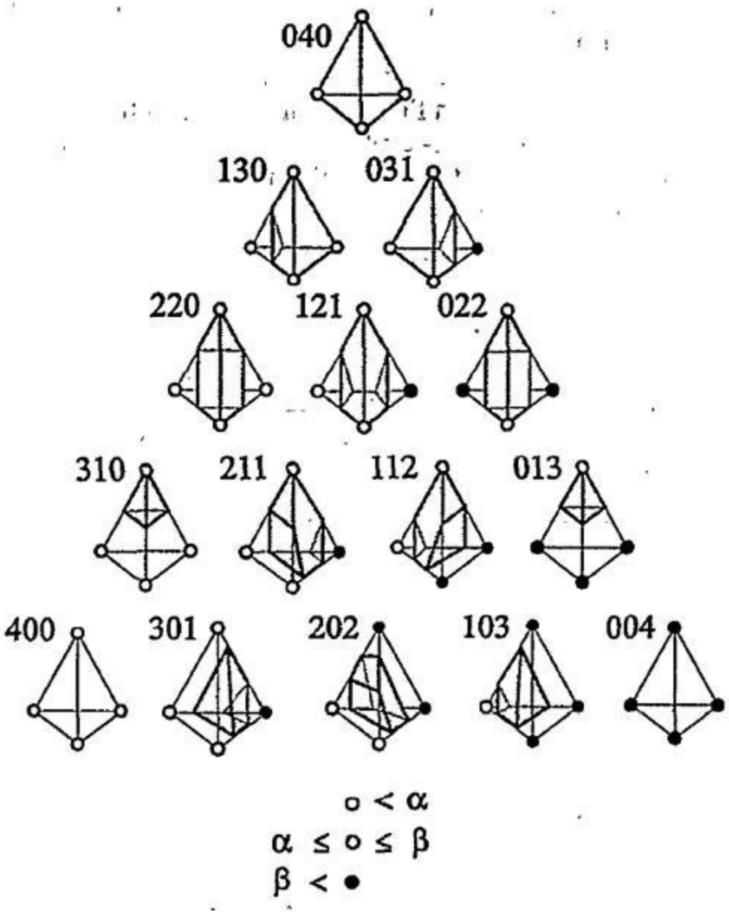


Jules Bloomenthal
“An implicit surface polygonizer”
Graphics Gems IV



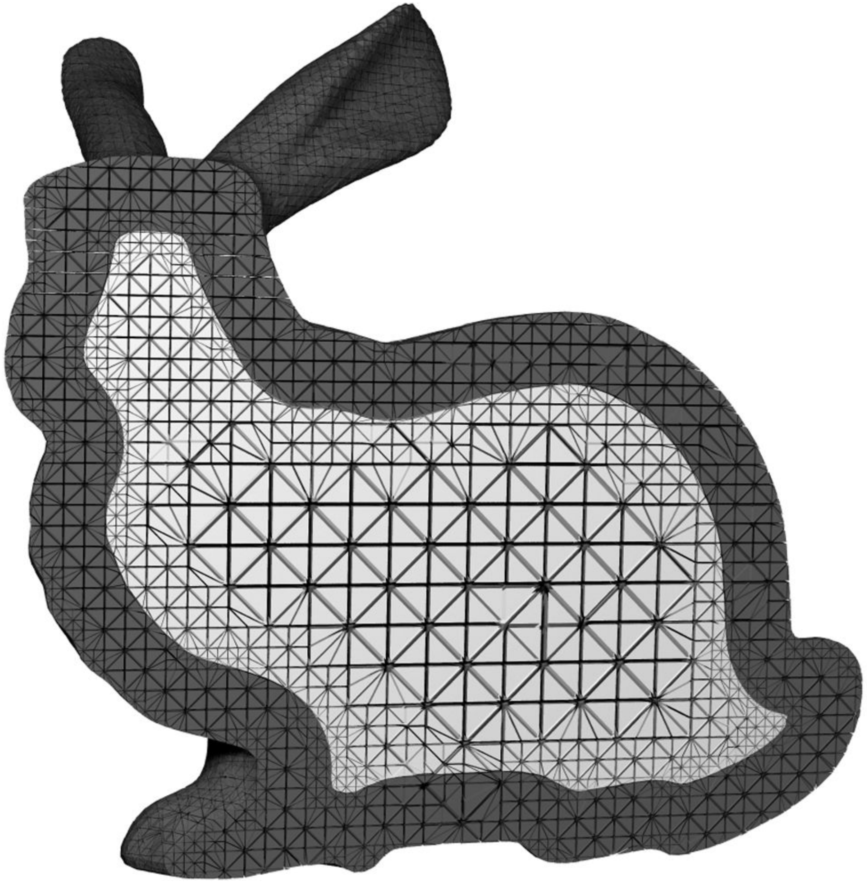
“When the Blobs Go
Marching Two by Two”,
Jeff Lander, Gamasutra

“Marching Tetrahedra”



“Interval volume tetrahedrization”
Visualization '97
Nielson & Sung

Similarly, we can create volumetric models:



Today

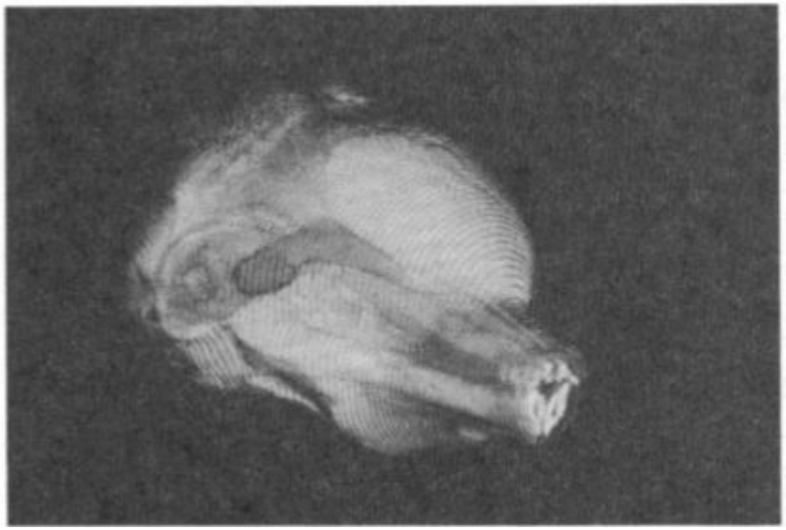
- Homework 8: Volume Visualization: What do we want to visualize?
- Isocontours & Implicit Surfaces
  - Surface/Triangle Mesh → Signed Distance Field: Fast Marching Method
- Voxels: Volumetric Elements / Data
  - Signed Distance Field → Surface/Triangle Mesh: Marching Cubes
- Papers for Today (& a couple others)
  - "A Survey of Algorithms for Volume Visualization"
  - "Interactive Dynamic Volume Illumination with Refraction and Caustics"
- Readings for Friday

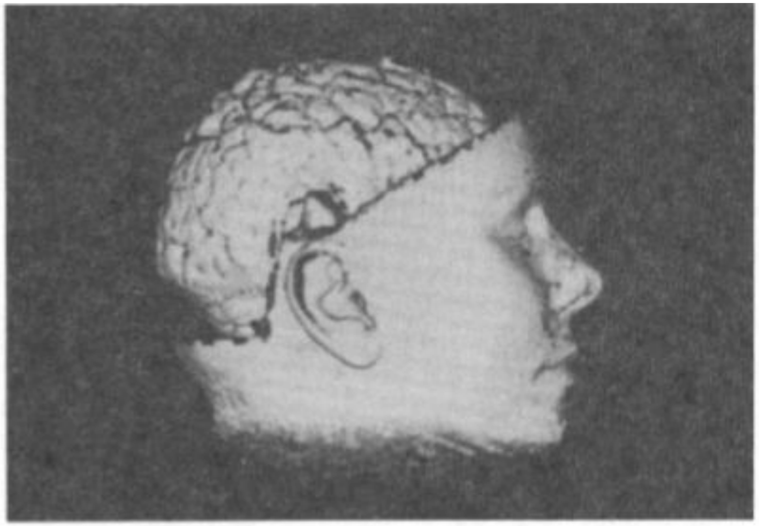
Today

- Homework 8: 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 (& a couple others)
  - "A Survey of Algorithms for Volume Visualization"
  - "Interactive Dynamic Volume Illumination with Refraction and Caustics"
- Readings for Friday

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 '91

- 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 threshhold values & Choosing appropriate color & opacity tables
  - Highly dependent on dataset! Examine data, chose initial values, visualize, adjust values, repeat
- 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

Today

- Homework 8: 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 (& a couple others)
  - "A Survey of Algorithms for Volume Visualization"
  - "Interactive Dynamic Volume Illumination with Refraction and Caustics"
- Readings for Friday

Readings for Today:

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

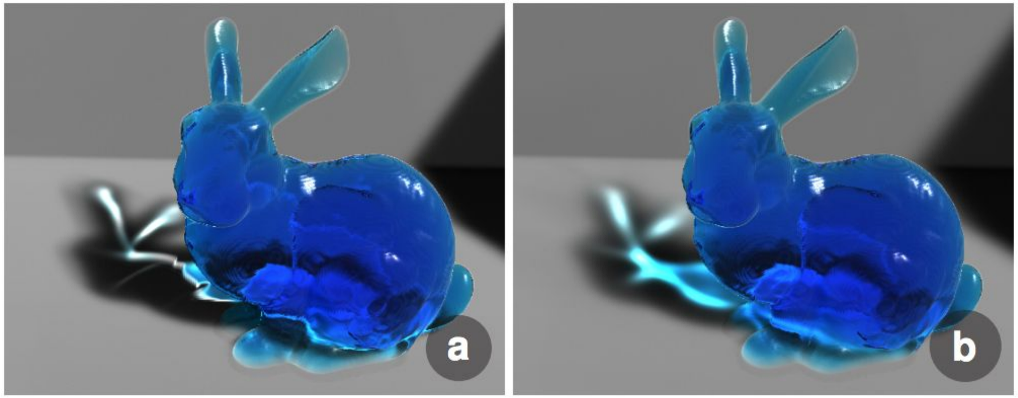


Fig. 3: Effects of light filtering. (a) No filtering. (b) Filtering of light and light direction.

