CSE 332
Introduction to Visualization

Scientific Visualization

Klaus Mueller

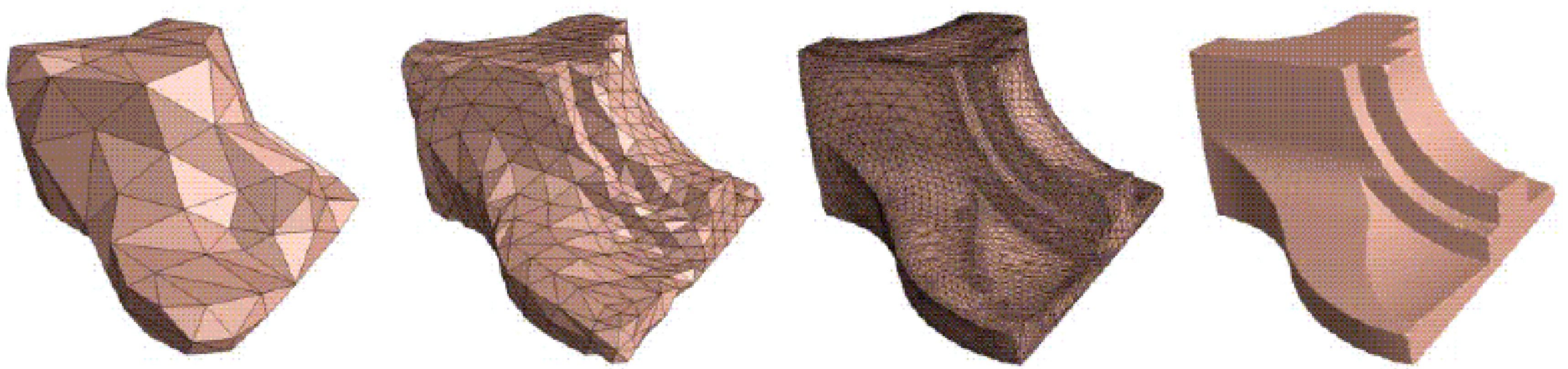
Computer Science Department
Stony Brook University

Lecture	Topic	Projects
1	Intro, schedule, and logistics	
2	Applications of visual analytics, data types	
3	Data sources and preparation	Project 1 out
4	Data reduction, similarity & distance, data augmentation	
5	Dimension reduction	
6	Introduction to D3	
7	Visual communication using infographics	
8	Visual perception and cognition	Project 2 out
9	Visual design and aesthetic	
10	D3 hands-on presentation	
11	Cluster analysis	
12	Visual analytics tasks and design	
13	High-dimensional data VIS: linear projections	Project 3 out
14	High-dimensional data VIS: optimized layouts	
15	Visualization of spatial data	
16	Midterm	
17	Visualization of spatial data	
18	Illumination and isosurface rendering	
19	Scientific visualization	
20	Midterm discussion	Project 4 out
21	Principles of interaction	
22	Visual analytics and the visual sense making process	
23	Visualization of graphs and hierarchies	
24	Visualization of time-varying and streaming data	Project 5 out
25	Maps	
26	Memorable visualizations, visual embellishments	
27	Evaluation and user studies	
28	Narrative visualization, storytelling, data journalism, XAI	

Rendering Volumes as Surfaces

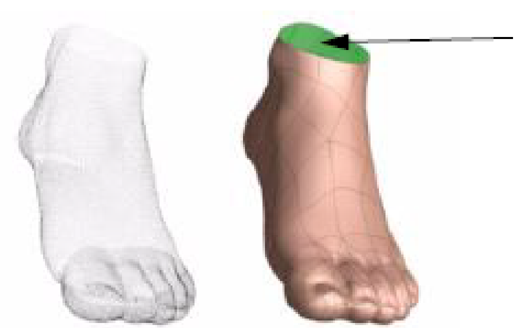
- Objects are explicitely defined by a surface or boundary representation (explicit inside vs outside)
- This boundary representation can be given by:

  - a mesh of polygons:



200 polys 1,000 polys 15,000 polys

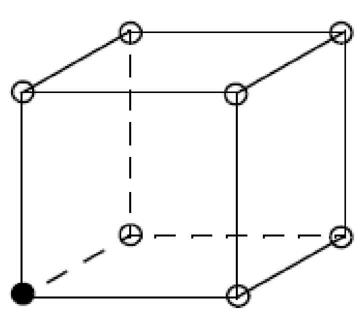
- a mesh of spline patches:



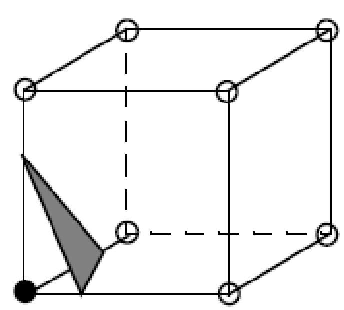
an “empty” foot

The Marching Cubes Polygonization Algorithm

- The *Marching Cubes (MC)* algorithm converts a volume into a polygonal model
  - this model *approximates* a chosen iso-surface by a mesh of polygons
  - the polygonal model can then be rendered, for example, using a fast z-buffer algorithm
  - if another iso-surface is desired, then MC has to be run again
- Steps:
  - imagine all voxels above the iso-value are set to 1, all others are set to 0
  - the goal is to find a polygonal surface that includes all 1-voxels and excludes all 0-voxels
  - look at one volume cell (a cube) at a time → hence the term *Marching Cubes*
  - here are 2 of 256 possible configurations:

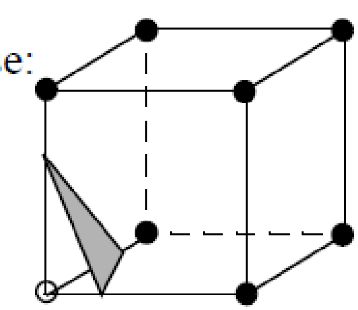


only 1 voxel > iso-value



the polygon that separates inside from outside

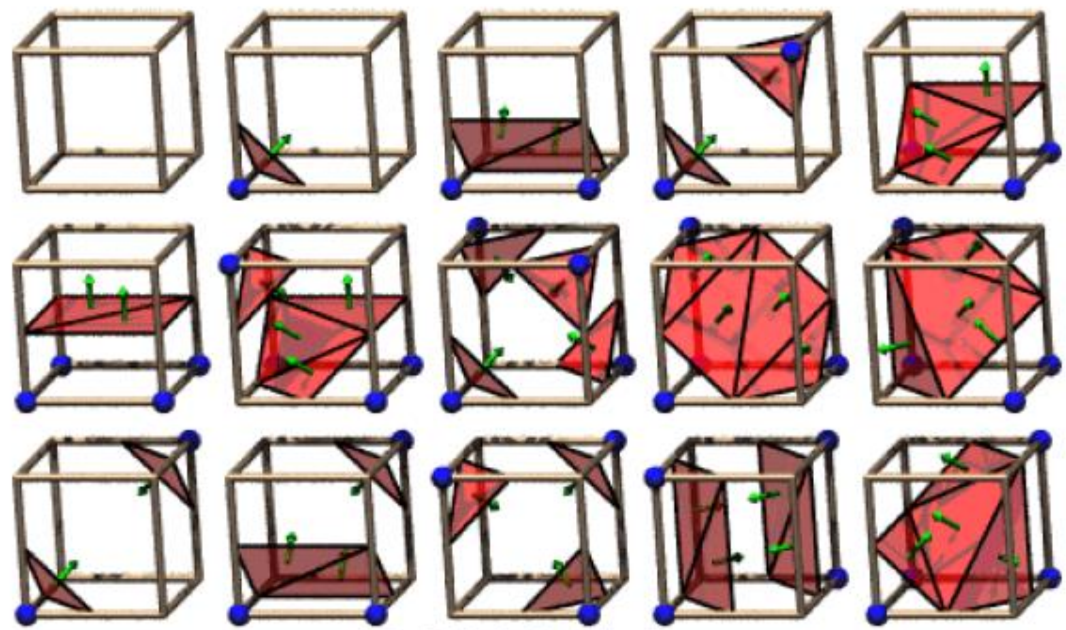
the reverse case:



7 voxels > iso-value
the same polygon results

Marching Cubes (2)

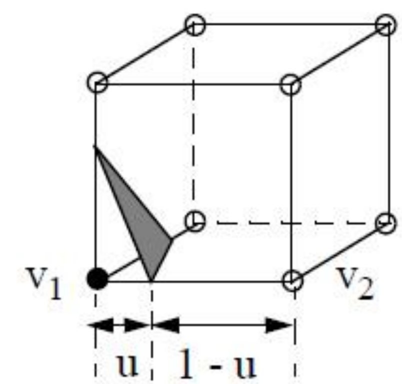
- One can identify 15 base cases
  - Use symmetry and reverses to get the other 241 cases



The 15 Cube Combinations

- The exact position of the polygon vertex on a cube edge is found by linear interpolation:

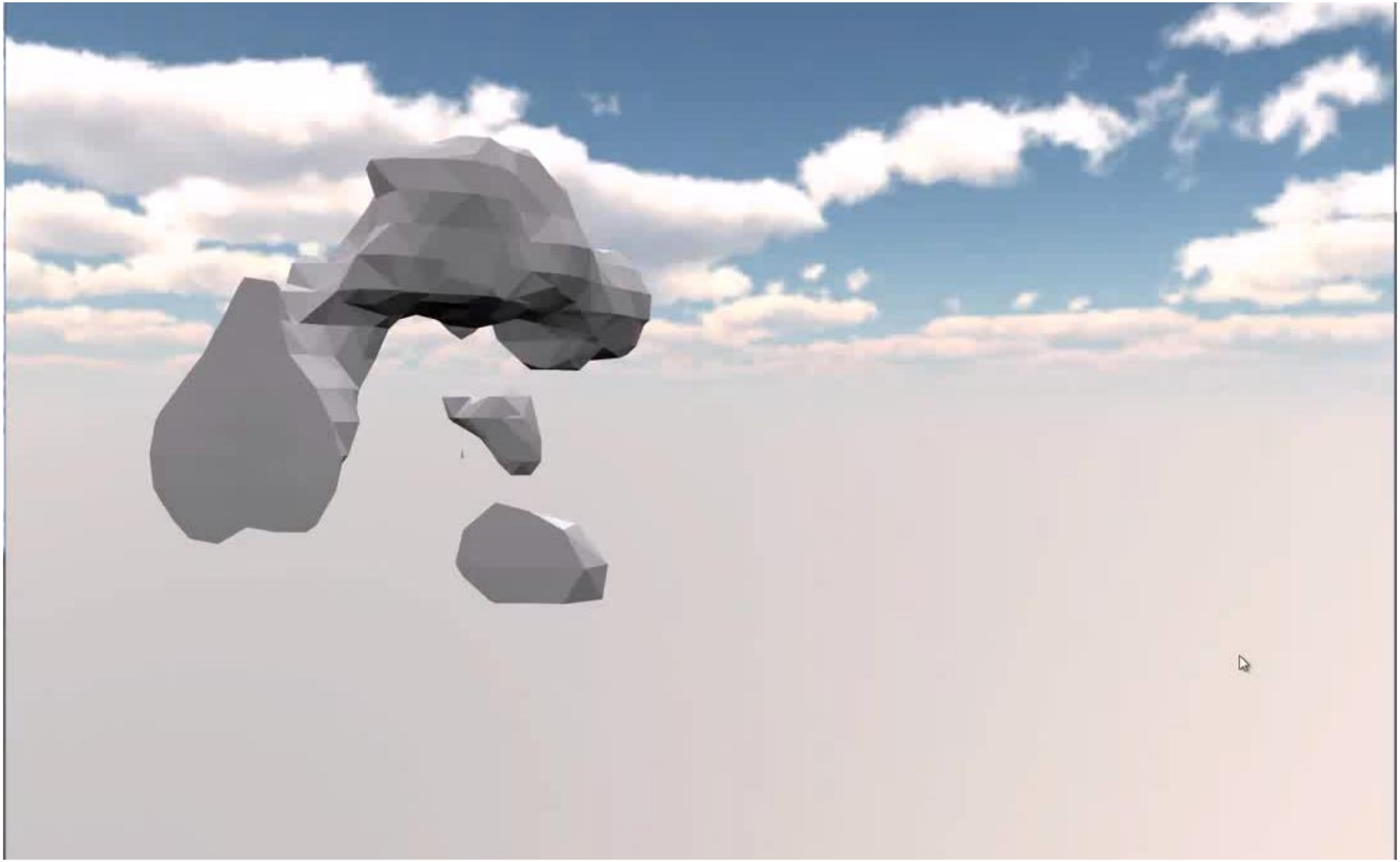
$$iso = v_1 \cdot (1-u) + v_2 \cdot u \longrightarrow u = \frac{v_1 - iso}{v_1 - v_2}$$



- Now interpolate the vertex color by: $c_1 = uc_2 + (1-u)c_1$
- Interpolate the vertex normal by: $\boldsymbol{n}_1 = u\boldsymbol{g}_2 + (1-u)\boldsymbol{g}_1$

(the **g1** and **g2** are the gradient vectors at v1 and v2 obtained by central differencing)

Real-Time Marching Cubes



What is It?

10 petaFLOPS Titan supercomputer (released in 2012)

- 10^{15} floating point ops per second (1 PetaFlop)

18,688 AMD Opteron 6274 16-core CPUs

18,688 Nvidia Tesla K20X GPUs

What Does it Do?

