CSE 564
VISUALIZATION & VISUAL ANALYTICS

SCIENTIFIC VISUALIZATION

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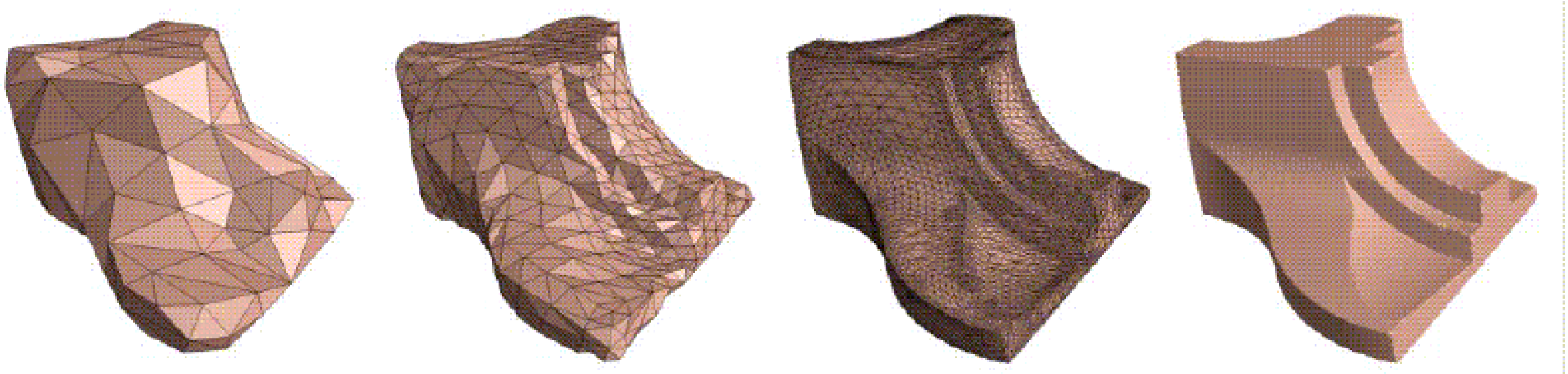
Lecture	Topic	Projects
1	Intro and logistics	
2	Basic visualizations and tasks, data types, examples, ethical considerations	
3	Data preparation (cleaning, imputation, data set integration)	
4	AI-assisted coding for VIS applications (design, debugging, refactoring)	Project #1 out
5	Big data and data reduction (distance/sim metrics, intro to clustering)	
6	High-D data: concept, subspaces, dimension reduction, PCA	
7	Cluster analysis: hierarchical, density, model, embedding, temporal	
8	Perception and cognition (human visual system, color, contrast)	Project #2(a) out
9	Visual design and aesthetics	
10	Visualization of multivariate and high-D data: linear methods, projections	
11	Vis. of multivariate and high-D data: non-linear methods, embeddings	
12	Visualization and AI: mutual support and capabilities (VIS4AI, AI4VIS)	Project #2(b) out
13	Principles of interaction: drive what is visualized, analyzed & how (HCI4VIS)	
14	Visual analytics, human-centered AI, mixed-initiative & collaborative VA	
15	Midterm #1 (tentative date)	
16	VA system design and evaluation, the nested model	
17	Midterm #1 discussion (tentative date)	Final proj. proposal call out
18	Visualization of hierarchical data	
19	Visualization of maps and data with geo-reference	
20	Vis. of time-varying, time-series, streaming data, progressive visualization	Final project proposal due
21	Applications in Visualization Research	
22	Applications in Visualization Research	
23	Ed Tufte’s principles and critiques, responsible visualization, uncertainty	
24	Design of effective infographics	Final proj. prelim report due
25	Foundations scientific and medical visualization, computer graphics	
26	Intro to volume rendering	
27	Scientific visualization	
28	Midterm #2 (tentative date)	
Final	Final project demo on zoom (public)	All final proj. materials due

Rendering Volumes as Surfaces

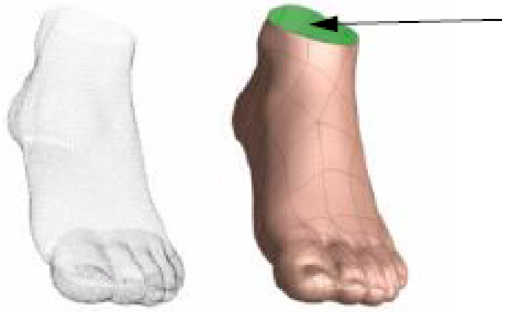
- Objects are explicitely defined by a surface or boundary representation (explicit inside vs outside)
- This boundary representation can be given by:

  - a mesh of polygons:



200 polys 1,000 polys 15,000 polys

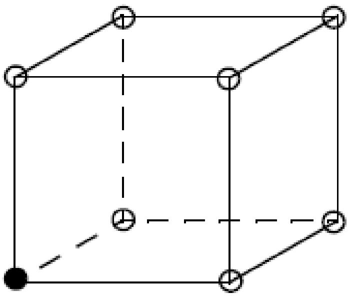
  - a mesh of spline patches:



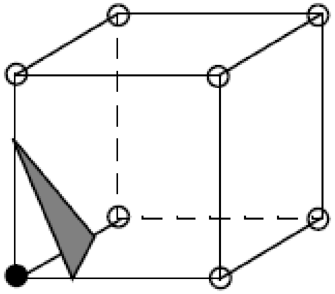
an “empty” foot

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:

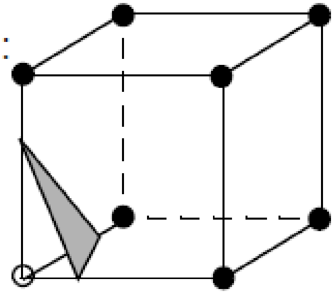


only 1 voxel > iso-value



the polygon that separates
inside from outside

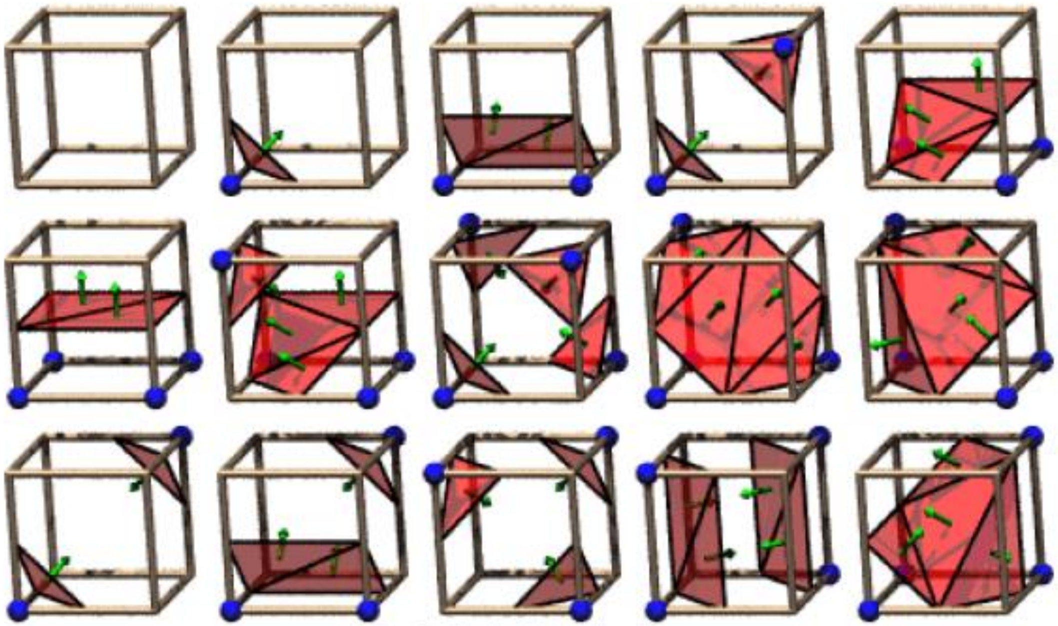
the reverse case:



7 voxels > iso-value
the same polygon results

Marching Cubes (2)

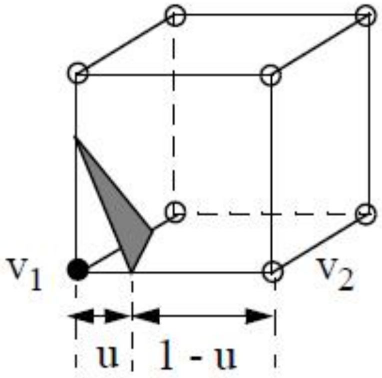
- One can identify 15 base cases
  - Use symmetry and reverses to get the other 241 cases