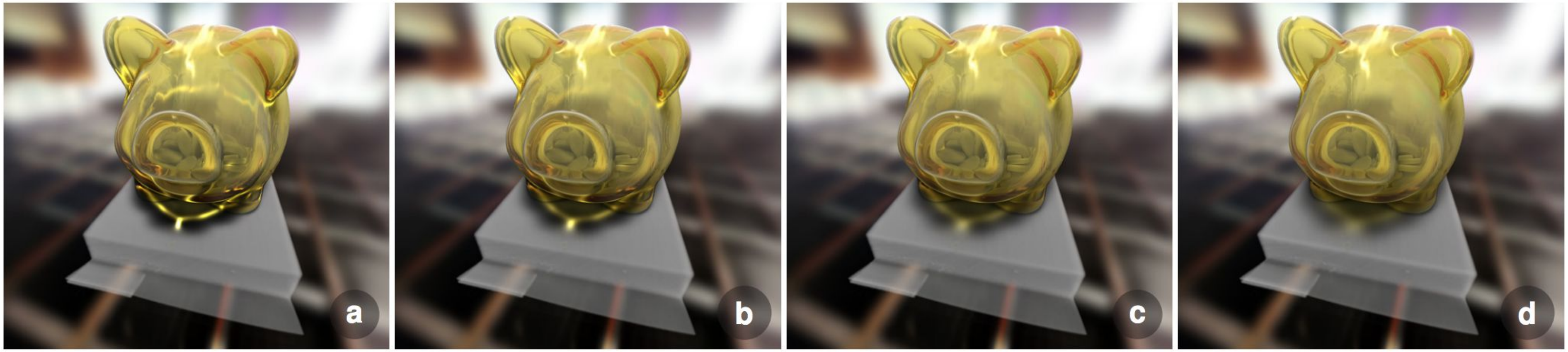


Fig. 7: CT scan of a piggy bank with refraction and combination of transmissive and reflective material properties and increasing light source softness from (a) to (d).

- 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

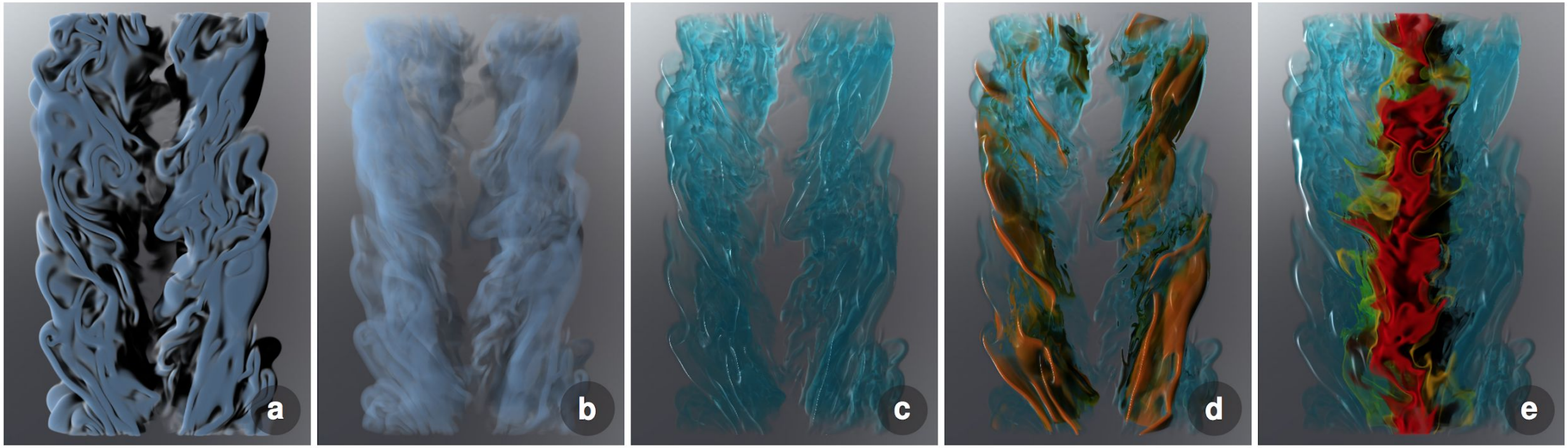
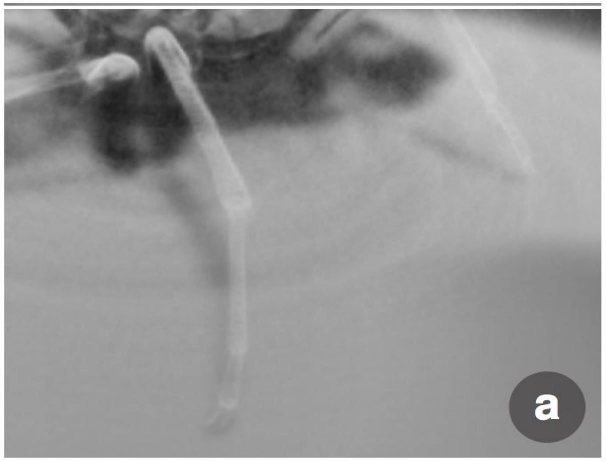
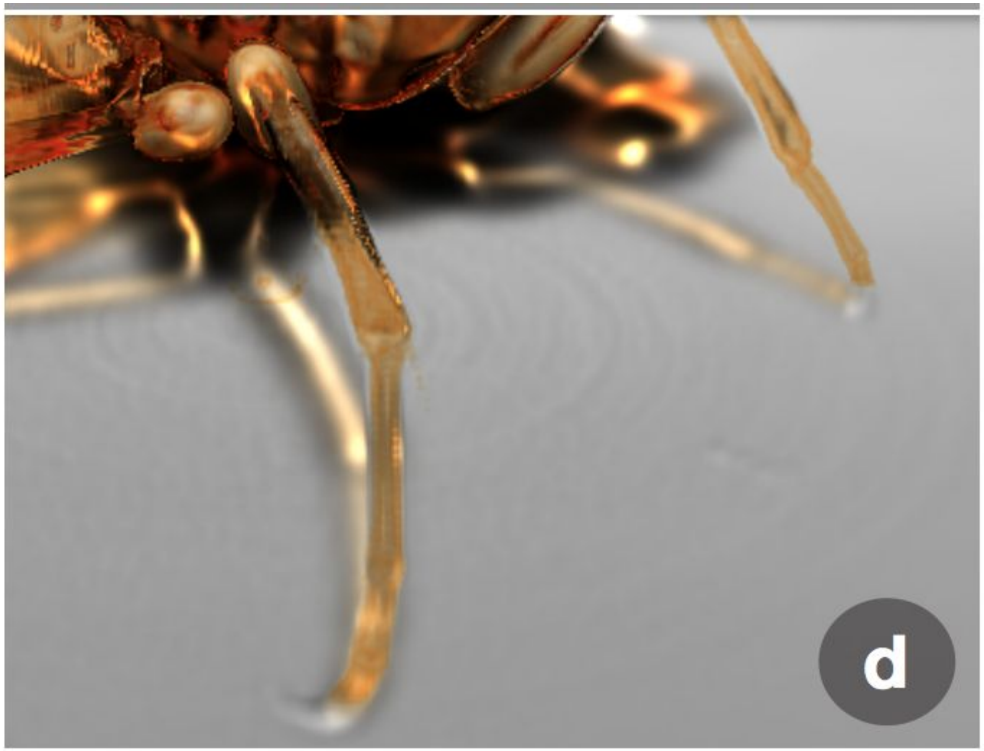