Compute, compute, compute

Examples:

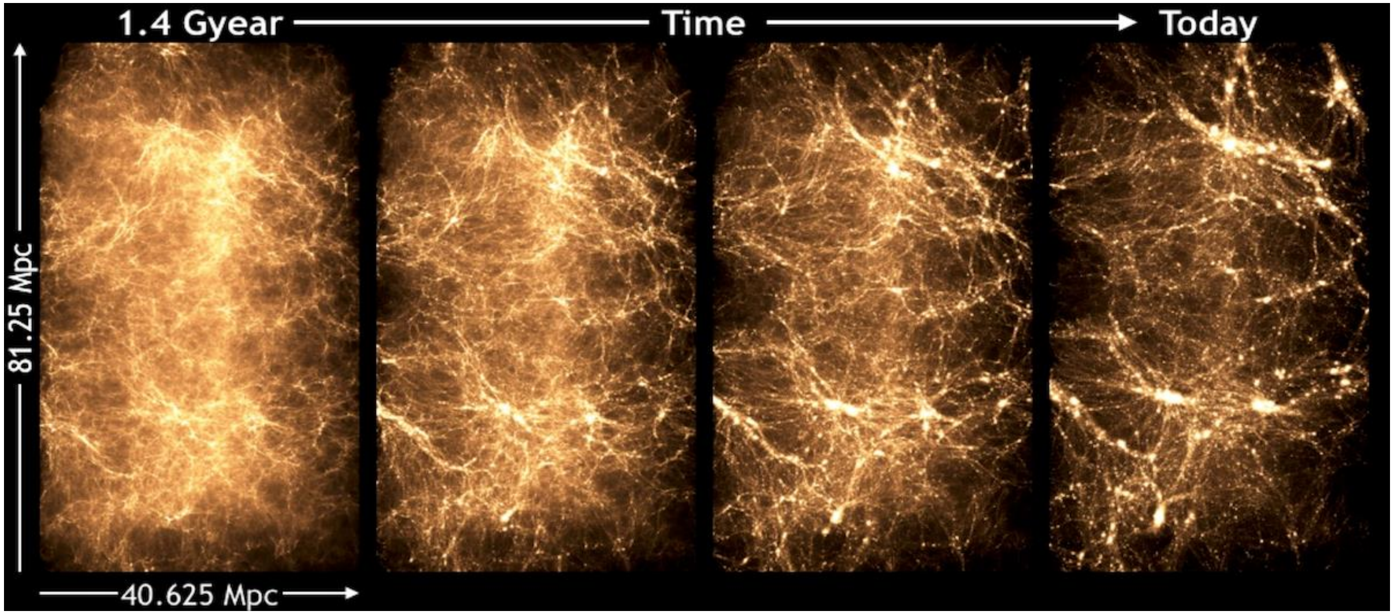
- S3D, a project that models the molecular physics of combustion, aims to improve the efficiency of diesel and biofuel engines
- Denovo simulates nuclear reactions with the aim of improving the efficiency and reducing the waste of nuclear reactors
- WL-LSMS simulates the interactions between electrons and atoms in magnetic materials at temperatures other than absolute zero
- Bonsai is simulating the Milky Way Galaxy on a star by star basis, with 200 billion stars
- Non-Equilibrium Radiation Diffusion (NRDF) plots non-charged particles through supernovae with potential applications in laser fusion, fluid dynamics, medical imaging, nuclear reactors, energy storage and combustion

What Does it Output

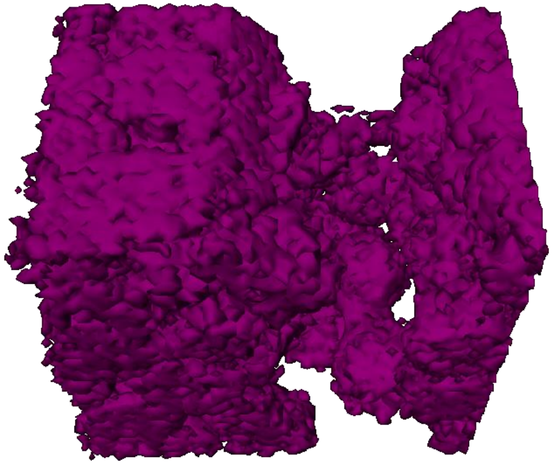
Numbers, lots of them

- Titan's I/O subsystem is capable of pushing around 240 GB/s of data
- that's a lot to visualize

Example: a visualization of the Q Continuum simulation for cosmology

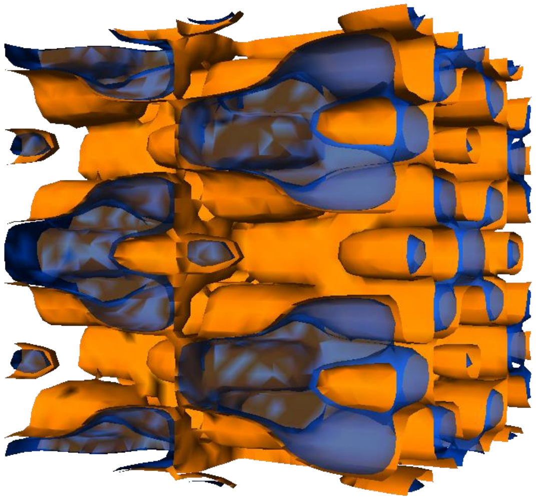


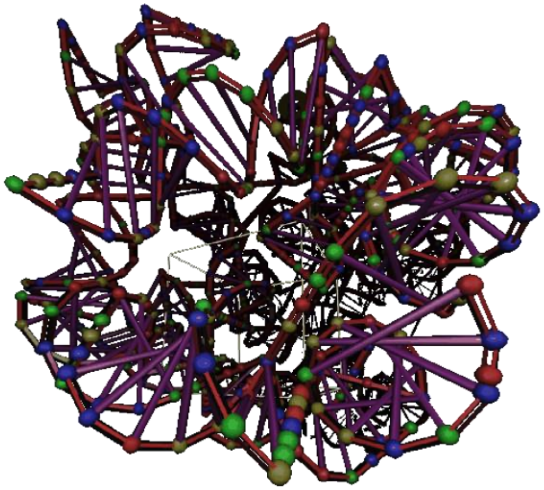
More Examples



Nuclear, Quantum, and Molecular Modeling

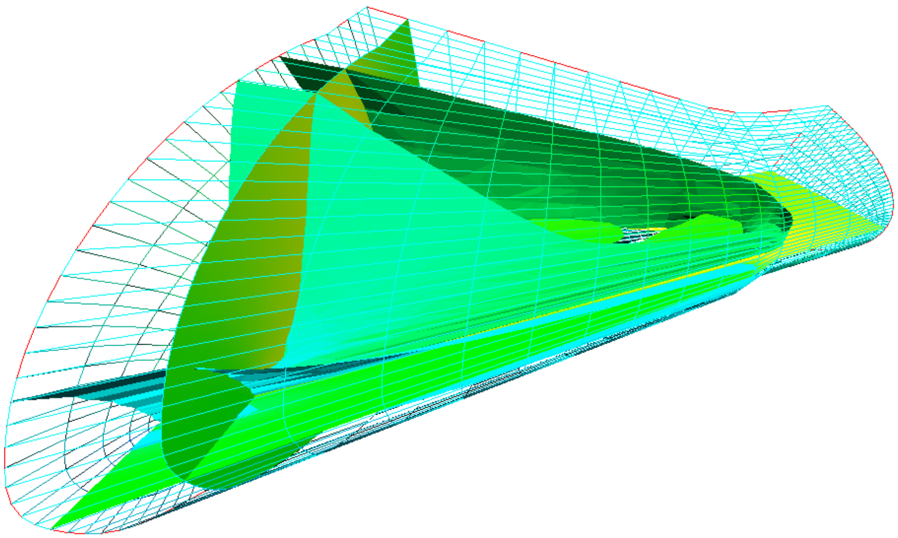
Structures, Fluids and Fields



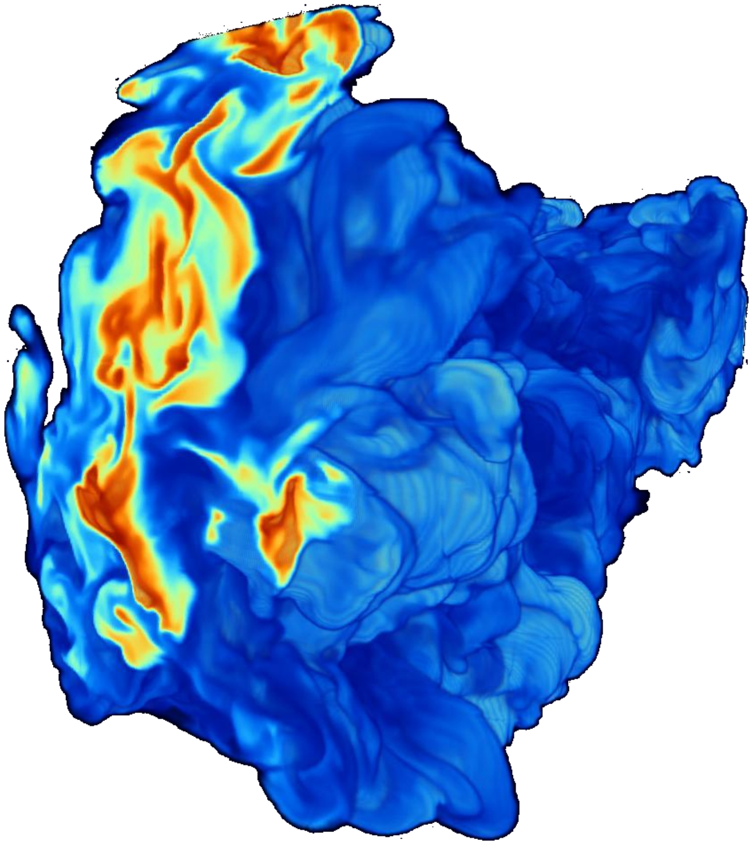


Advanced Imaging and Data Management

More Examples



Surface Rendering with vTK
(The Visualization Toolkit

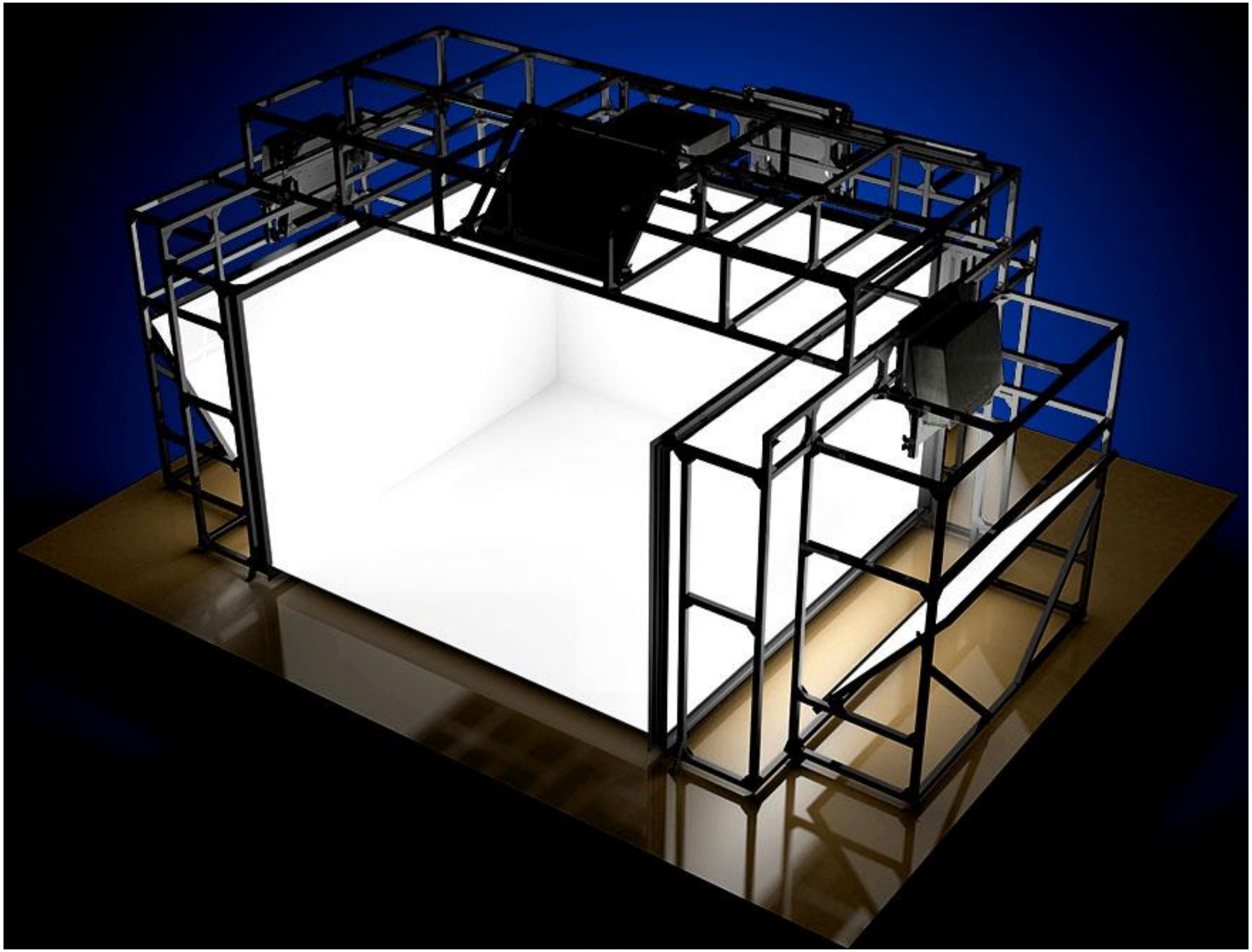


Volume Rendering

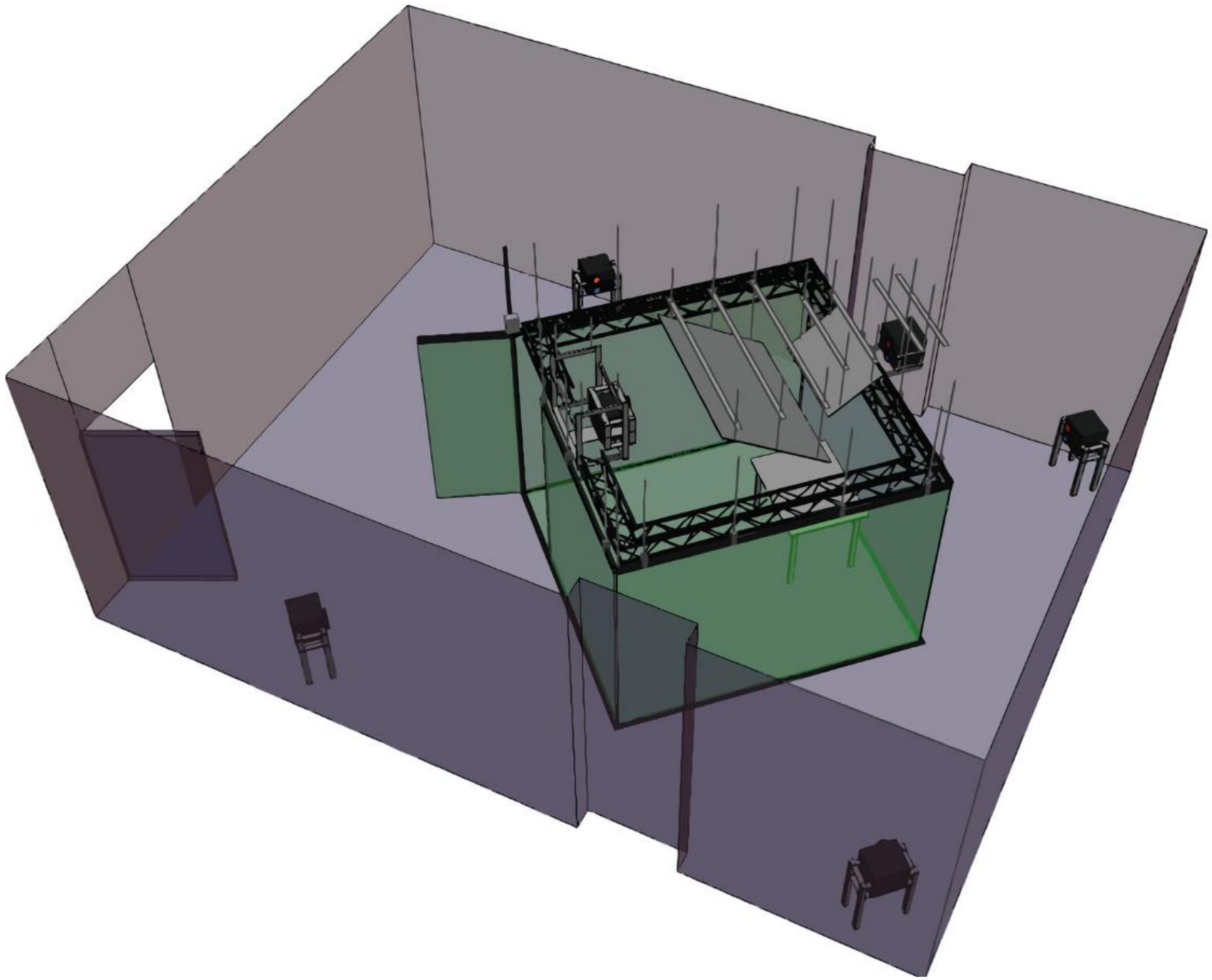
Where to Visualize All This?