The 15 Cube Combinations

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

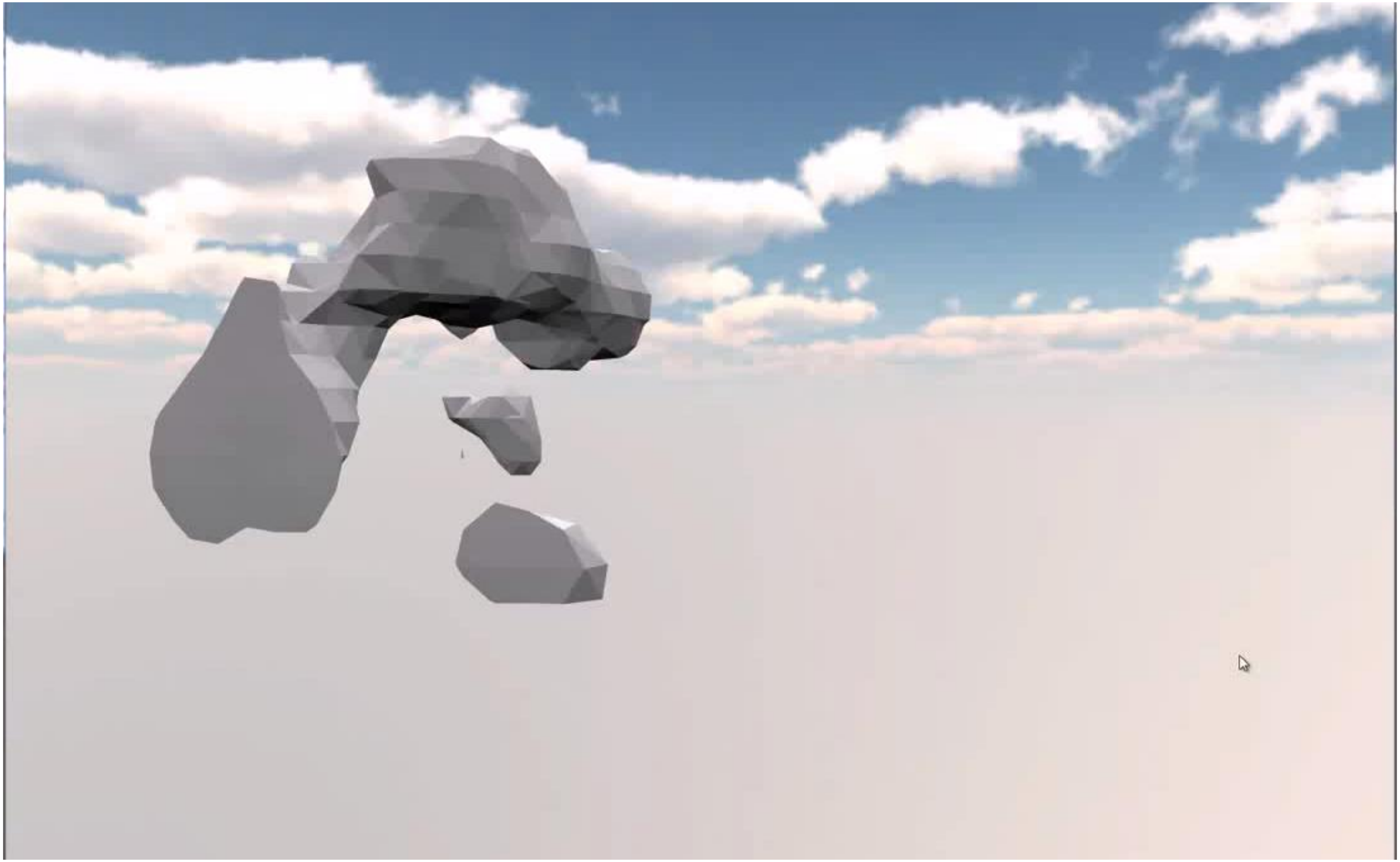
$$iso = v_1 \cdot (1-u) + v_2 \cdot u \longrightarrow u = \frac{v_1 - iso}{v_1 - v_2}$$



- 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)

- 1 petaFLOP = 10^{15} floating point ops per second

18,688 AMD Opteron 6274 16-core CPUs

18,688 Nvidia Tesla K20X GPUs

EVEN FASTER NOW…

Summit supercomputer (2018, #1 worldwide, Oak Ridge Nat'l Lab)

- 200 petaFLOPS (2x the top speed of TaihuLight, previous #1)
- 4,608 compute servers (each with two 22-core IBM Power9 processors and six NVidia Tesla V100 GPUs)

WHAT DOES IT DO?

Compute, compute, compute

Examples:

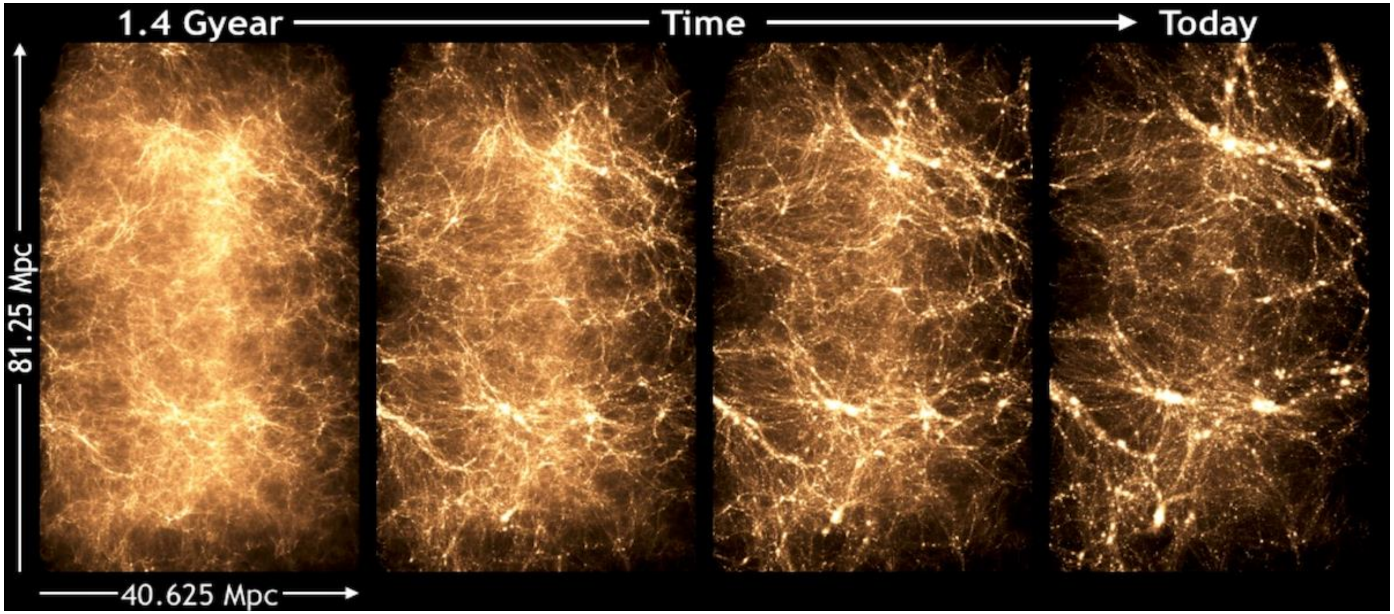
- **S3D:** models the molecular physics of combustion, aims to improve the efficiency of diesel and biofuel engines
- **Denovo:** simulates nuclear reactions with the aim of improving the efficiency and reducing the waste of nuclear reactors
- **WL-LSMS:** simulates the interactions between electrons and atoms in magnetic materials at temperatures other than absolute zero
- **Bonsai:** simulates 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