Fig. 12: A timestep of a combustion simulation. In (a) and (b), the chi variable is mapped to opacity, while in (c) the index of refraction is used instead, providing an overview visualization without introducing occlusion. (d) Reflective and refractive properties are combined to selectively highlight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

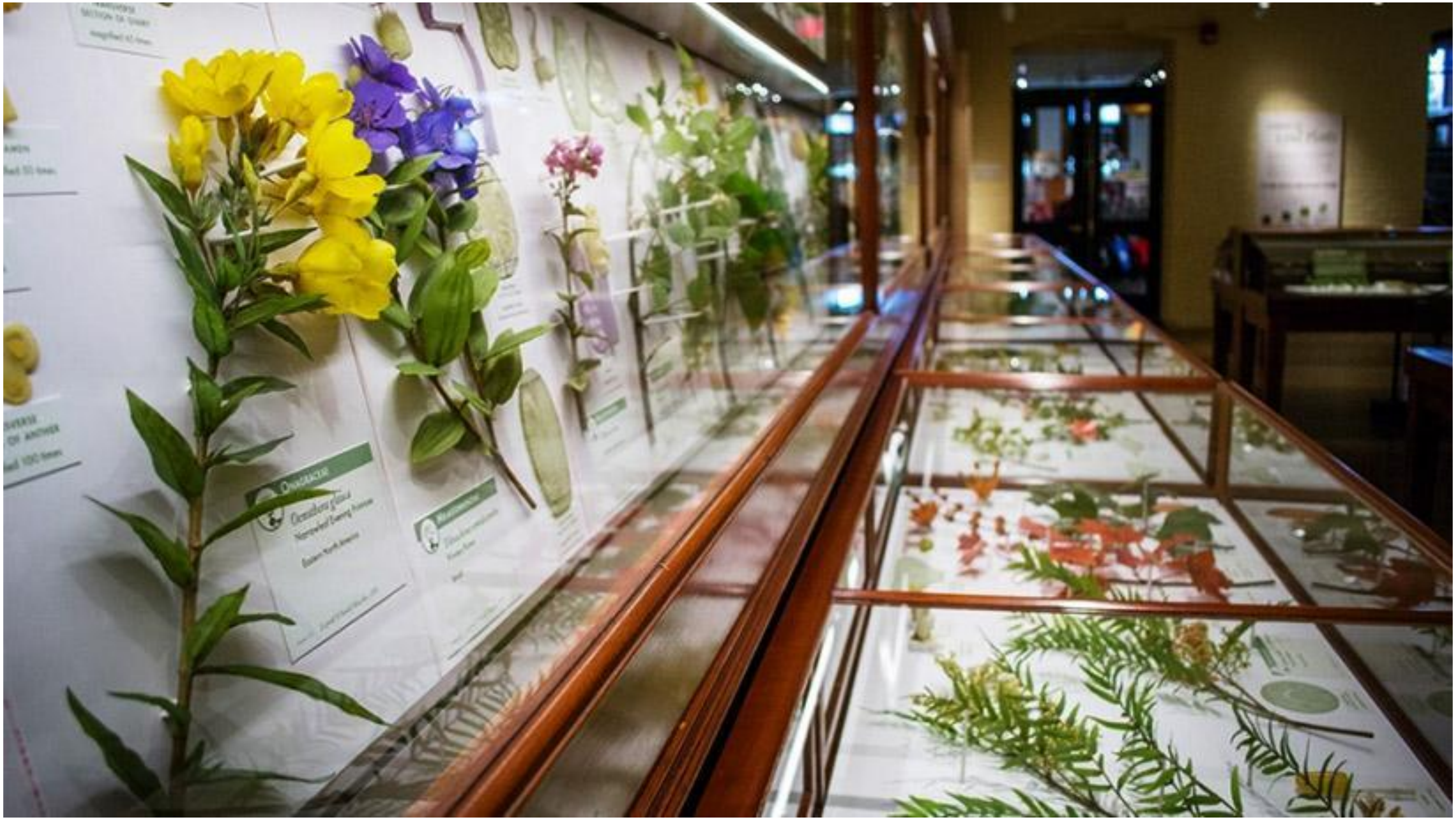
"For some visualization applications, the effects of refraction may be undesirable."