Display Wall

CAVE



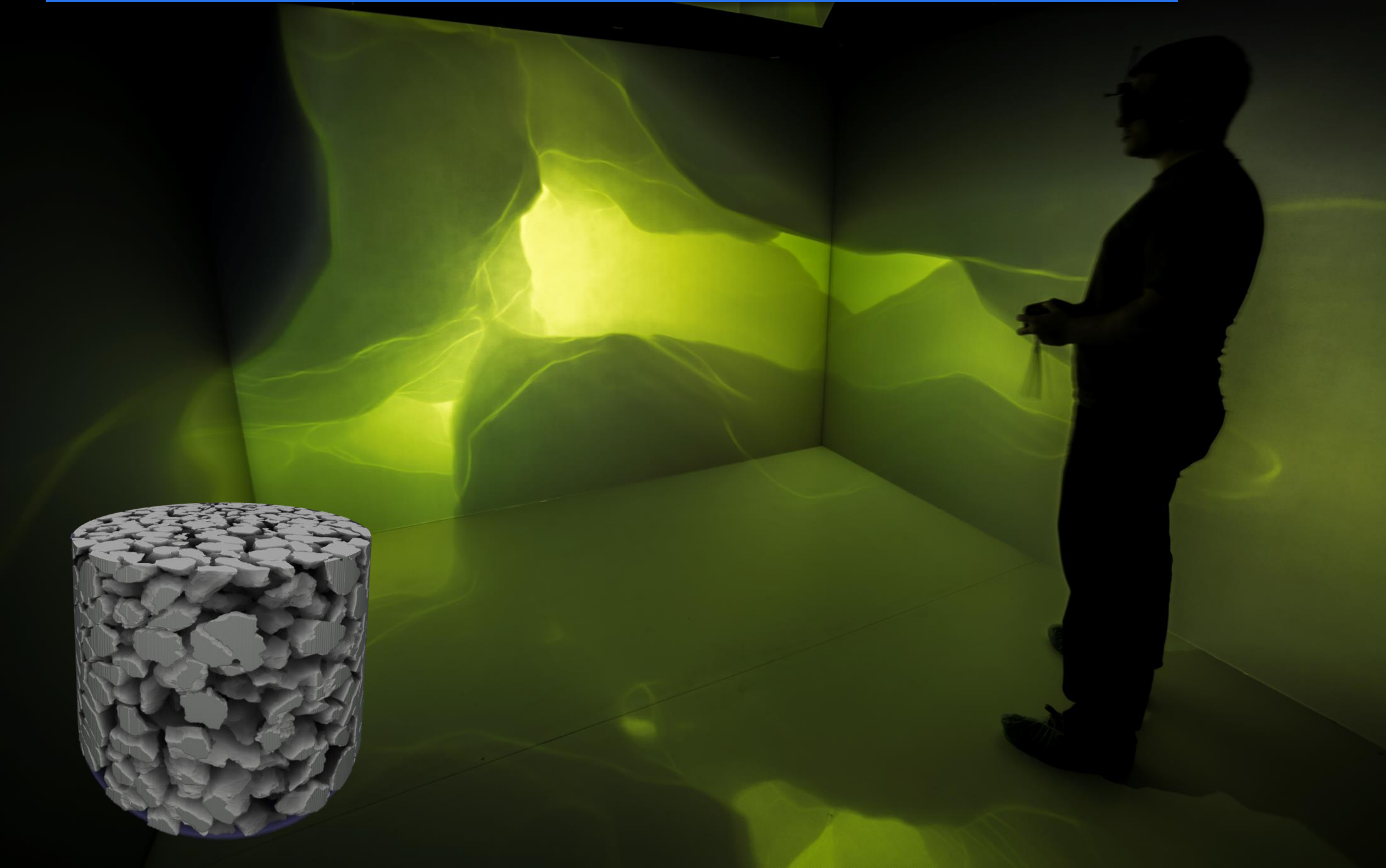
The Stony Brook Immersive Cabin



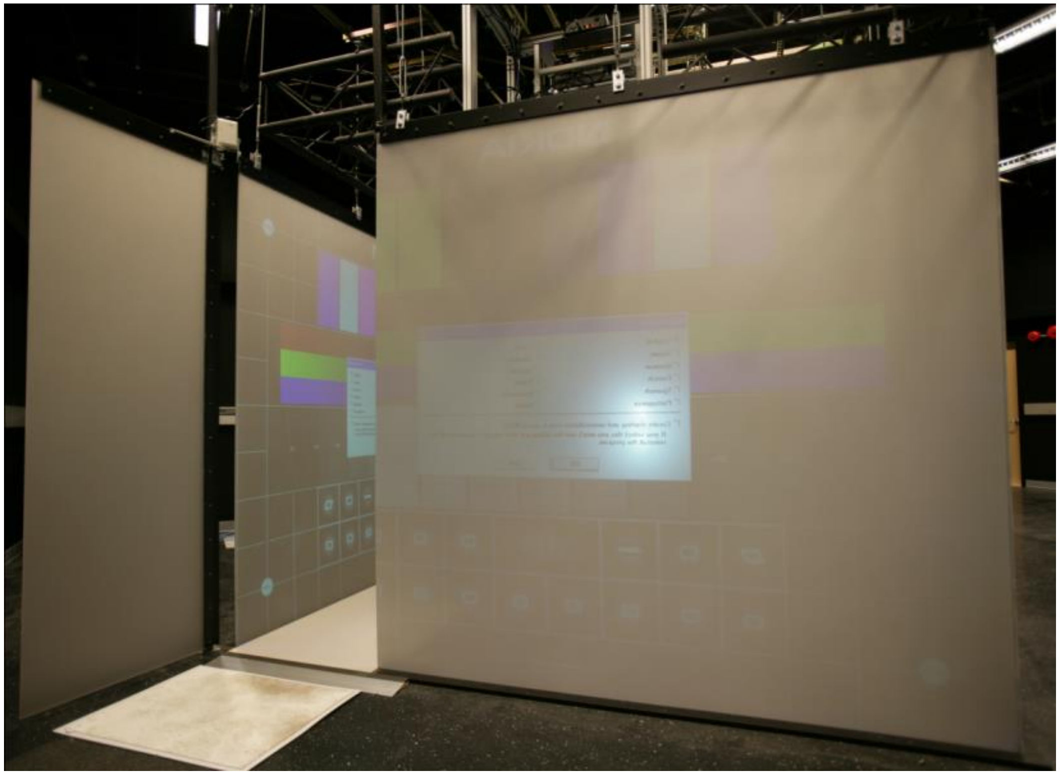
CAVE

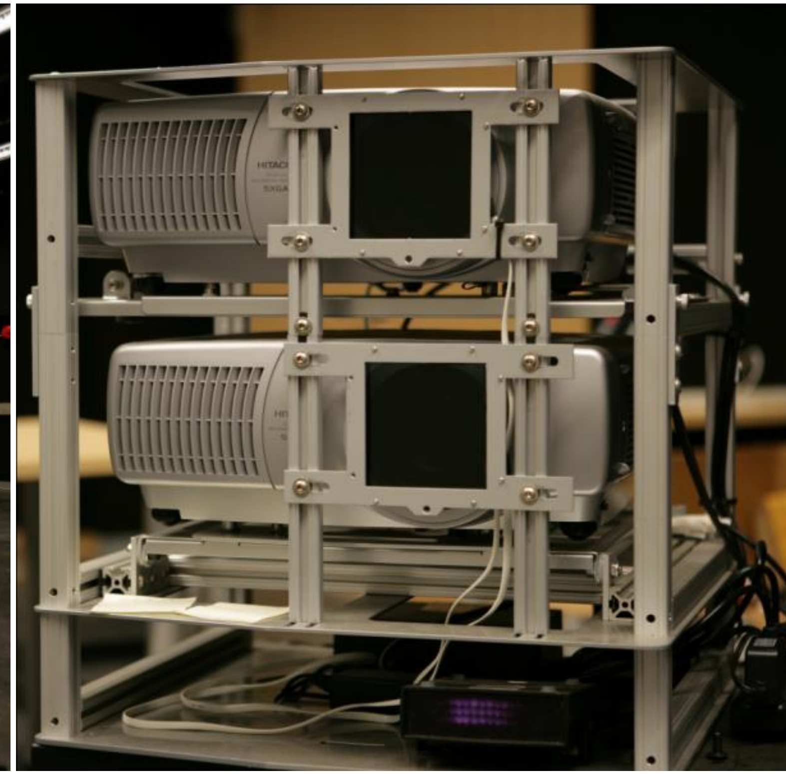
Microtomography

(BNL, soil sample)



The Stony Brook Immersive Cabin





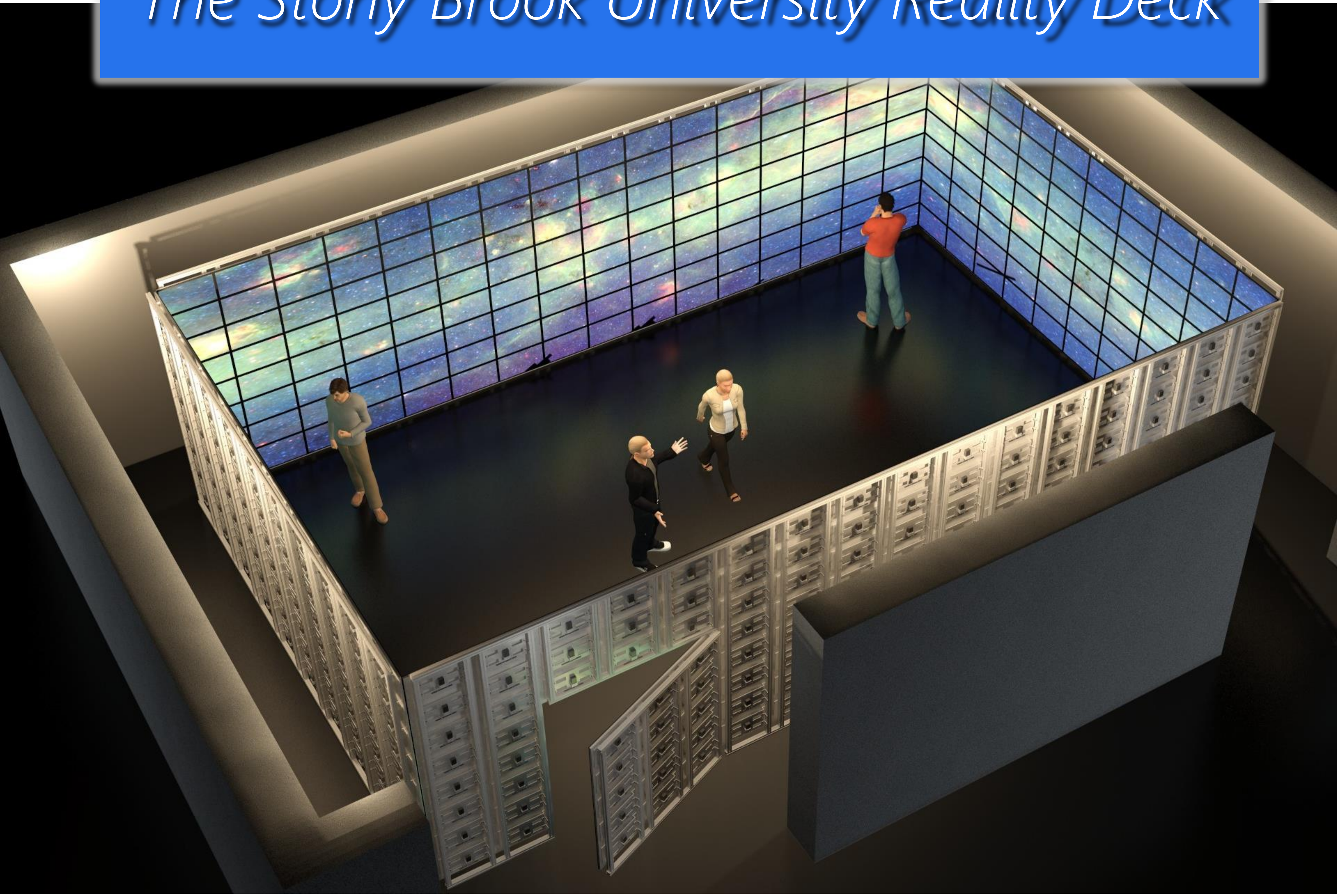
Projector based system

- 5 walls, 12′×12′ footprint, 8′ tall
- difficult to scale up to Giga-pixel range

Can We Get Bigger?