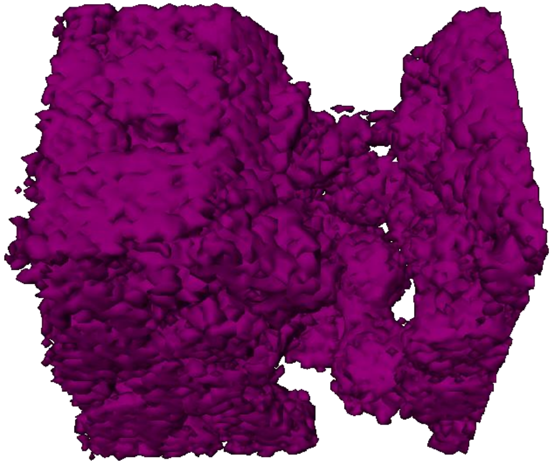
Numbers, lots of them

- 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

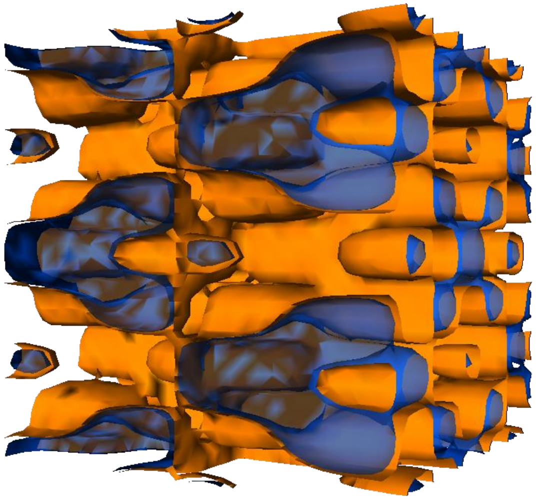


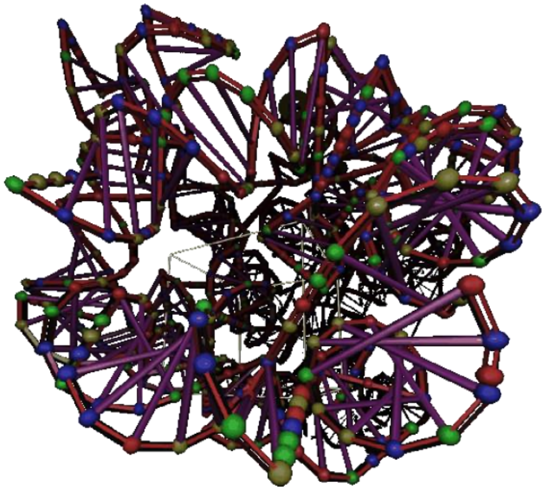
MORE EXAMPLES



Nuclear, Quantum, and Molecular Modeling

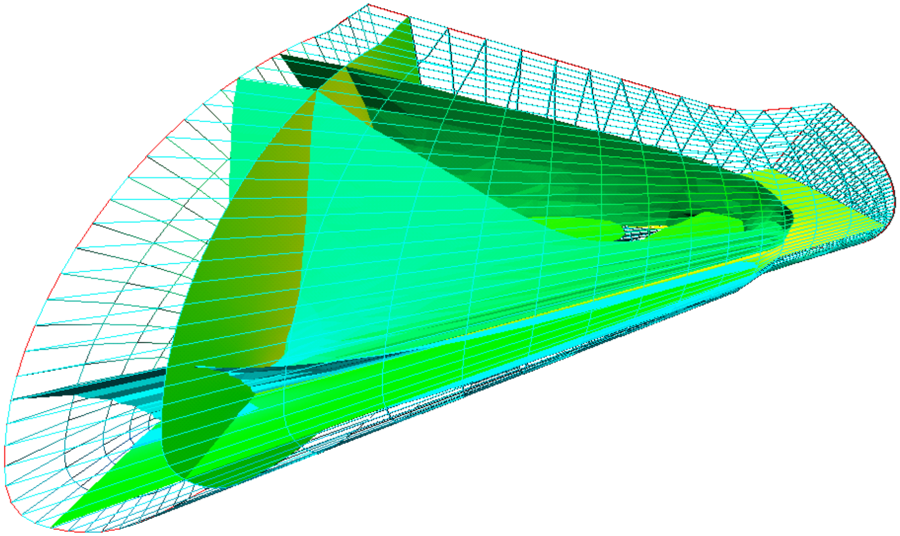
Structures, Fluids and Fields



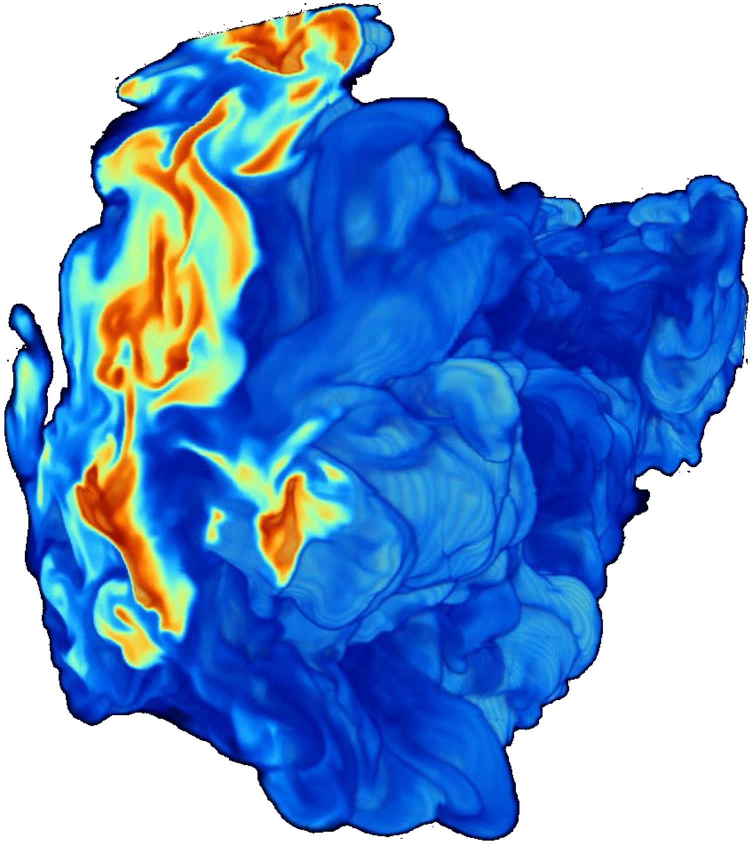


Advanced Imaging and Data Management

MORE EXAMPLES



Surface Rendering with VTK
(The Visualization Toolkit)