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



Harvard’s Glass Flowers



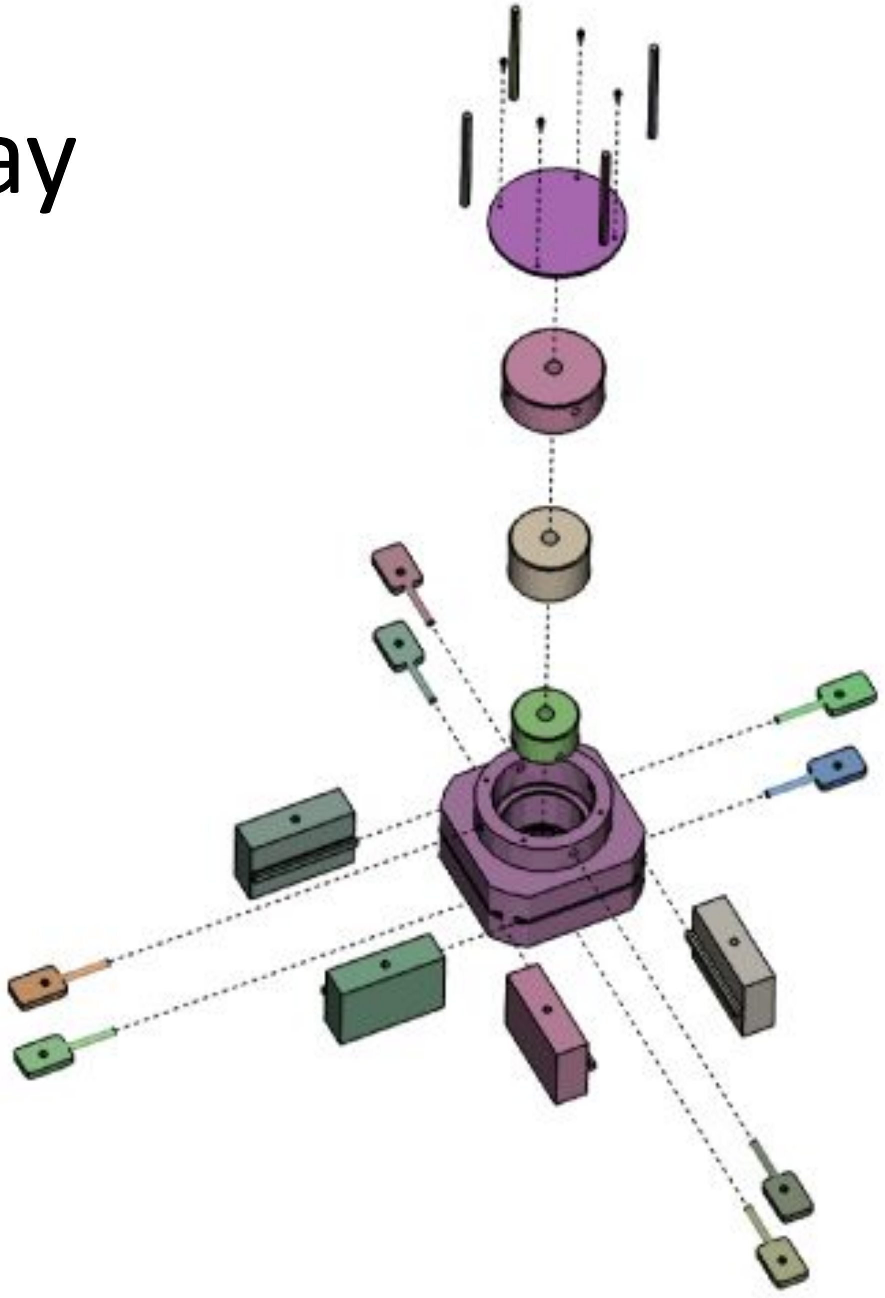
https://gardeninggonewild.com/glass-flowers-of-harvard/
https://hmnh.harvard.edu/glass-flowers

Today

- Homework 8: 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 (& a couple others)
  - "A Survey of Algorithms for Volume Visualization"
  - "Intuitive Exploration of Volumetric Data Using Dynamic Galleries"
  - "Interactive Dynamic Volume Illumination with Refraction and Caustics"
  - "Anisotropic Ambient Volume Shading"
- Readings for Friday

Reading for Tuesday

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



Homework Assignment 8: Volume Visualization Using Paraview

- *The last non-final project assignment*
- Download and experiment with Paraview...
- which is based on VTK: The Visualization Toolkit...
- from Kitware, and open-source software company *in Clifton Park, NY -- just north of RPI!*
- 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