(yes we can)

The Stony Brook University Reality Deck



The Reality Deck – Under the Hood

Visualization

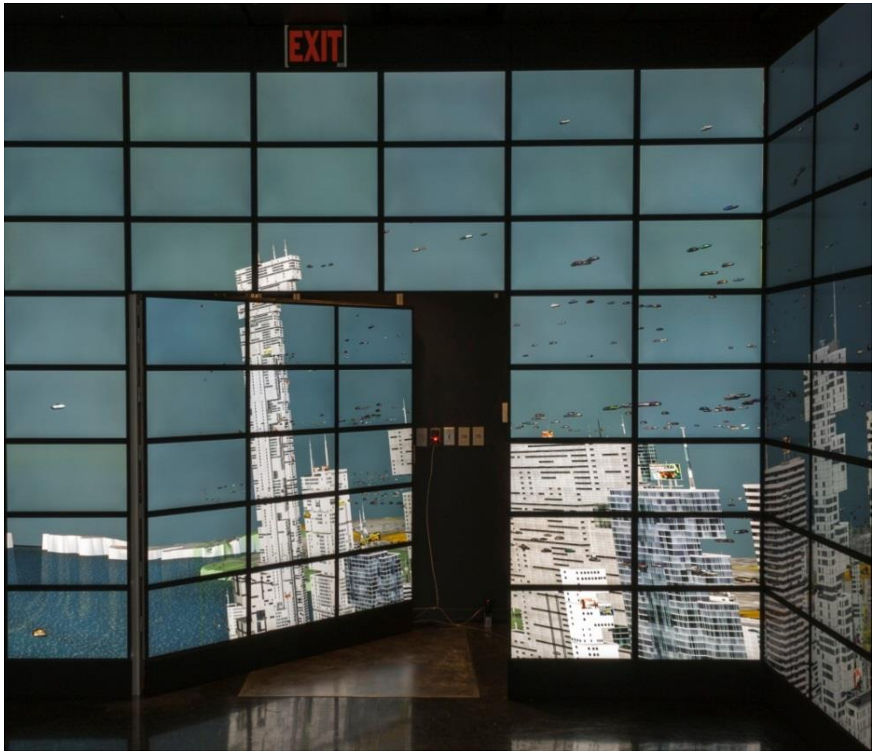
- 30′×40′×11′ environment
- 416 UQXGA LCD Displays
  - 2,560×1,440 resolution over 50’-100’ DisplayPort cables
  - fast response time, wide viewing angles, good dynamic range
- 20-node GPU cluster, each node equipped with:
  - 2× Six-core CPUs, 48 GB Ram
  - 4× AMD FirePro V9800 with 4GB Ram and 6 DisplayPort outputs each
  - AMD S400 hardware video synchronization card
  - 40Gb Infiniband adapter
  - 1TB storage
- In total:
  - 1,533,542,400 pixels (1.5 Gigapixel) over 6 miles of DisplayPort cables
  - 240 CPU cores: 2.3 TFLOPs peak performance, 20 TB distributed memory
  - 80 GPUs: 220 TFLOPs peak performance, 320 GB distributed memory

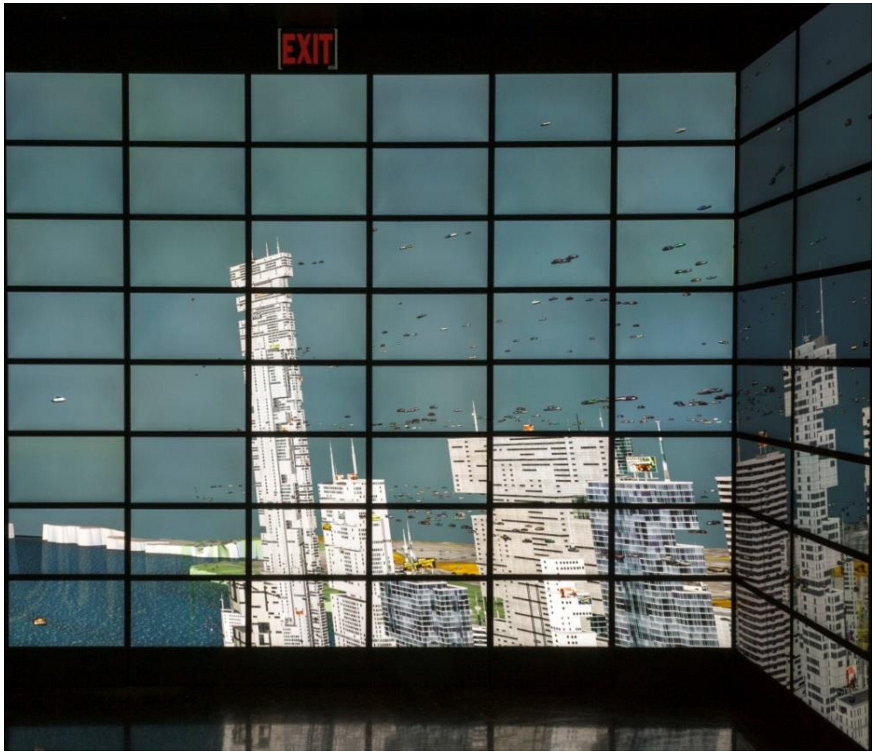
Automatic Door

3×5 section of displays

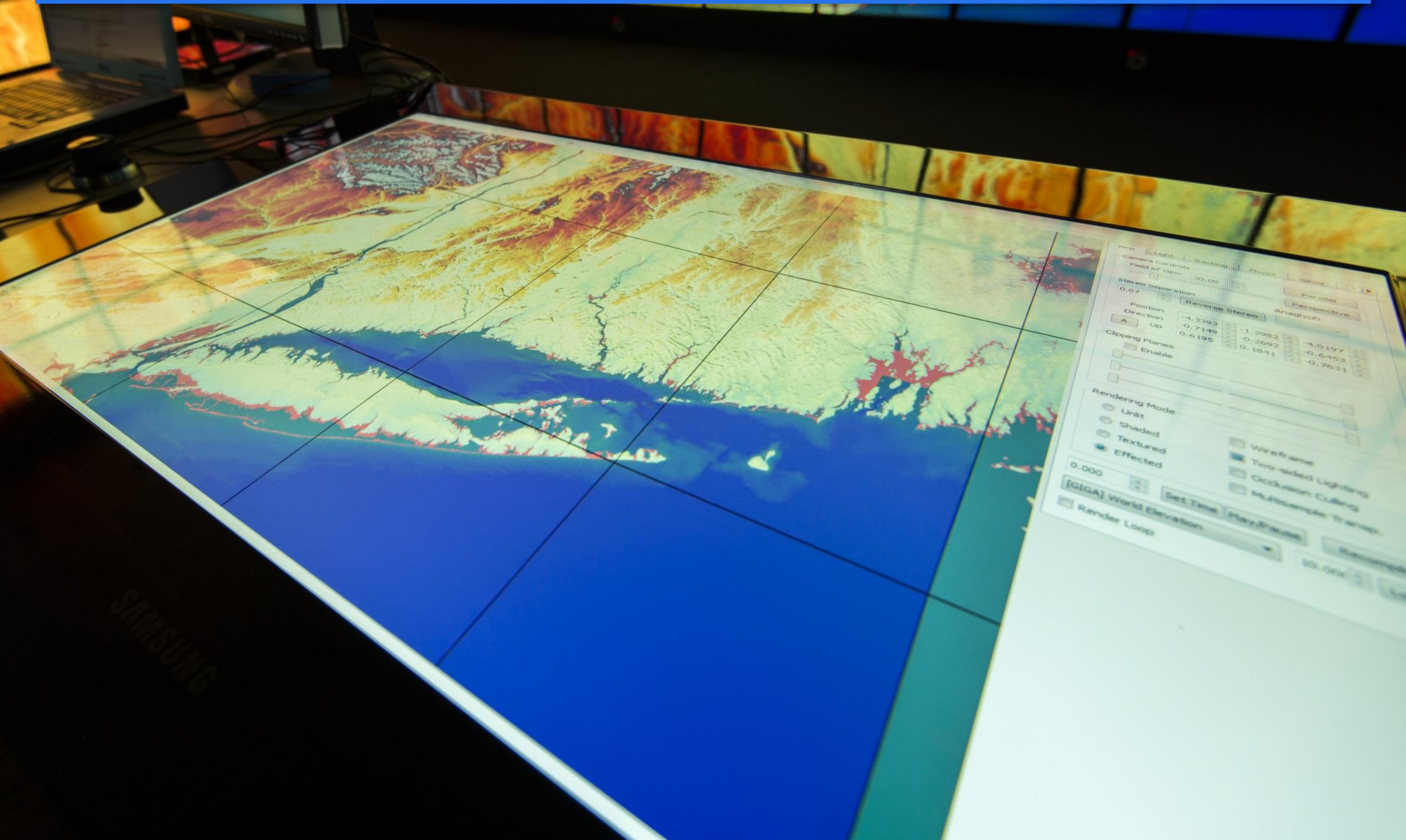
Visually indistinguishable from rest of display

- allows for a fully enclosed visualization environment



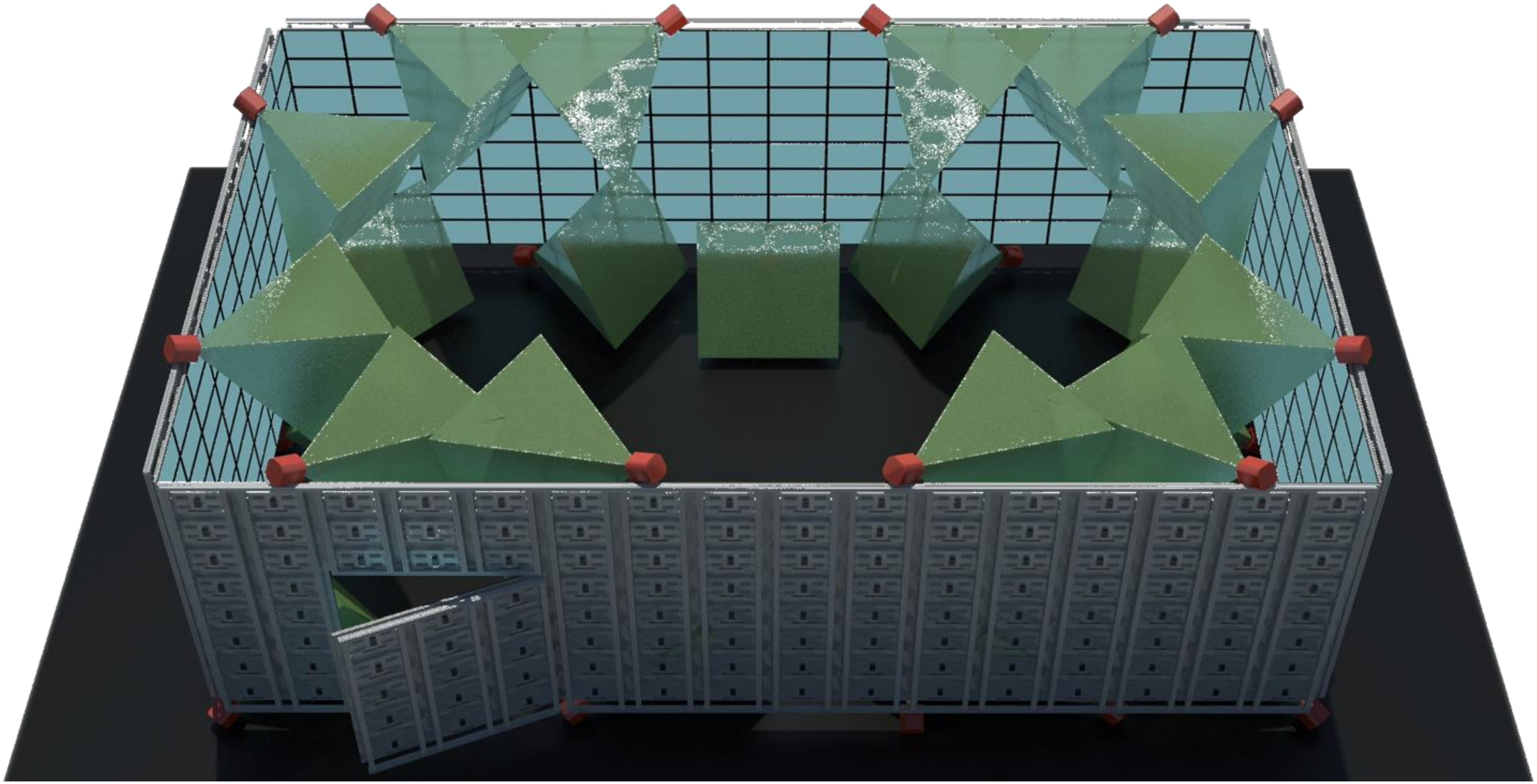


Touch Table


Rendering Mode
Unlit
Shaded
Textured
Effected
Wireframe
Two-sided Lighting
Occlusion Culling
[GIGA] World Elevation
Set Time
Play/Pause
Render Loop