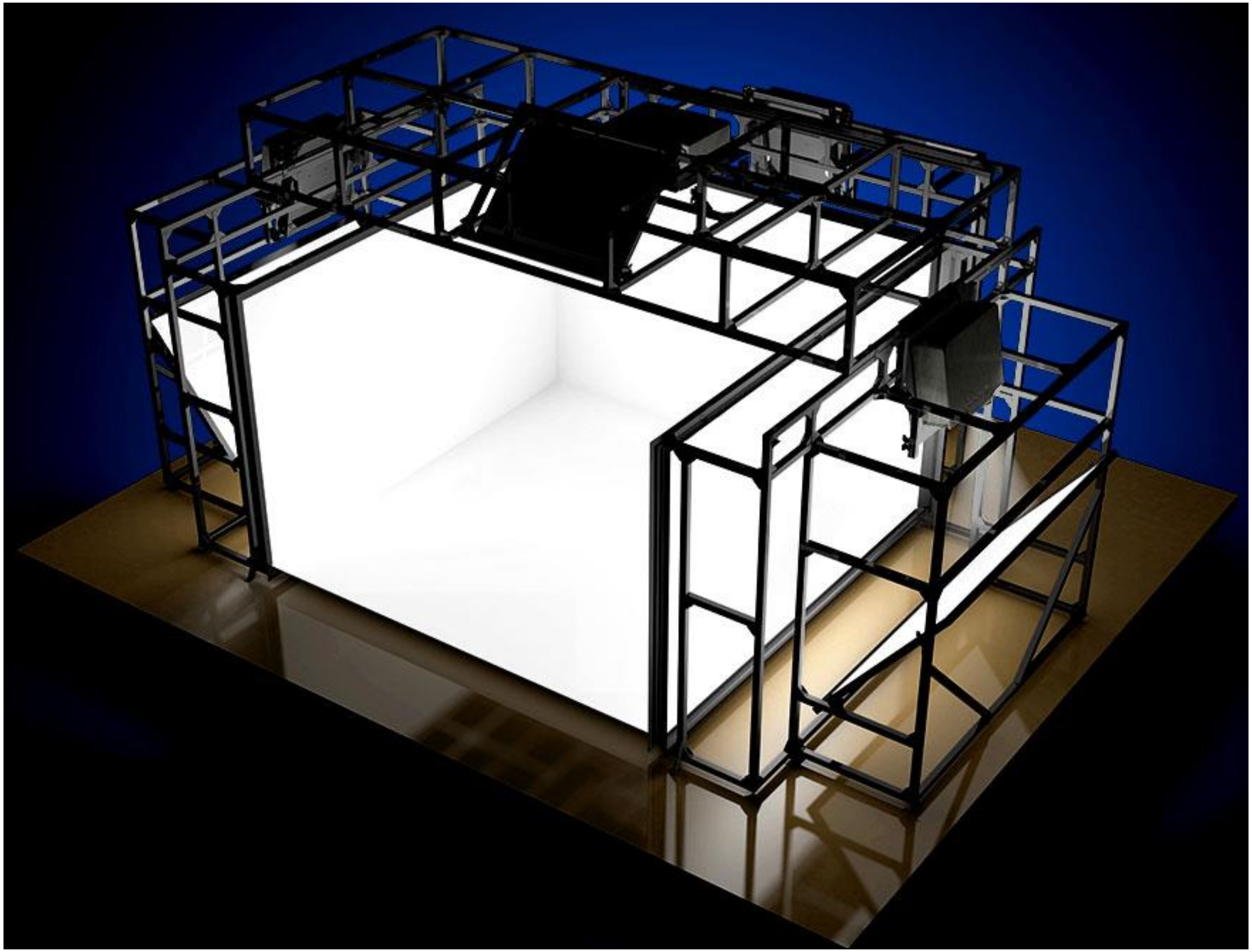


Volume Rendering

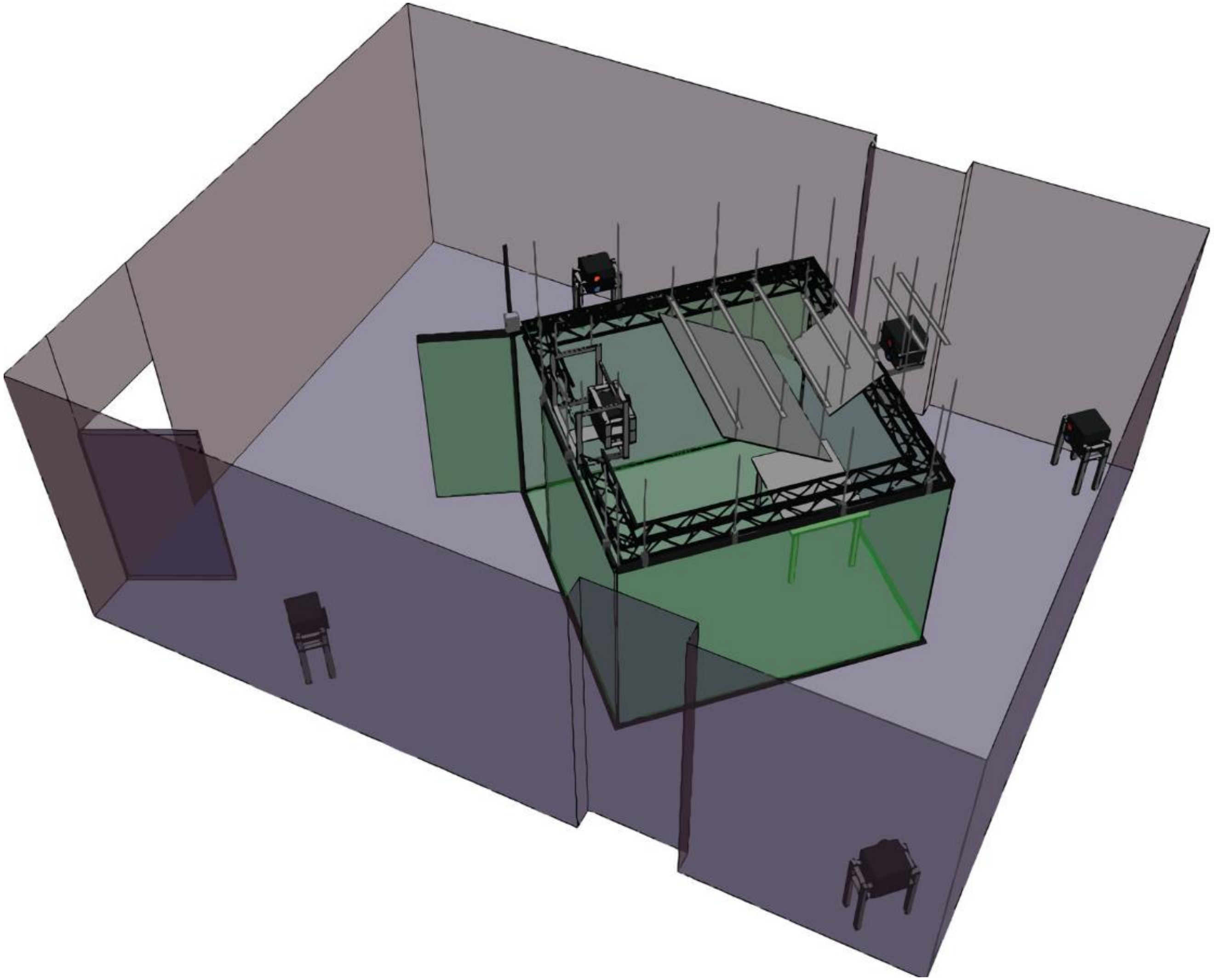
Where to Visualize All This?