Visualize data values on the surface of a volume

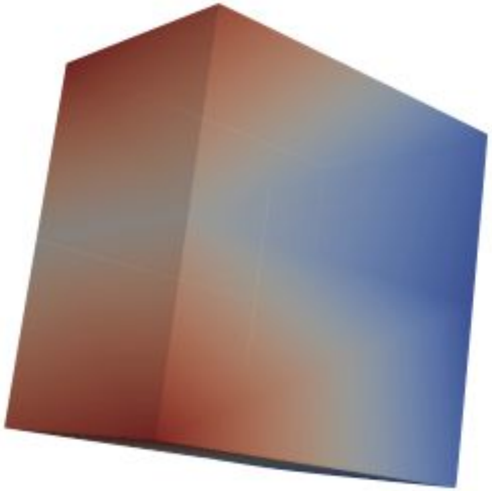


Figure 1: Frame 17 of the visualization

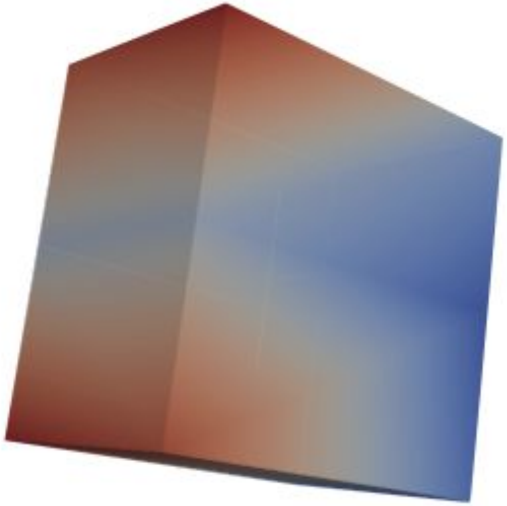


Figure 2: Frame 18 of the visualization