Reality Deck Tracking System

24-camera infrared optical system from OptiTrack

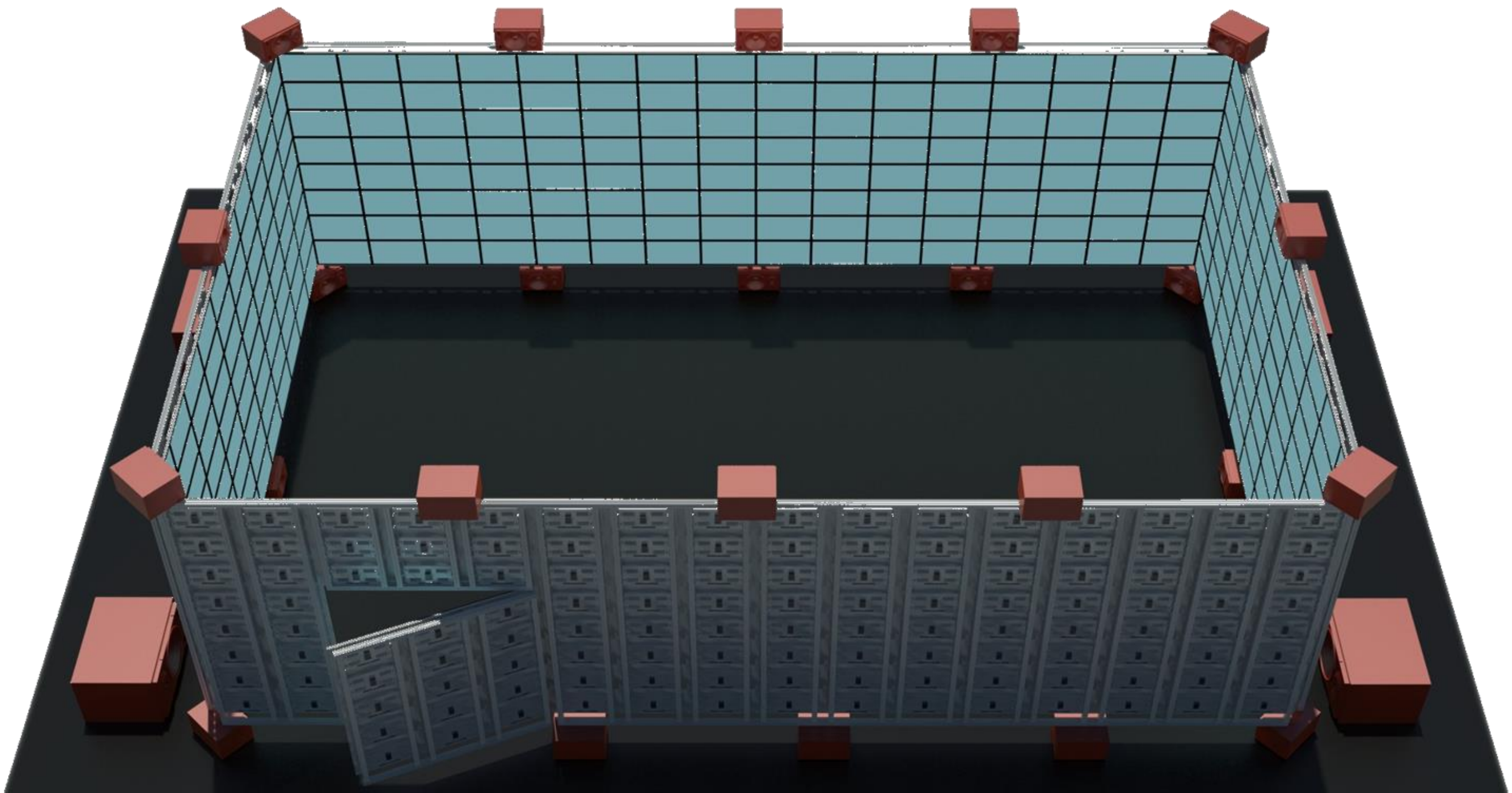


Reality Deck Sound System

24.4 channel professional-grade system

Positional audio with real-time ambisonics

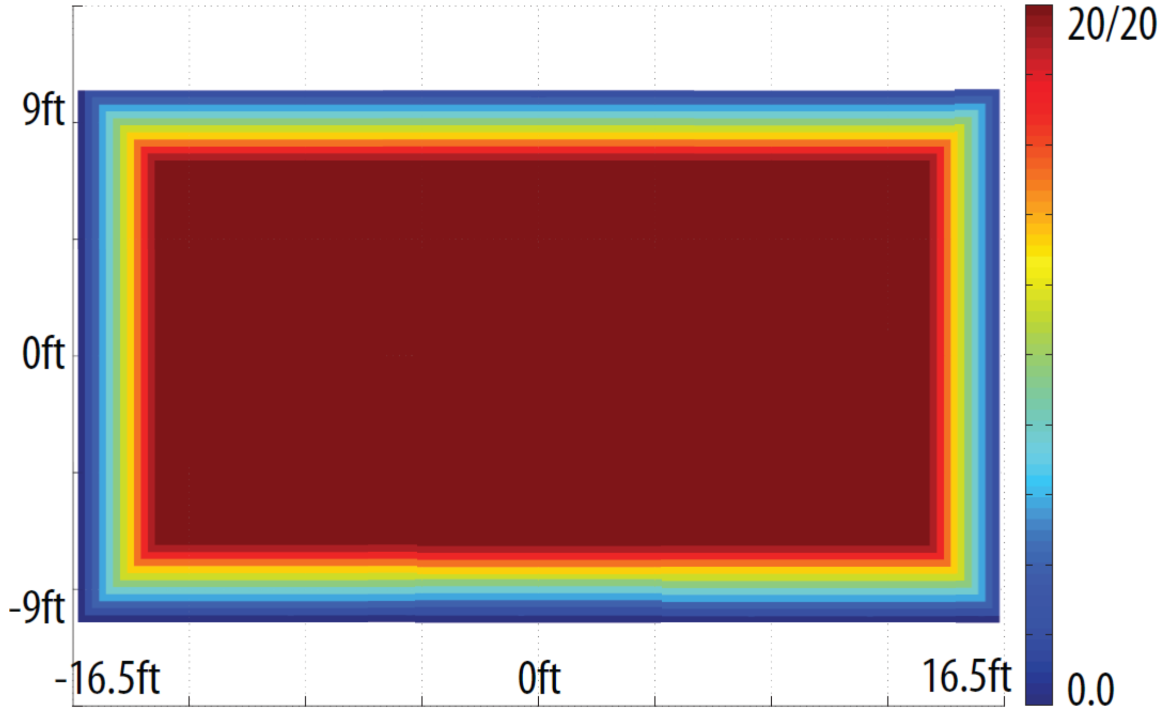
- using the Rapture3D OpenAL driver



Uniformly High Visual Acuity

User can make visual queries at an instant

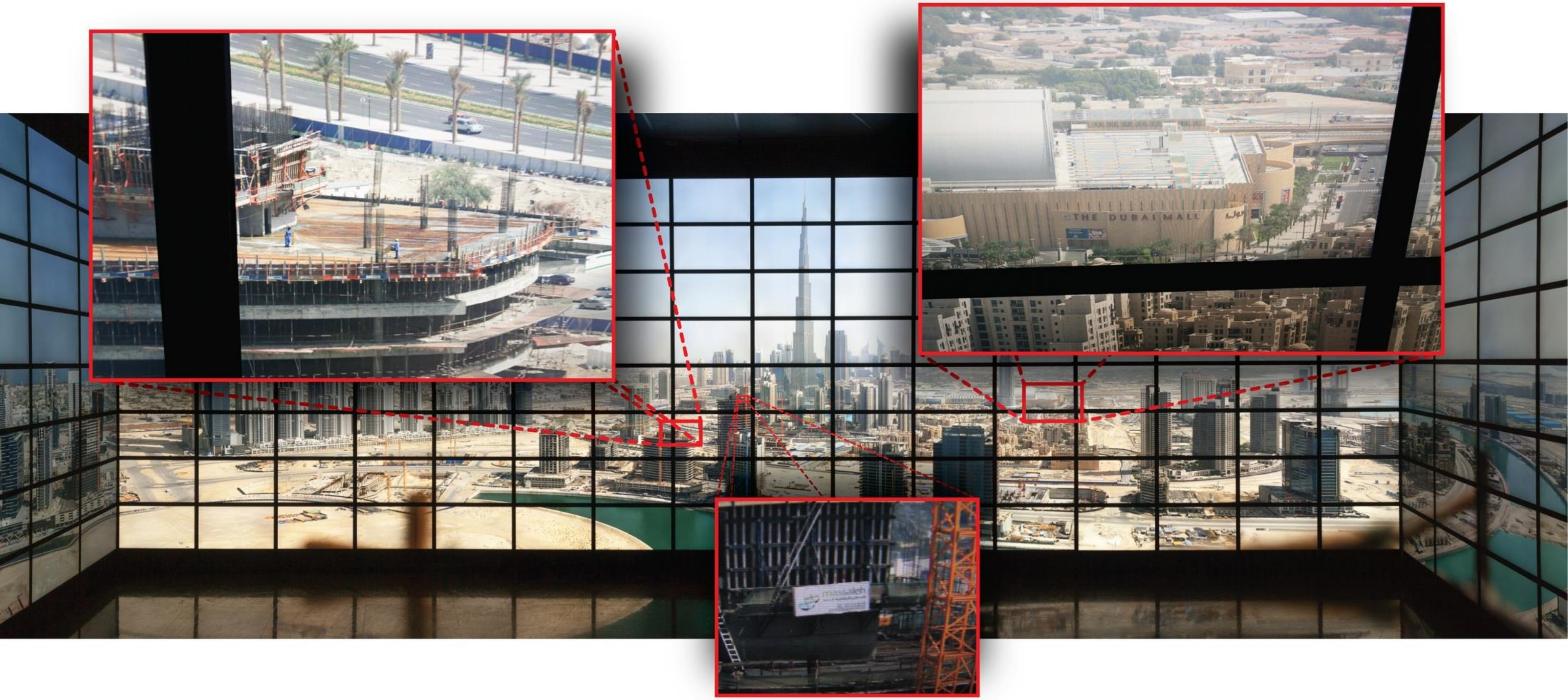
- walk up to obtain more detail
- just like in real life – hence the Realty Deck
- 20/20 visual acuity at 1.5′-2′ away