DISPLAY WALL

CAVE =
CAVE AUTOMATIC VIRTUAL ENVIRONMENT



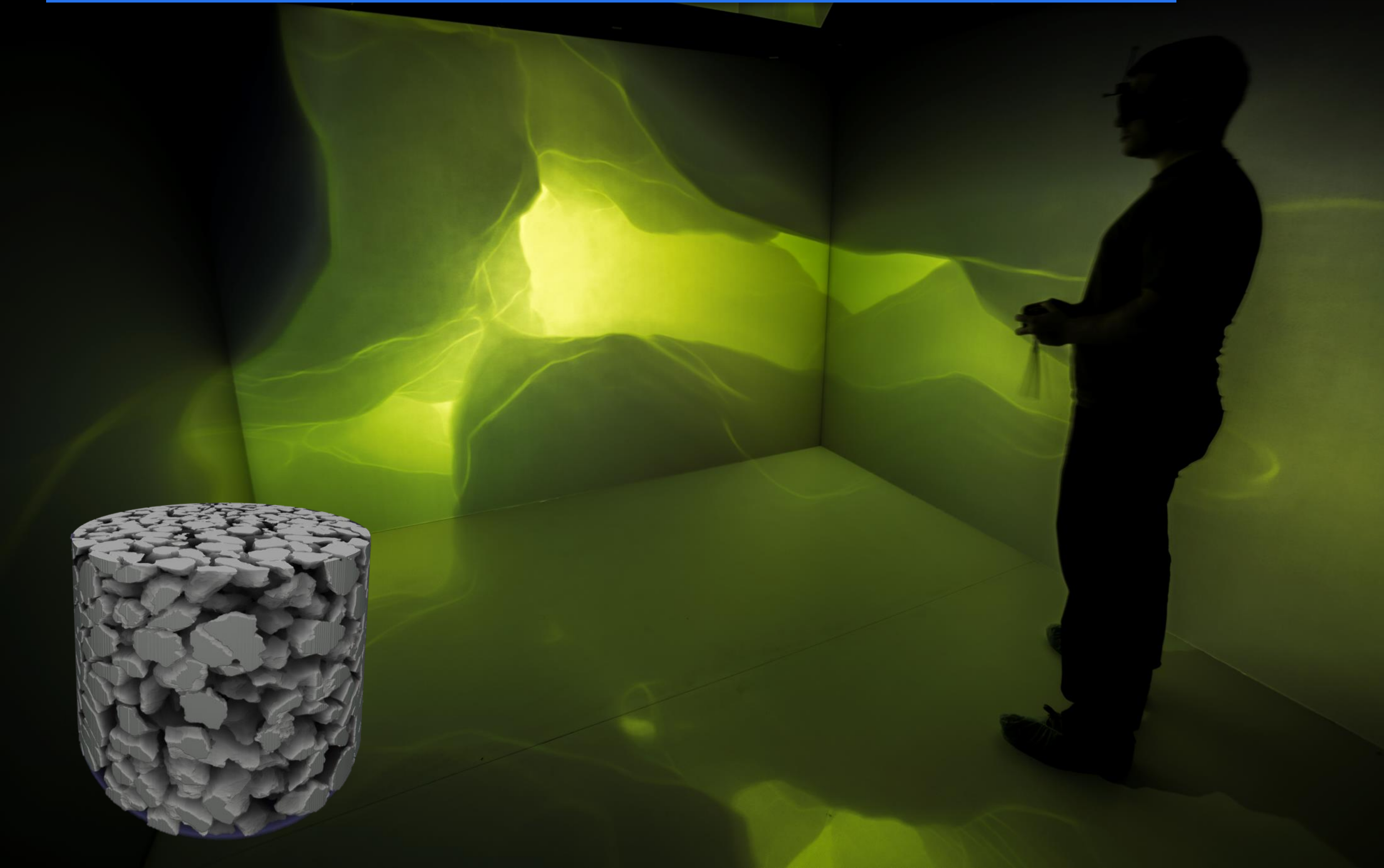
The Stony Brook Immersive Cabin



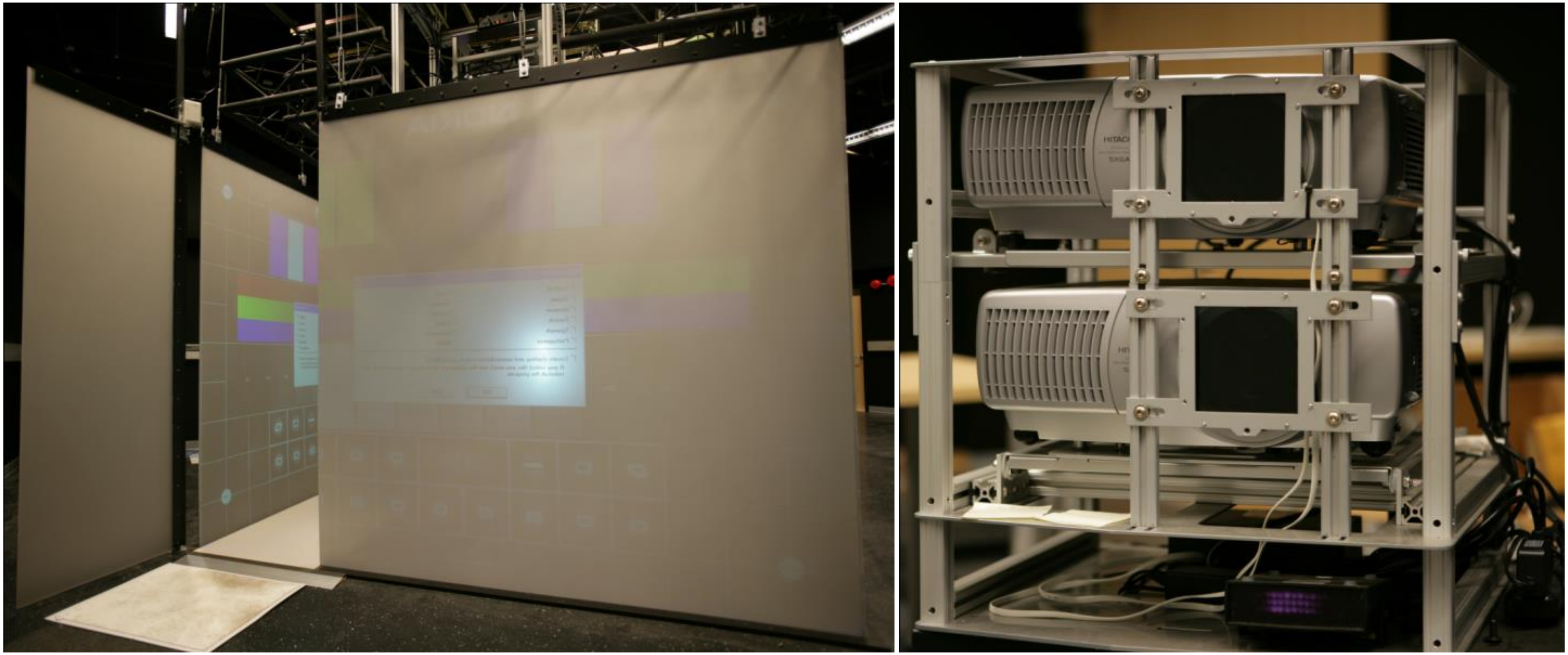
INSIDE THE IMMERSIVE CABIN

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

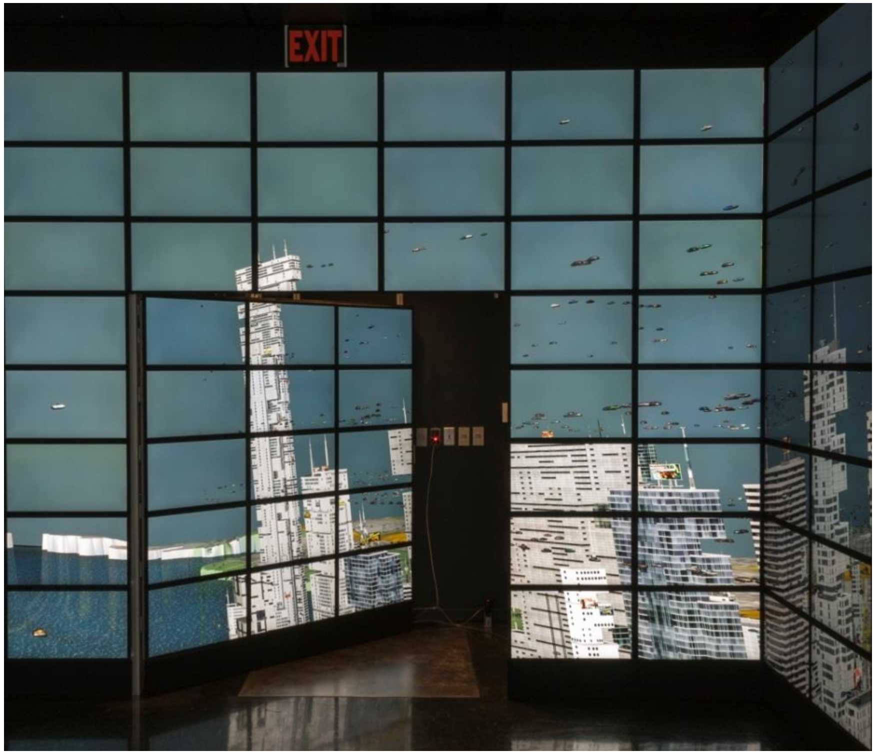
- 30′×40′×11′ environment
- 416 UQXGA LCD Displays
  - 2,560×1,440 resolution over 50’-100’ DisplayPort cables
  - fast response time, wide viewing angles, good dynamic range
- 20-node GPU cluster, each node equipped with:
  - 2× six-core CPUs, 48 GB Ram
  - 4× AMD FirePro V9800 with 4GB Ram and 6 DisplayPort 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