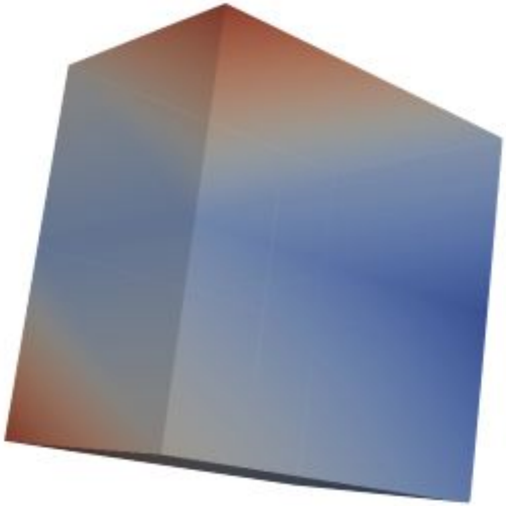


Figure 3: Frame 19 of the visualization

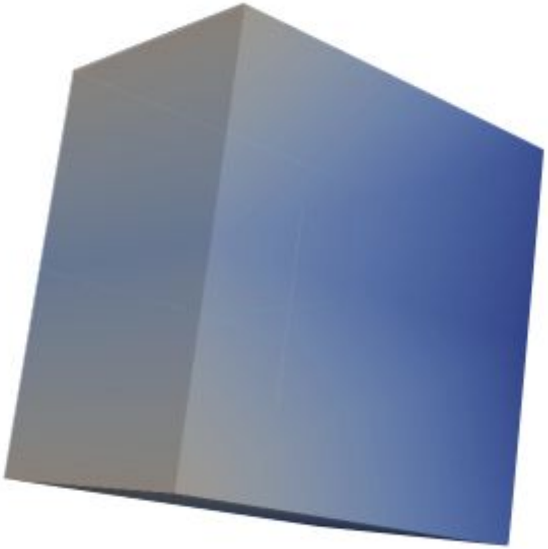
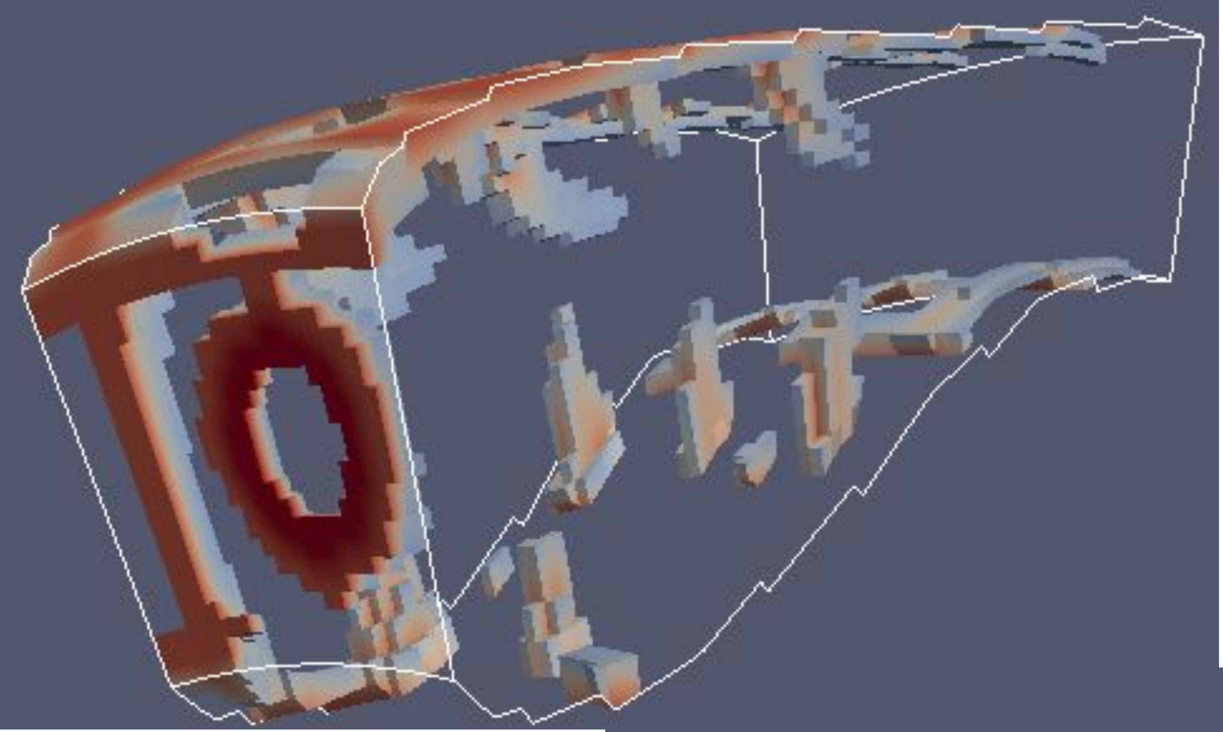
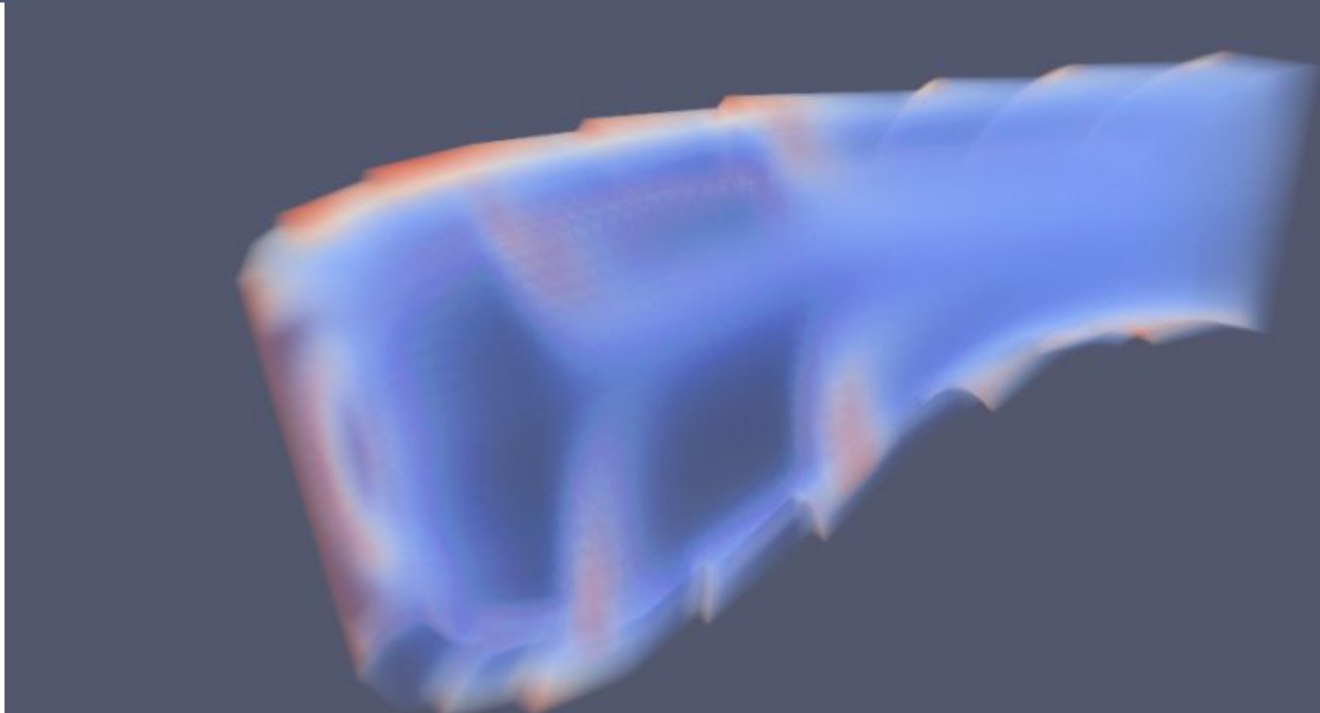