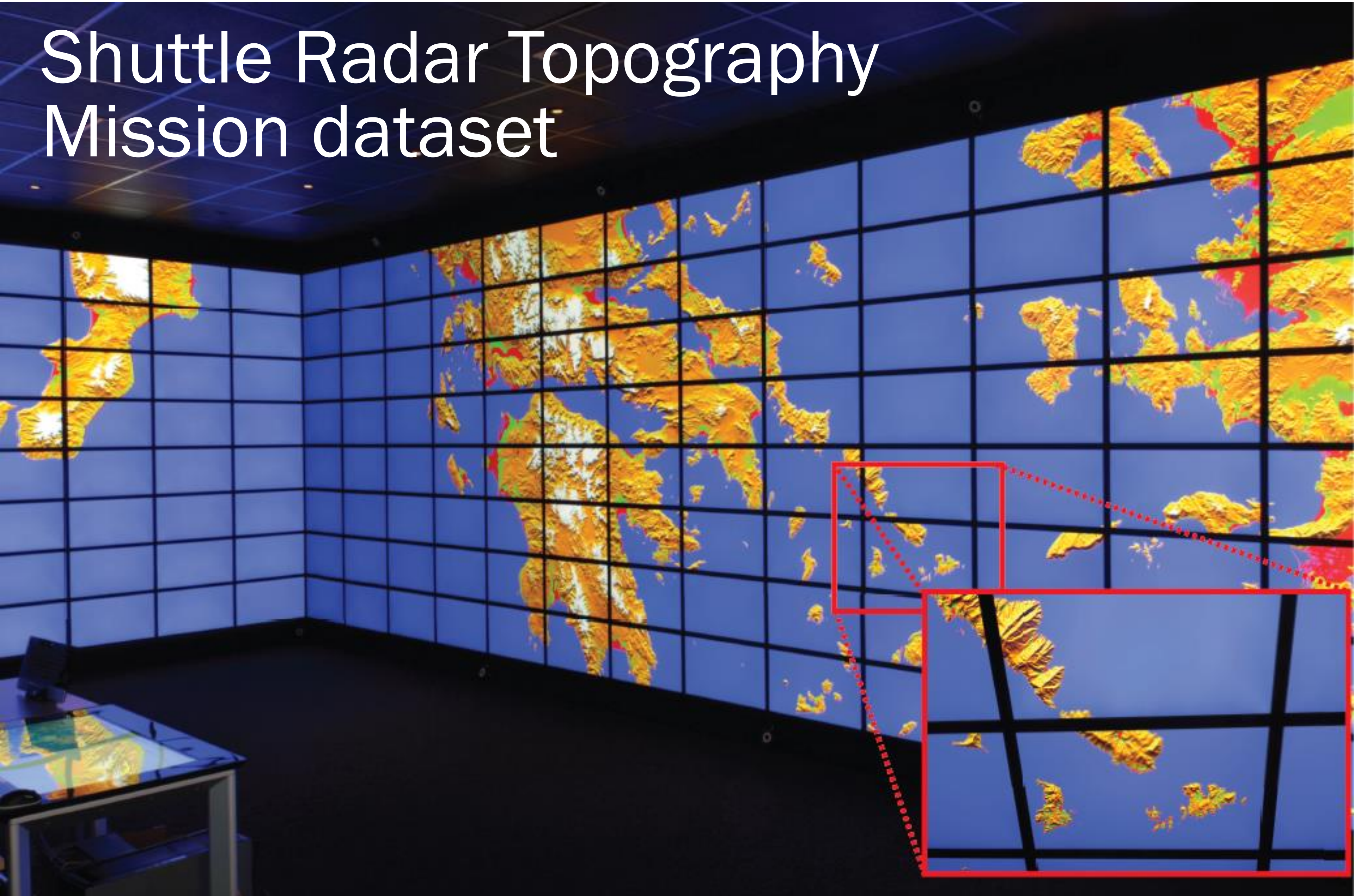
Gigapixel Visualization

Dubai dataset

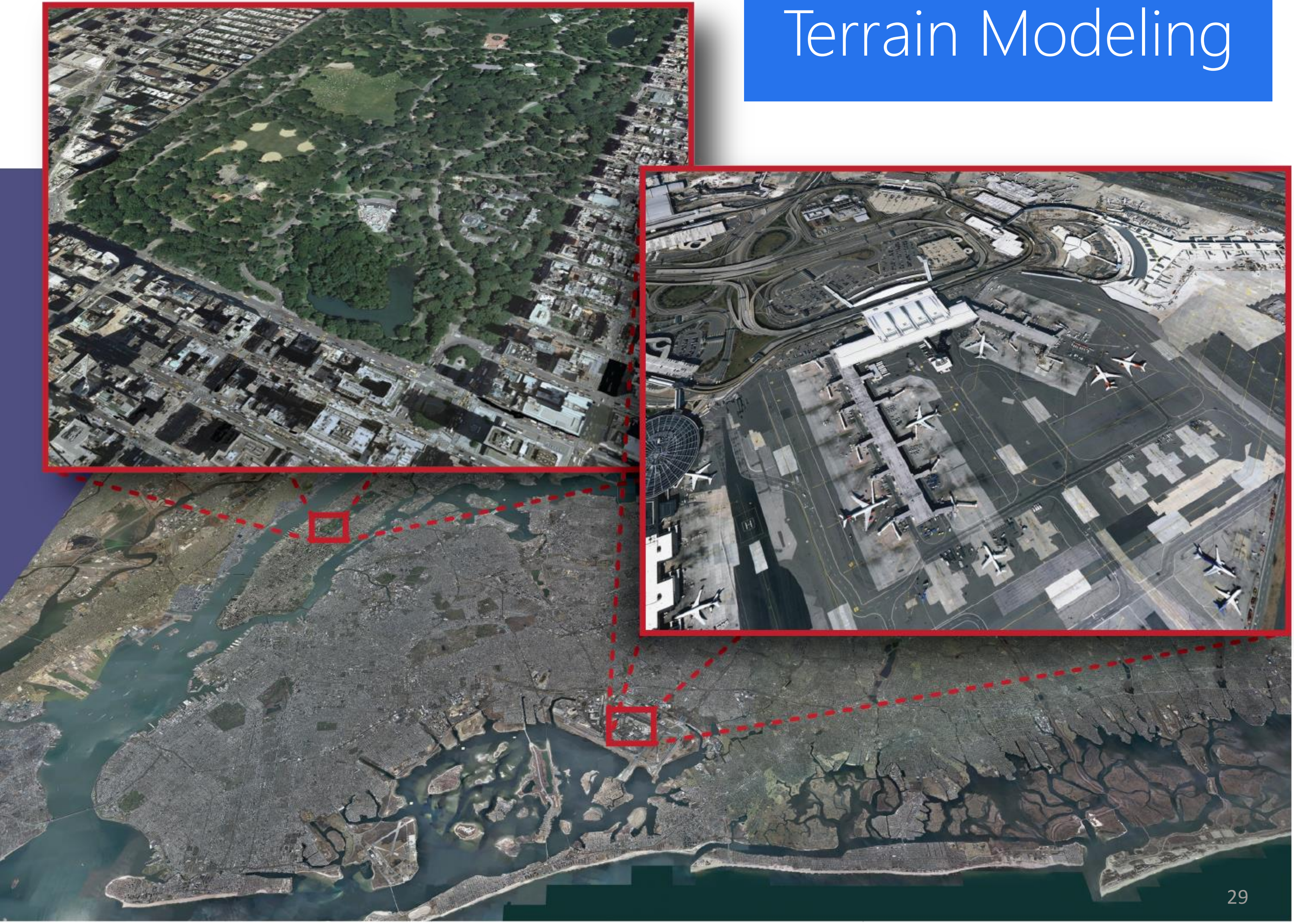
- 45 Gigapixels, 180° field of view



Shuttle Radar Topography Mission dataset



Terrain Modeling



3D Relief Map

Sea level simulation

Protein Visualization

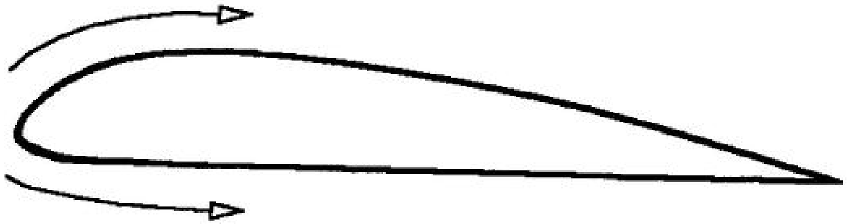
Reality Deck

Scientific Simulation

Say, you want to simulate the airflow around an airplane wing

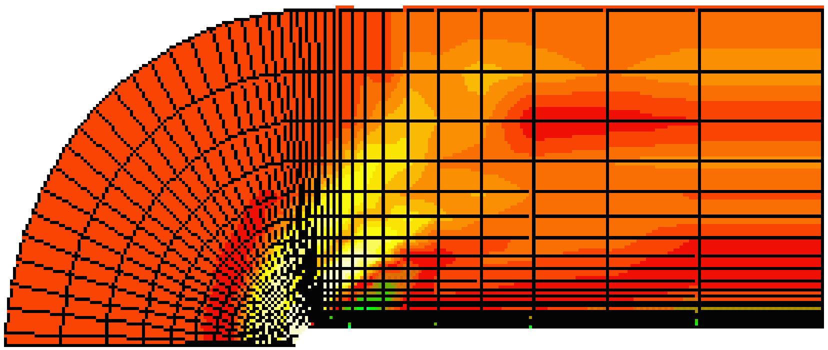
- where is the flow most interesting?

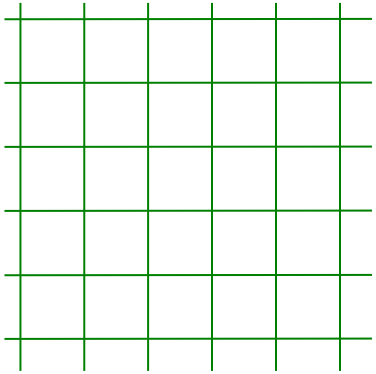
- right, close to the surface



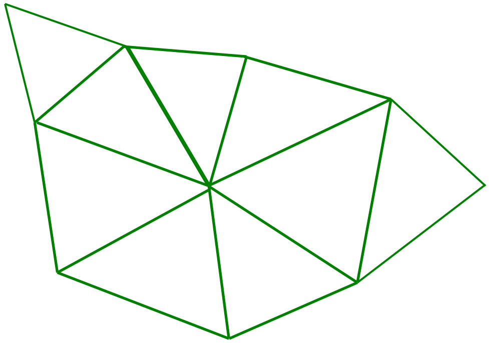
Simulation lattice

Make the simulation lattice densest along the surface





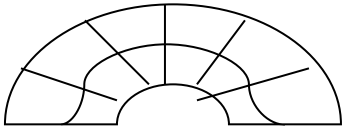
Regular → irregular grids



GRIDS

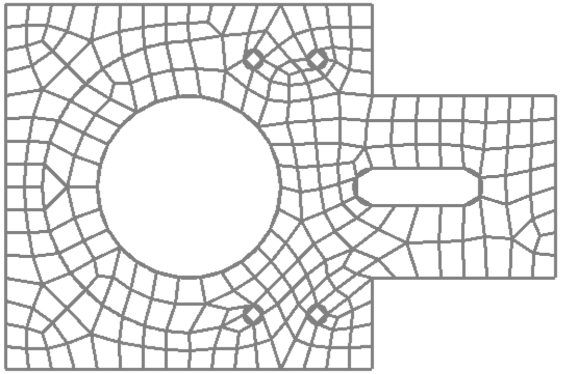
Structured grid

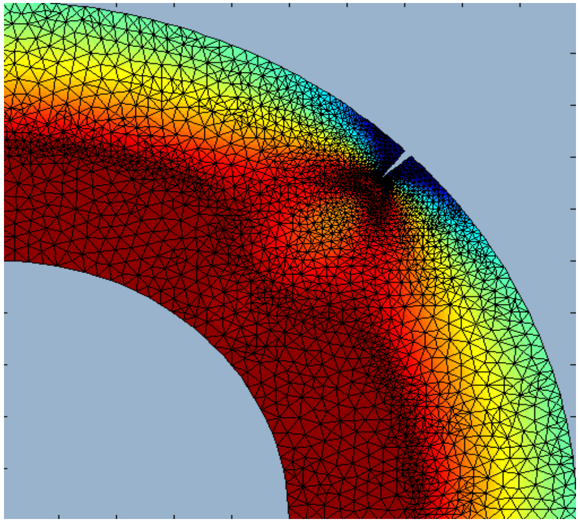
- more or less a bent regular grid

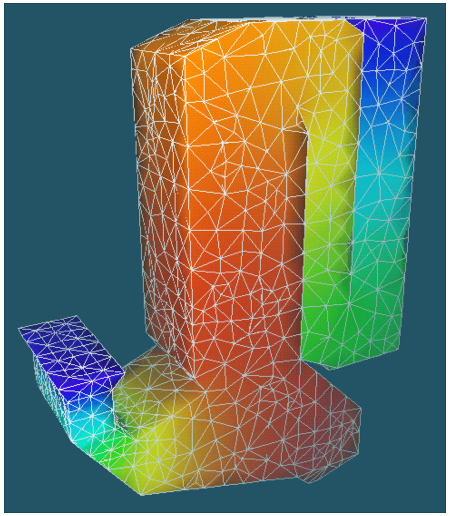


Unstructured grid

- collection of vertices, edges, faces and cells whose connectivity information must be explicitly stored