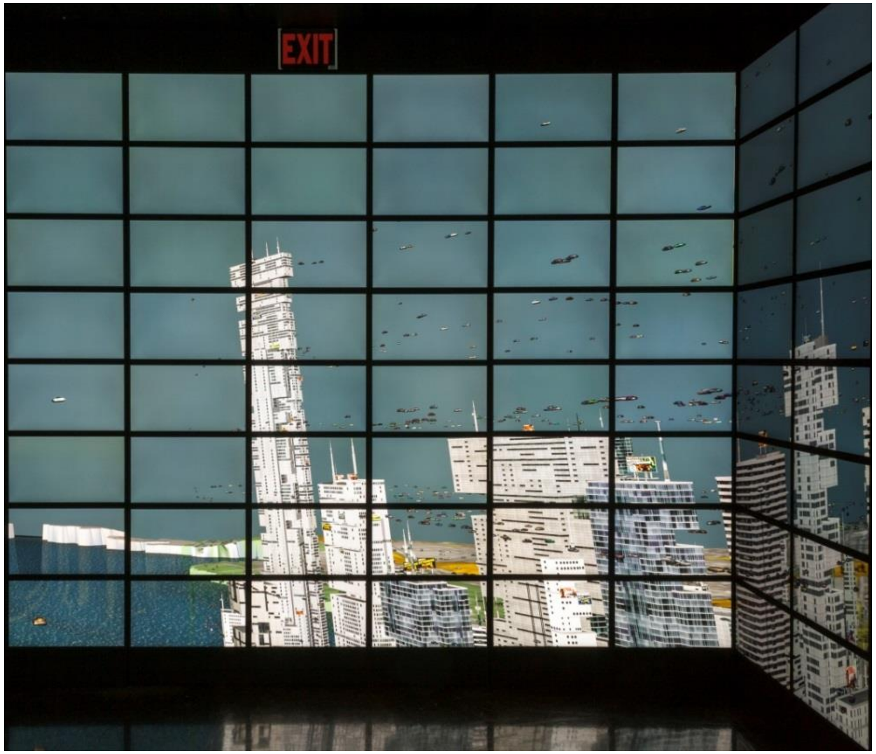
AUTOMATIC DOOR

3×5 section of displays

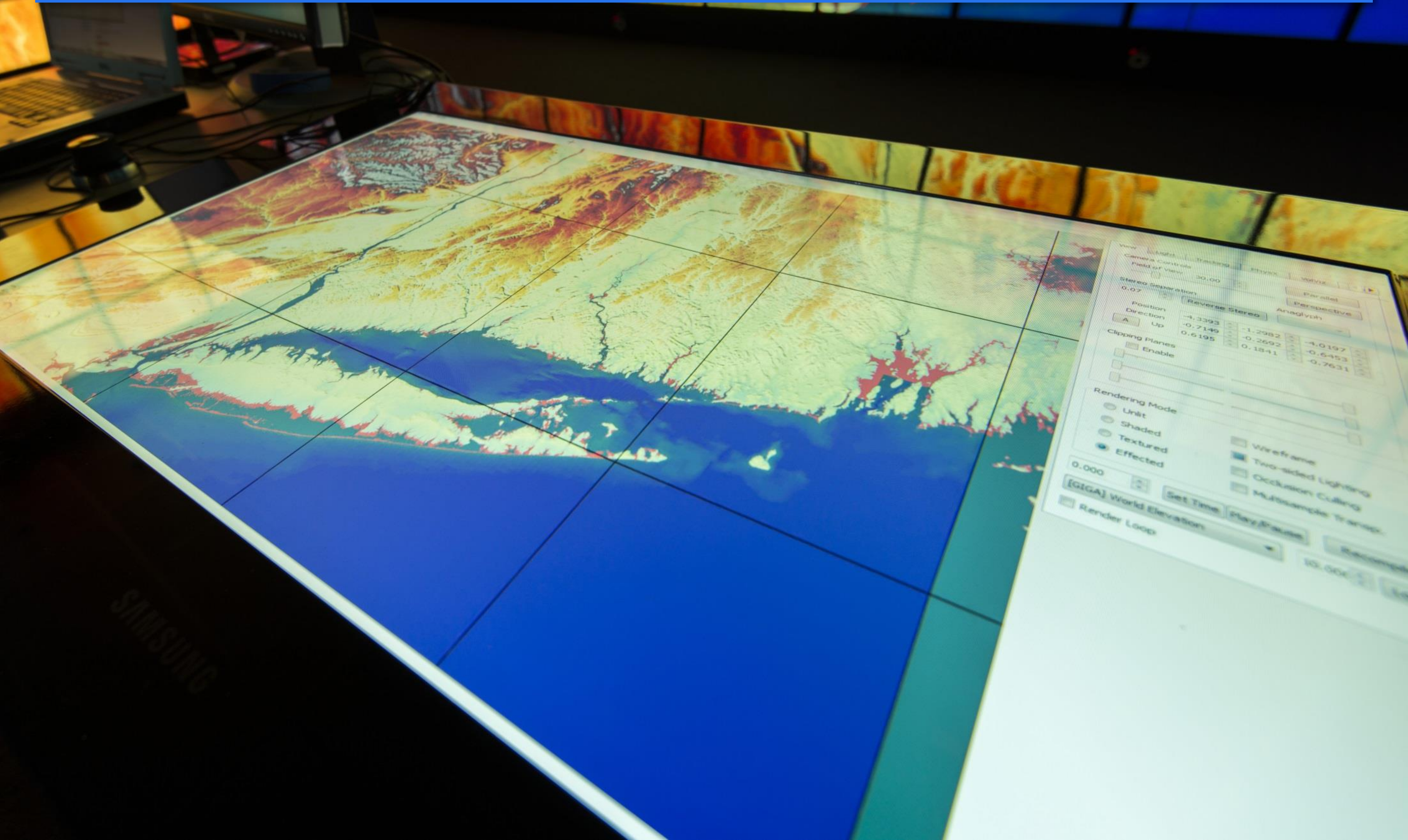
Visually indistinguishable from rest of the display

  - allows for a fully enclosed visualization environment



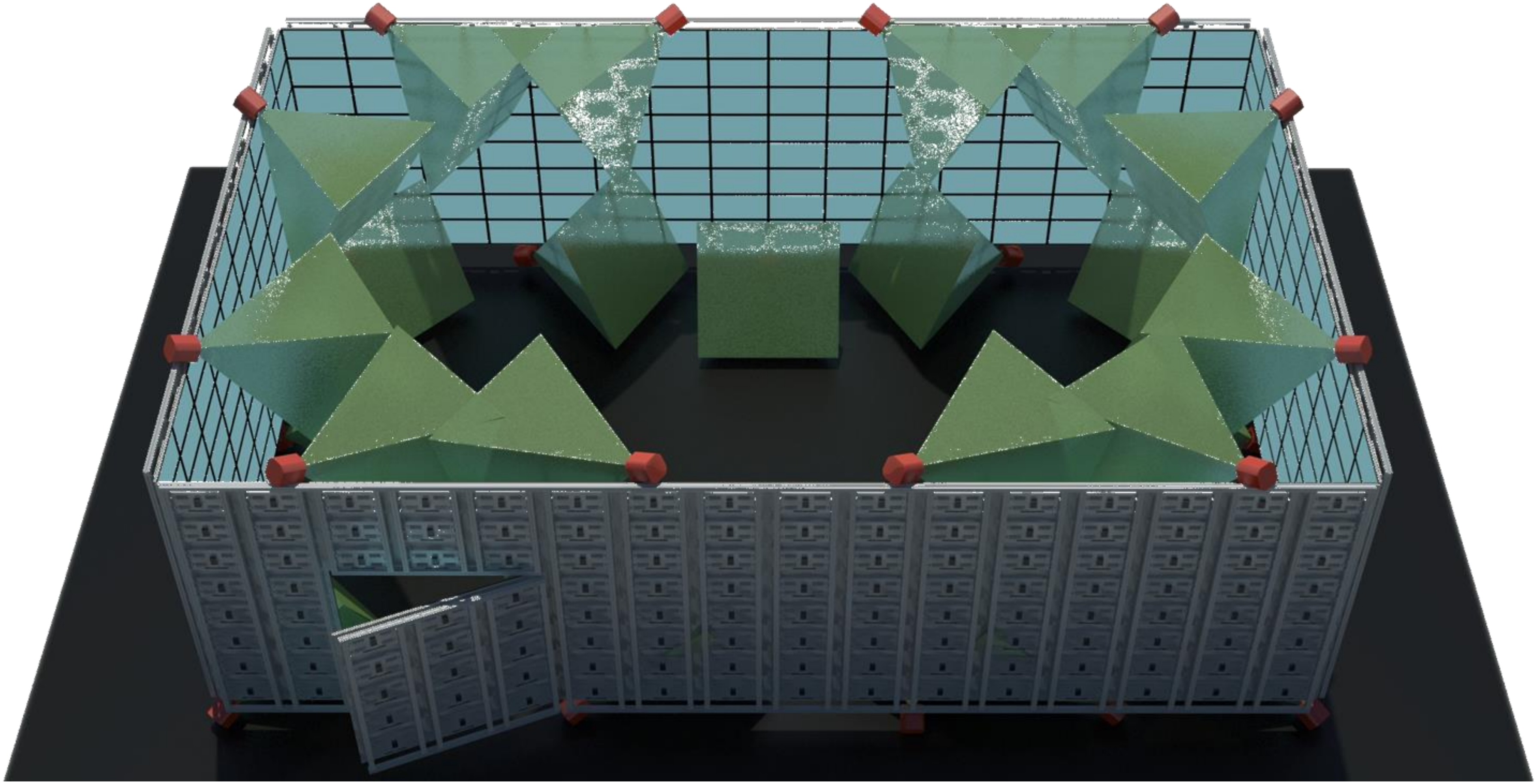


Touch Table


View
Light
Tracking
Physics
Volviz
Camera Controls
Field of View
30.00
Stereo Separation
0.07
Reverse Stereo
Parallel
Perspective
Anaglyph
Position
Direction
Up
-4.3393
-0.7149
0.6195
-1.2982
-0.2692
0.1841
-4.0197
-0.6453
-0.7631
Clipping Planes
Enable
Rendering Mode
Unlit
Shaded
Textured
Effected
Wireframe
Two-sided Lighting
Occlusion Culling
Multisample Transp.
0.000
[GIGA] World Elevation
Set Time
Play/Pause
Render Loop
SAMSUNG