Figure 4: Frame 20 of the visualization

Using VTK HW - Elsa

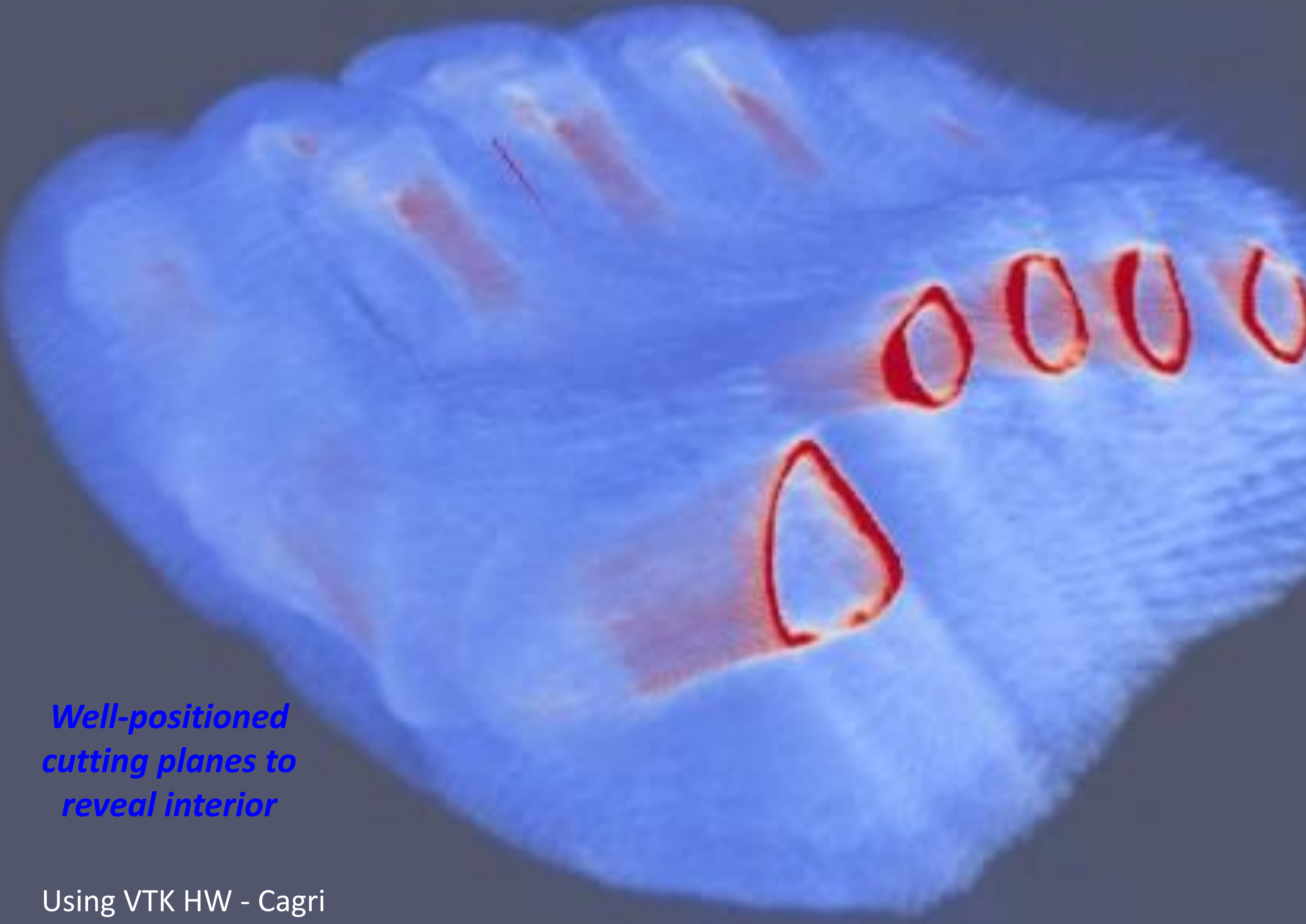


Threshold and show/hide cells



Transparency

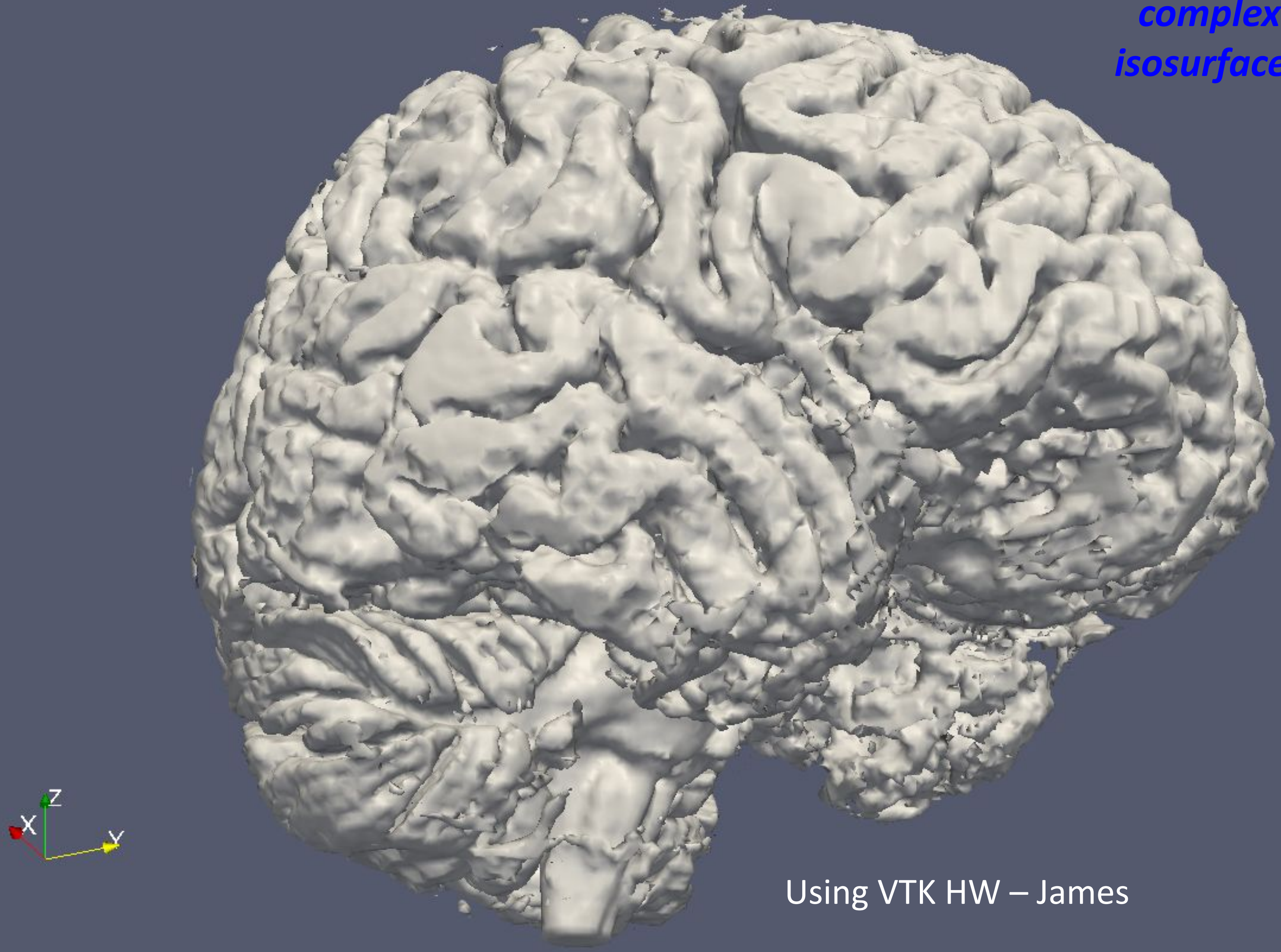
Using VTK HW - Artem



Well-positioned cutting planes to reveal interior

Using VTK HW - Cagri

Extraction of complex isosurfaces



Using VTK HW – James