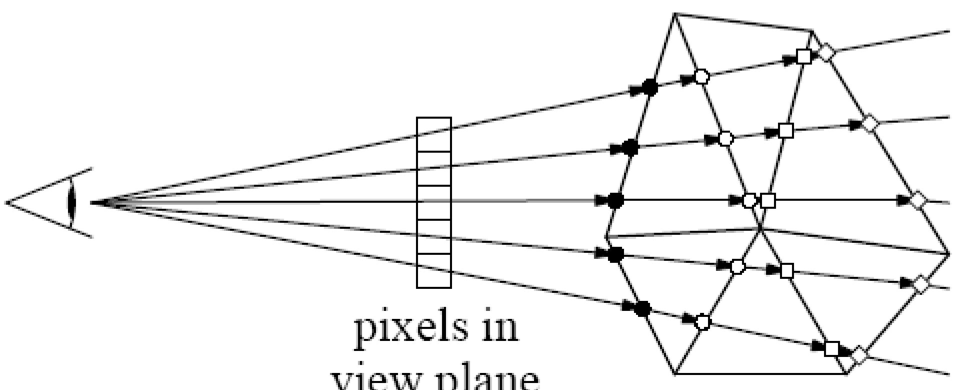


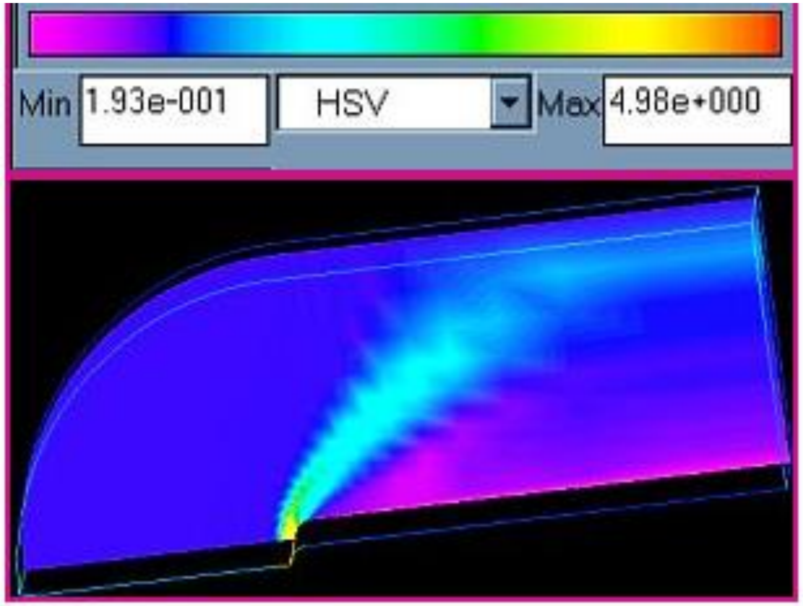
The Bluntfin Dataset

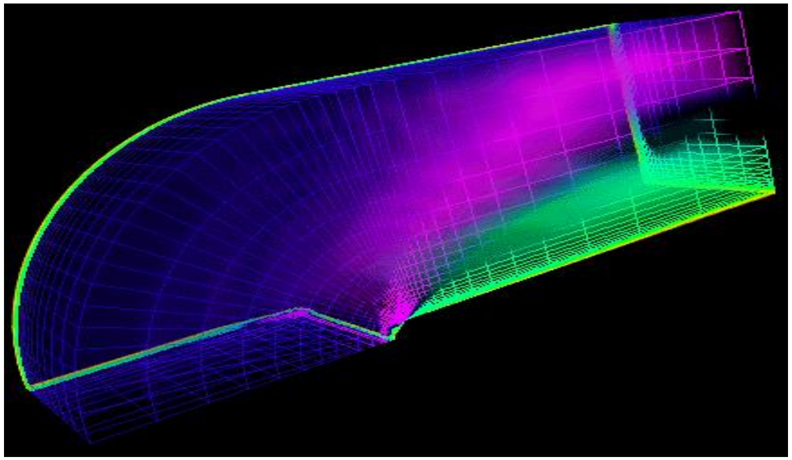
Mapping flow strength to color

Rendering by cell traversal

- go from cell to cell
- composite colors and opacities

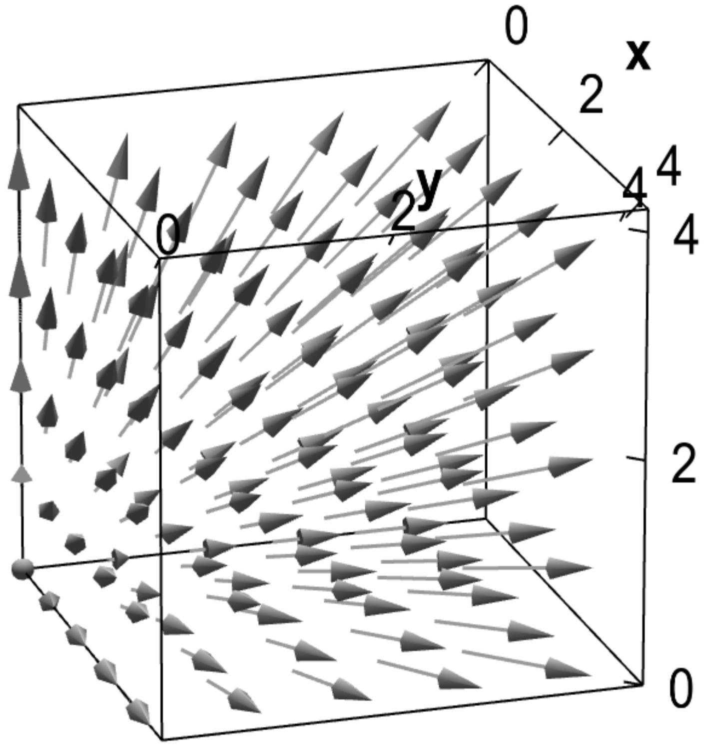


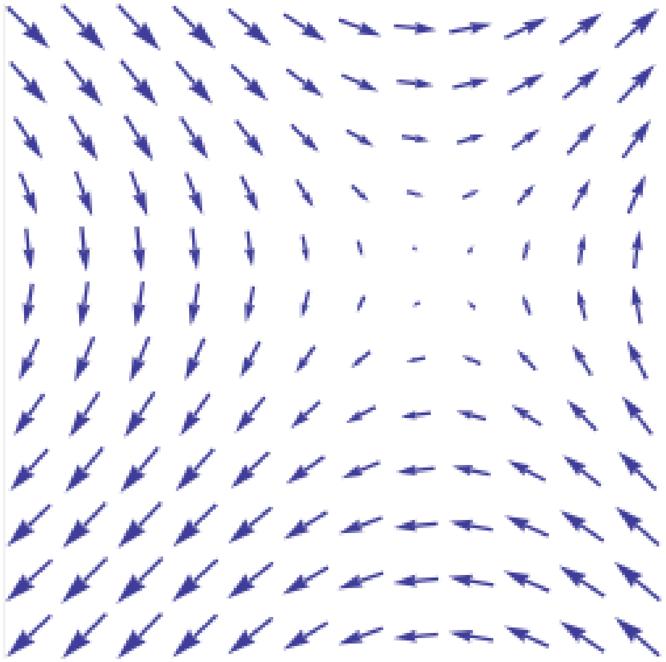




Flow Visualization

Also called vector field visualization

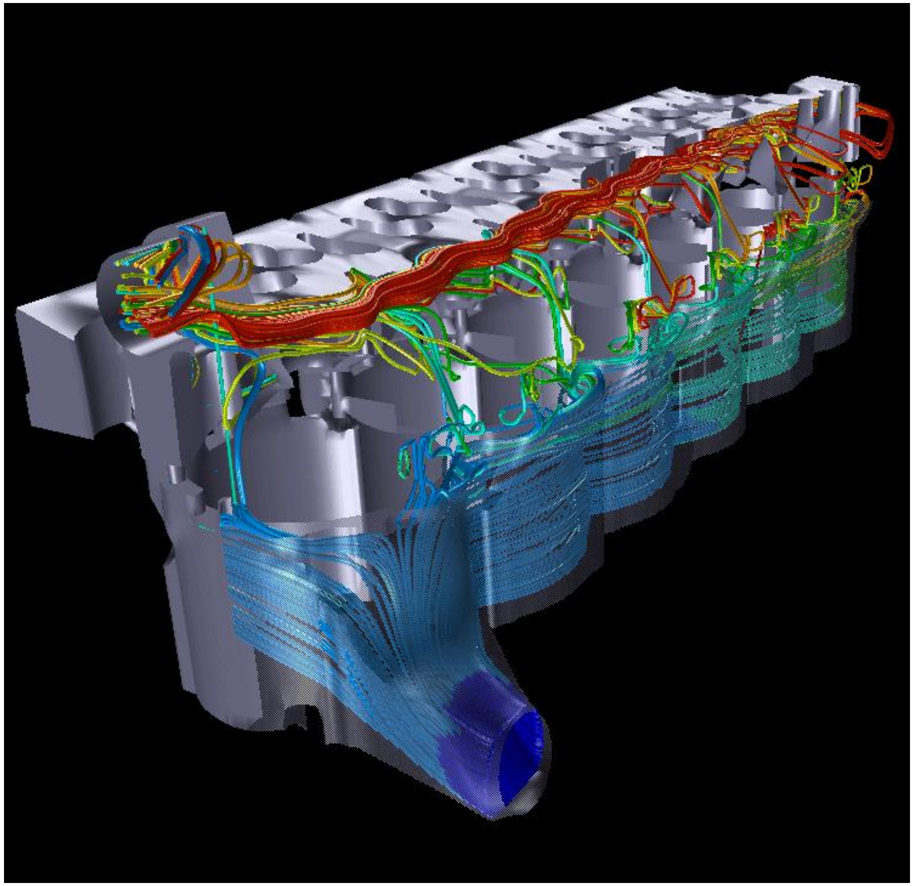




Stream Lines

Perform an integration through the vector field

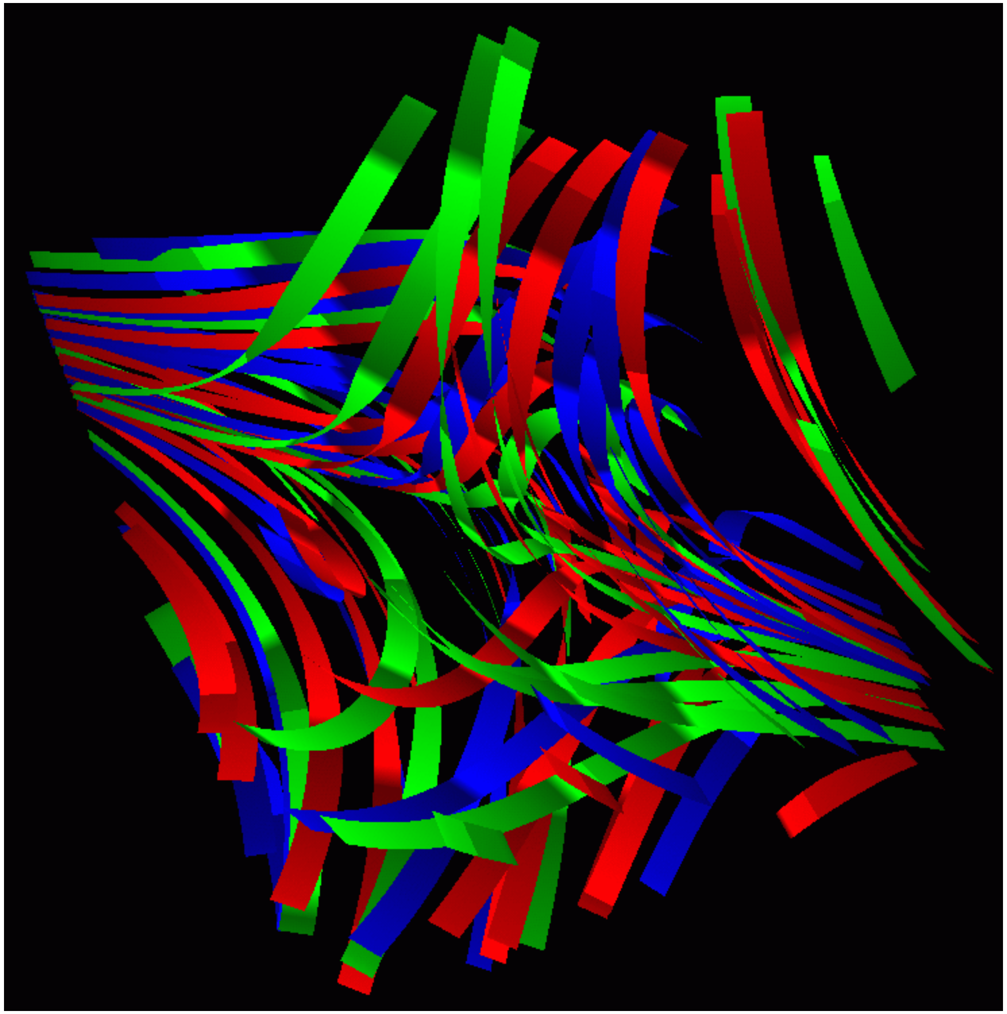
- color maps to temperature



Stream Ribbons

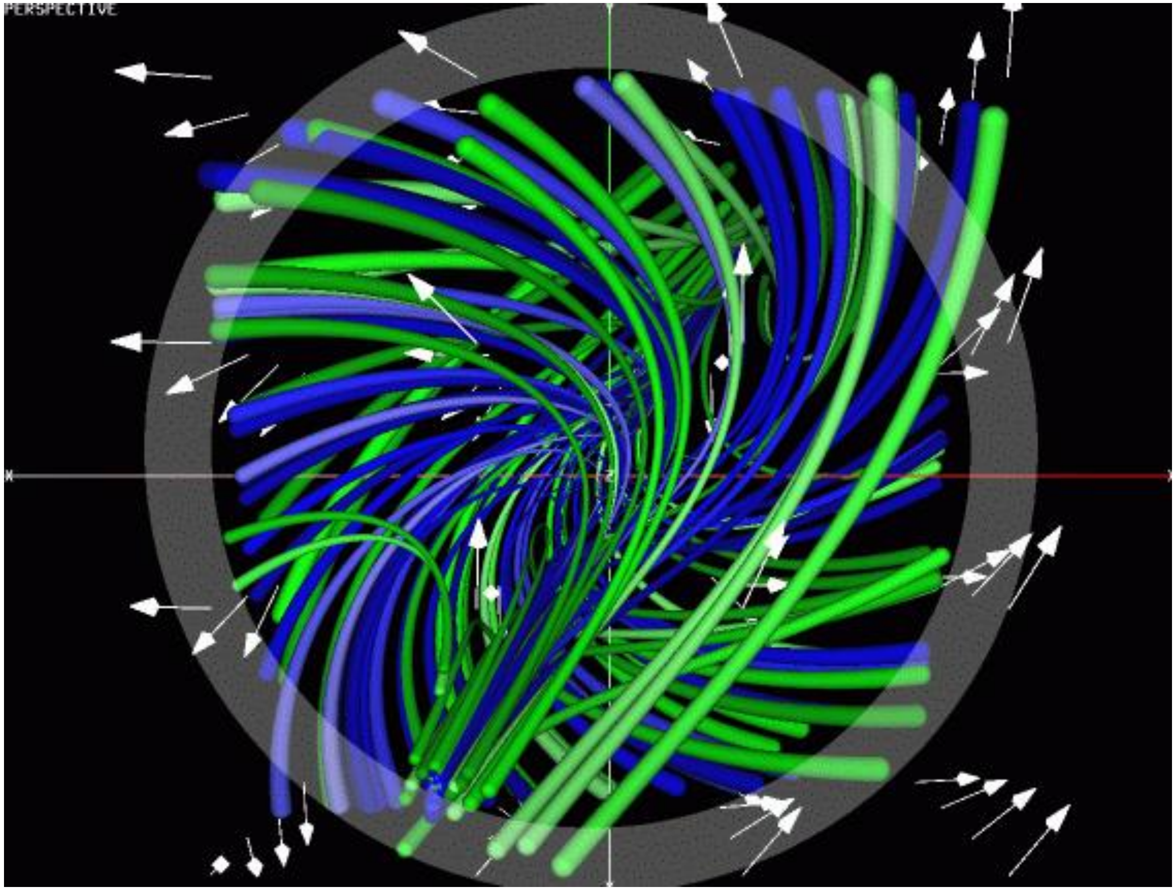
Connect two streamlines

- the center streamline gives direction, the other two indicate the twisting



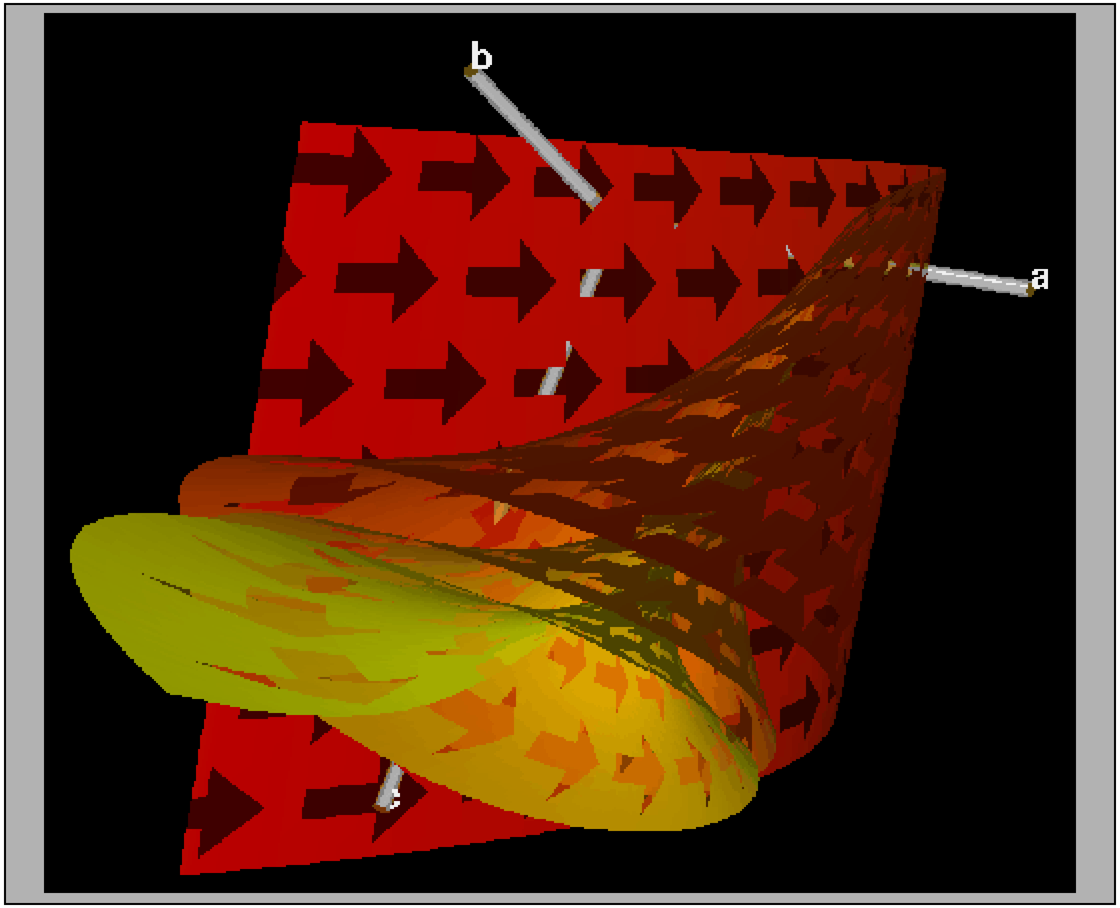
Stream Tubes

Connect three or more streamlines



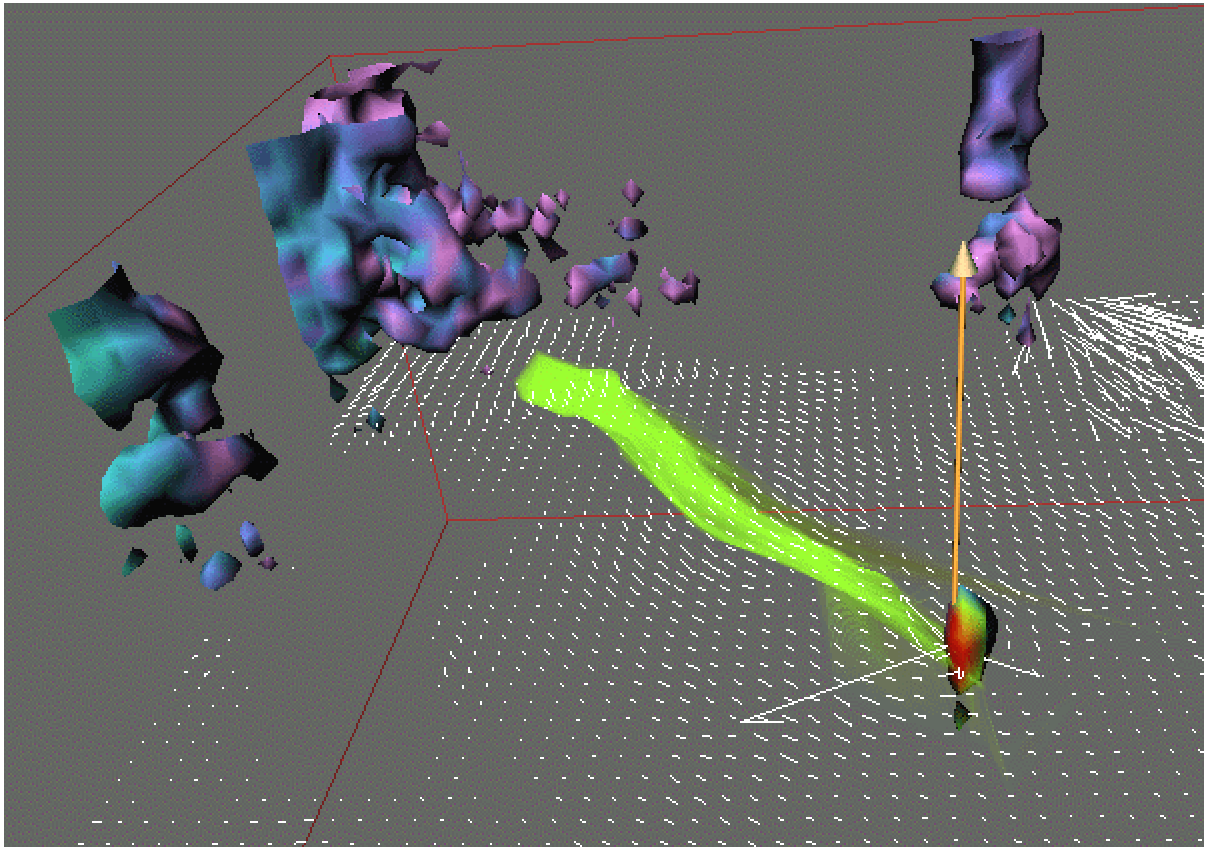
Stream Surfaces

Sweep a line segment through the vector field



Stream Balls

Smoke is injected into the flow field and compresses/expands due to the vector field