REALITY DECK TRACKING SYSTEM

24-camera infrared optical system from OptiTrack

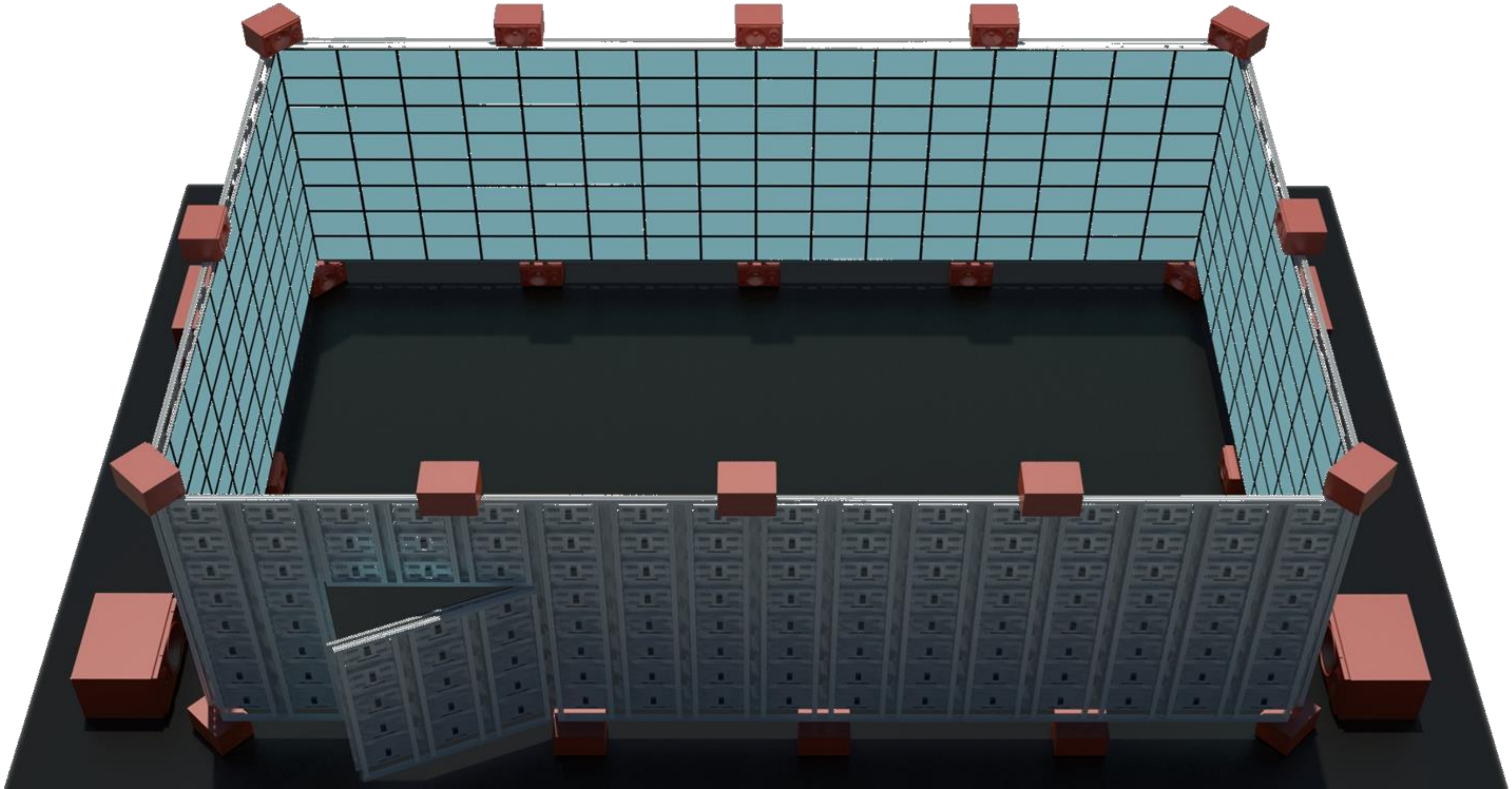


REALITY DECK SOUND SYSTEM

24.4 channel professional-grade system

Positional audio with real-time ambisonics

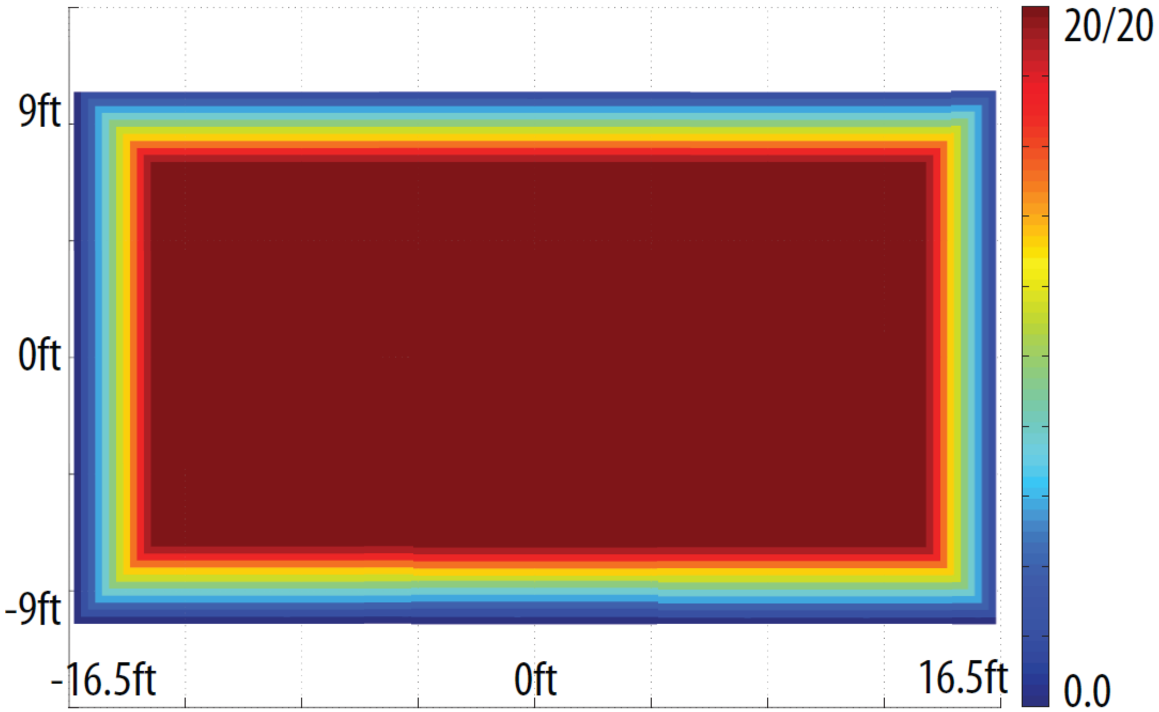
- using the Rapture3D OpenAL driver



UNIFORMLY HIGH VISUAL ACUITY

User can make visual queries at an instant

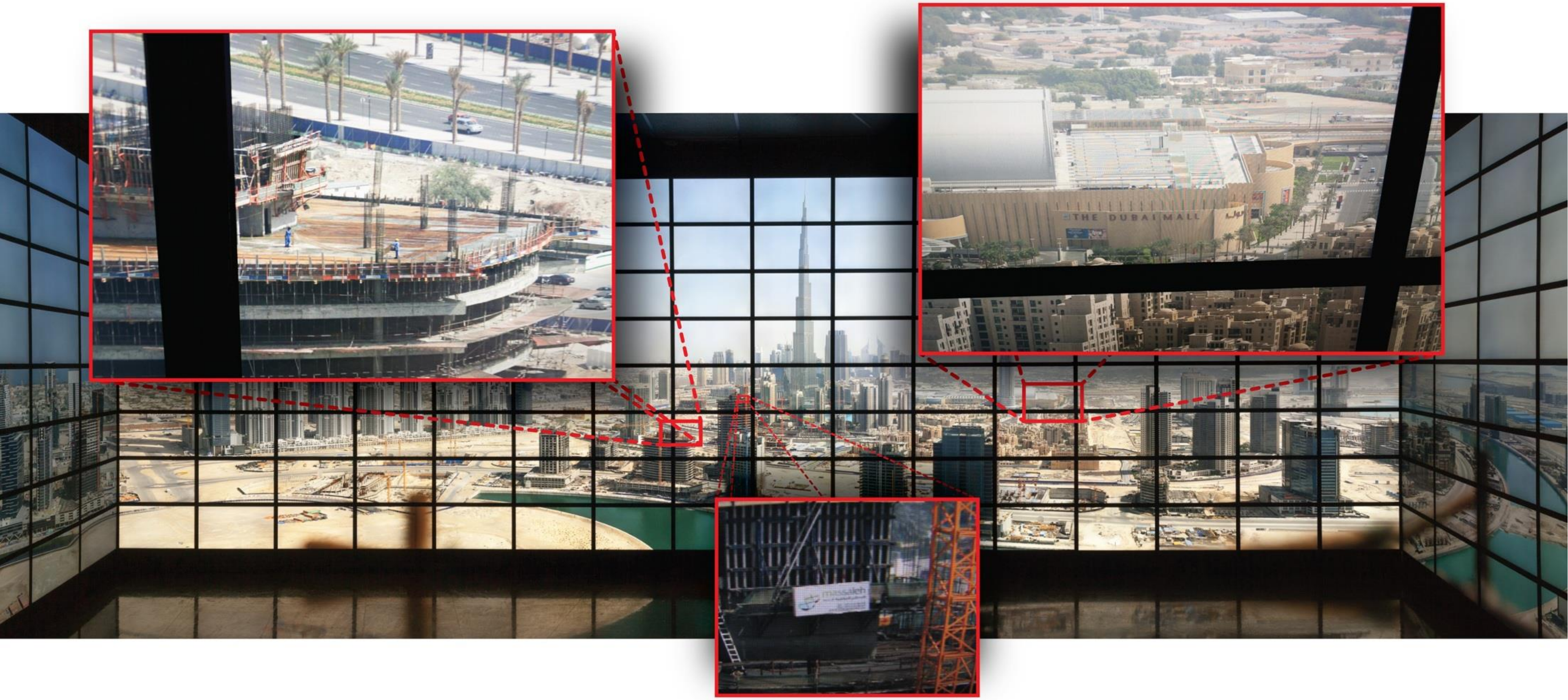
- walk up to obtain more detail
- just like in real life – hence the Reality Deck
- 20/20 visual acuity at 1.5′-2′ away