Global Techniques

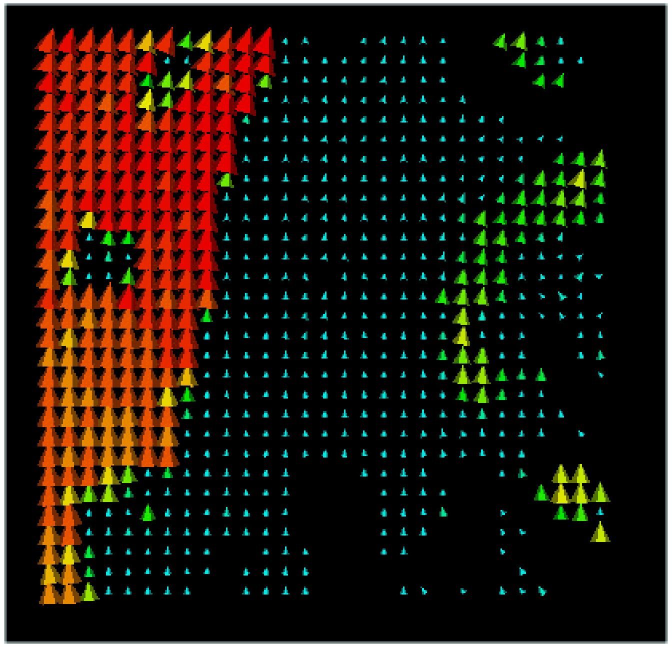
Seek to give a more global view of the vector field

Hedgehogs

- oriented lines spread over the volume, indicating the orientation and magnitude of the flow
- do not show directional information

Glyphs, arrows

- icons that show directions,
  but tend to clutter the display

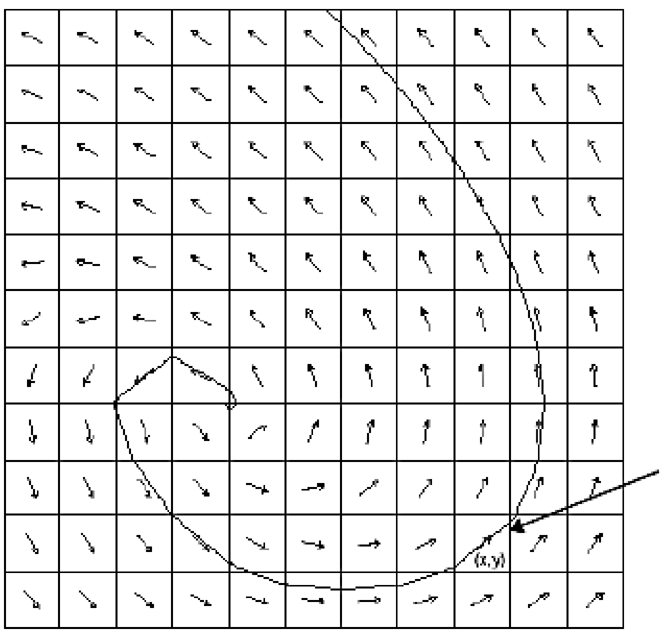


Line Integral Convolution (LIC)

- Input:

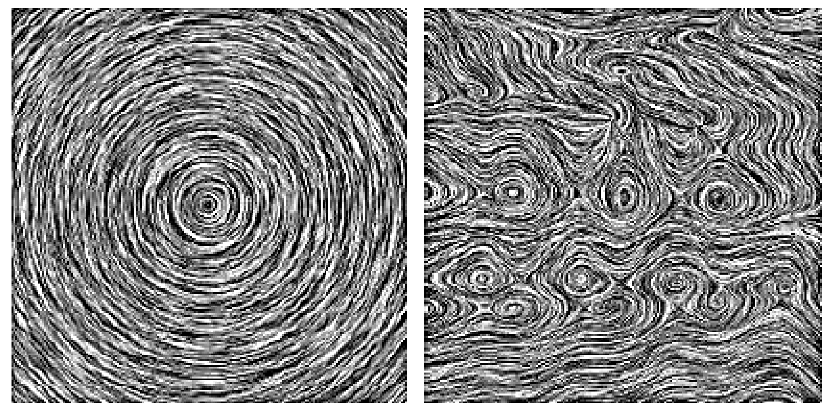
  - a 2D vector field

  - an image that will be “smeared” according to the stream lines described by the vector field



stream line

input vector field



output image = line-integrated white noise image

For each ouput pixel (x, y)

Follow the stream line forward for some distance Δs

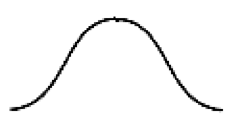
Multiply each pixel value by a 1D filter kernel and add

Follow the stream line backward for some distance Δs

Multiply each pixel value by a 1D filter kernel and add

Follow the stream line backward for some distance Ds

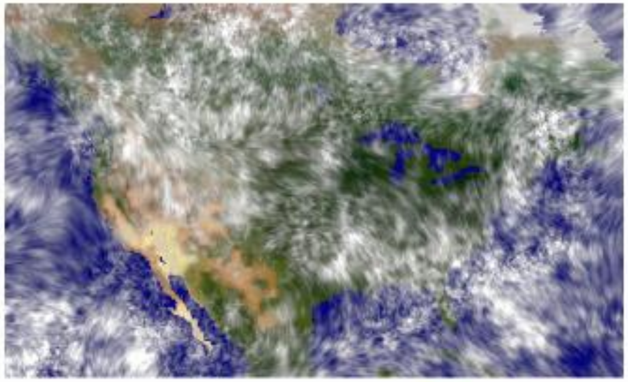
filter aligned with the stream line



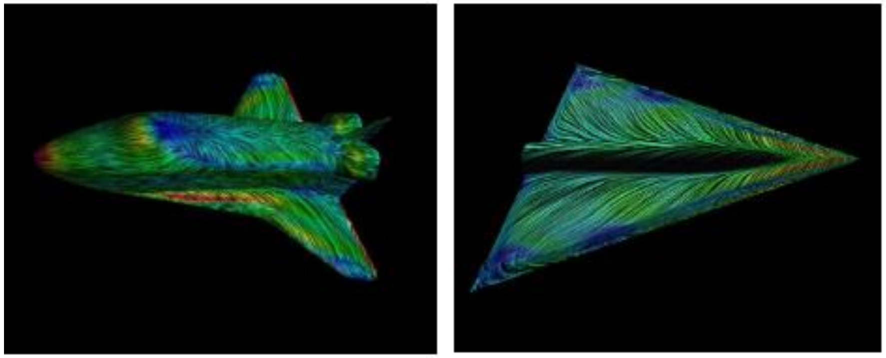
Line Integral Convolution (LIC)

a flower image with different vector fields

a simple motion vector field over the hand



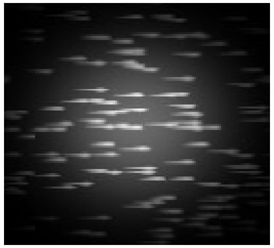
using vector magnitude to determine Δs



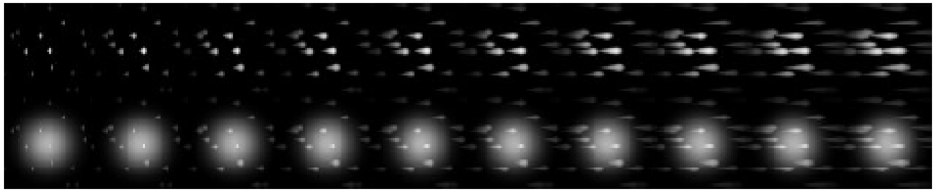
mapping LIC onto an object surface

Textured Splats

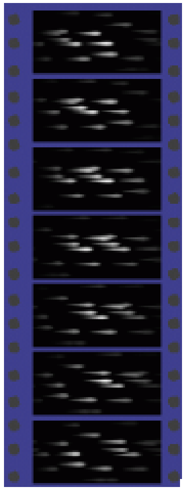
- Embed flow field vector icons into a splat
  - this enables smooth blending of neighboring icons



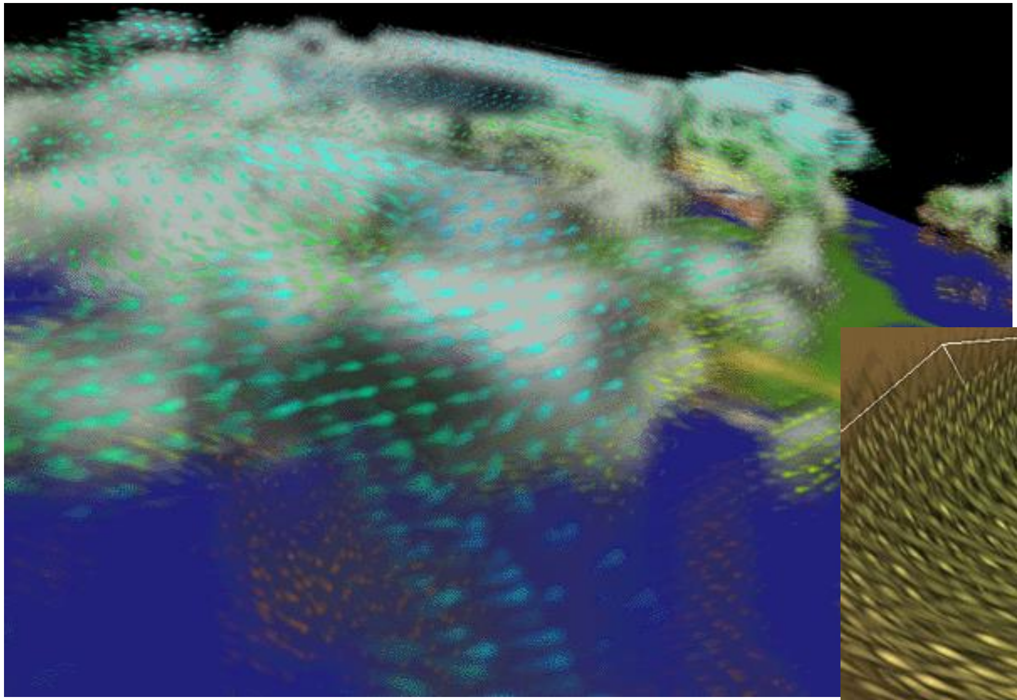
- Create a table of texture splats with varying icon distribution (to prevent regular patters)
- For a given location, select a random splat and rotate corresponding to the flow field direction
- Since the flow field is 3D, the component of the vectors that is parallel to the screen varies
- Need to provide splats that accommodate for vector foreshortening when the flow heads towards us

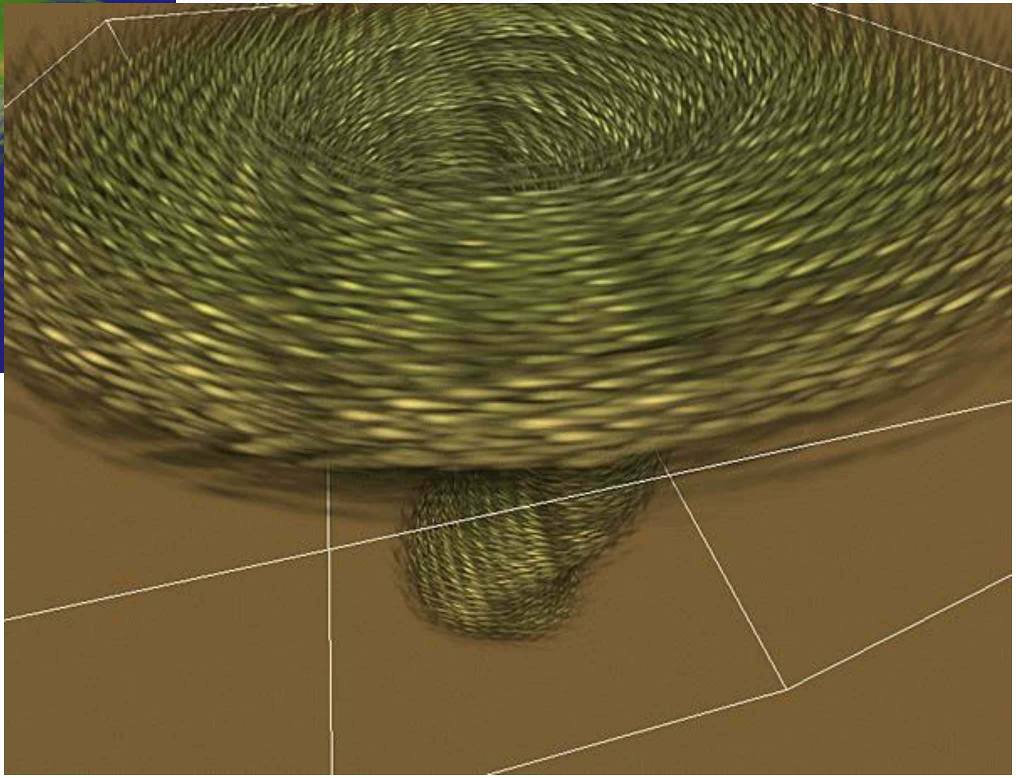


- Animated display
  - store a splat table with vector icons that are cyclically shifted from left to right
  - cycle through this table when picking splats to update the animated display



Textured Splats Examples





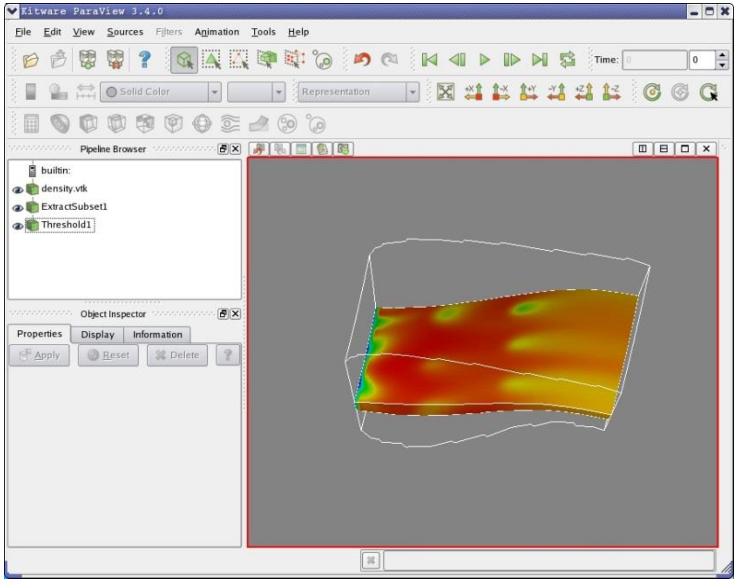
Popular Software & Libraries

VTK

- The Visualization Toolkit library
- developed by Kitware

Paraview

- built on top of VTK
- open-source
- multi-platform
- developed by
  Sandia & Los Alamos National Labs



VisIt

- open source
- developed by Lawrence Livermore National Lab