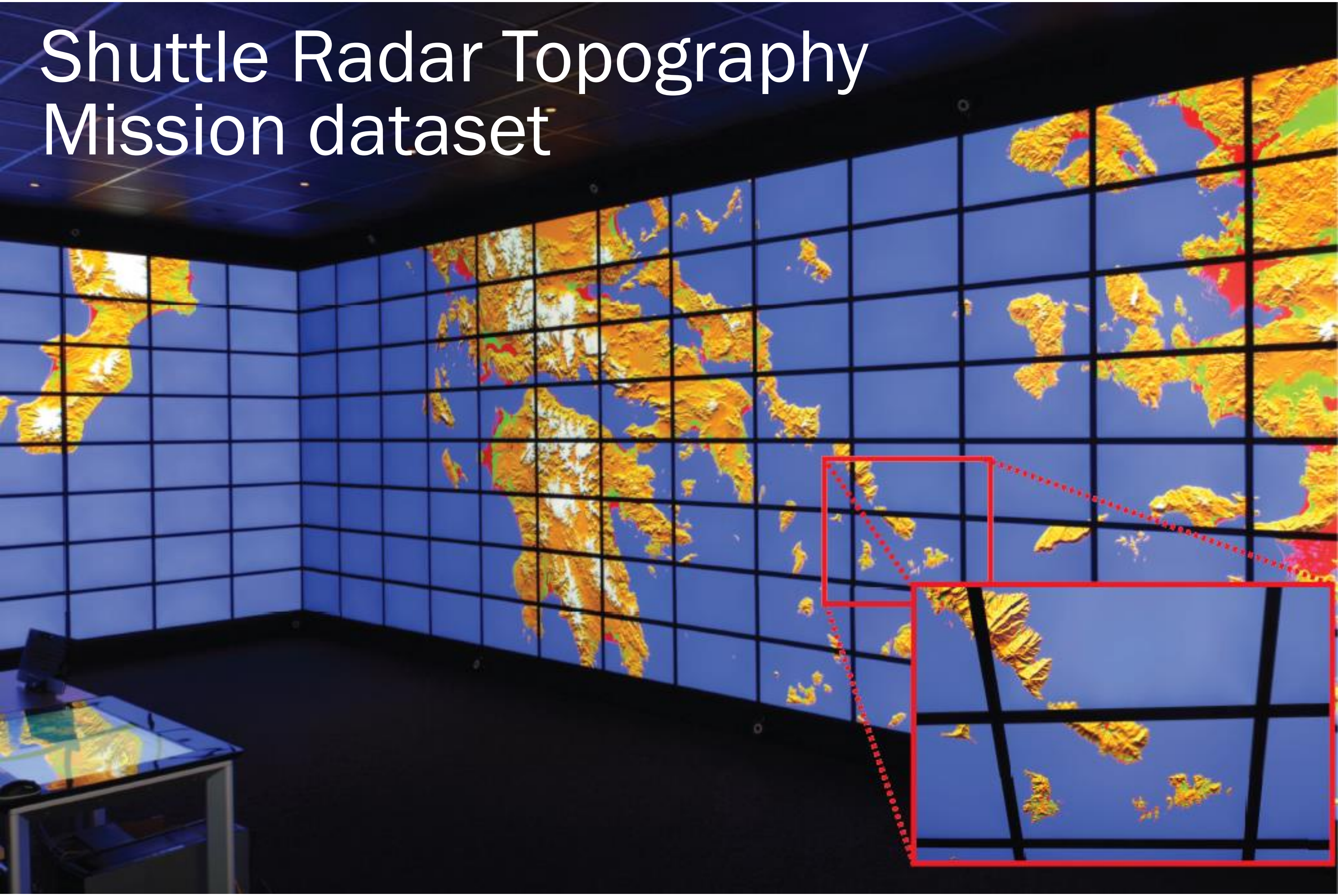
GIGAPIXEL VISUALIZATION

Dubai dataset

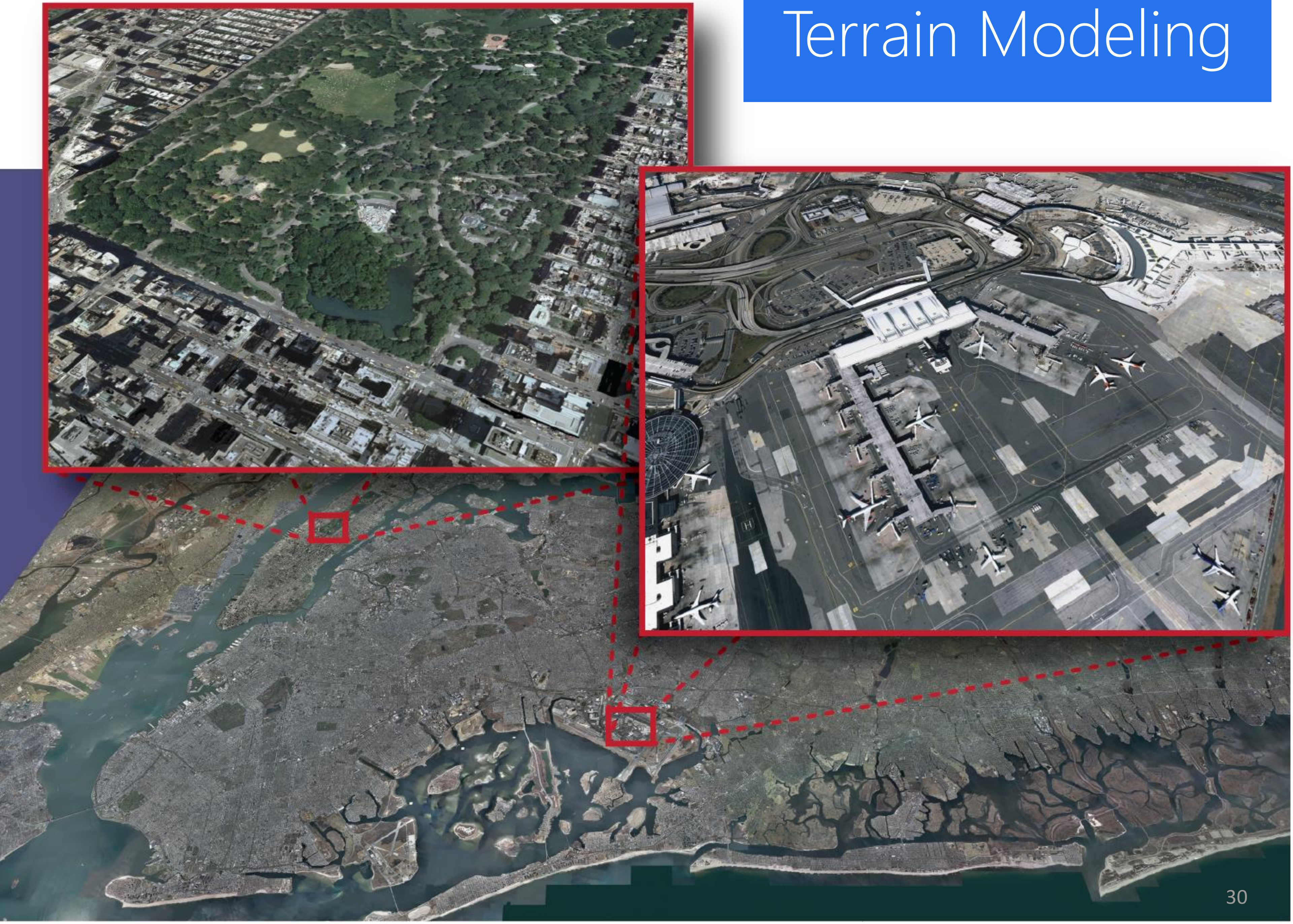
- 45 Gigapixels, 180° field of view



Shuttle Radar Topography Mission dataset



Terrain Modeling



3D Relief Map

Sea level simulation

Protein Visualization

Reality Deck

SCIENTIFIC SIMULATION

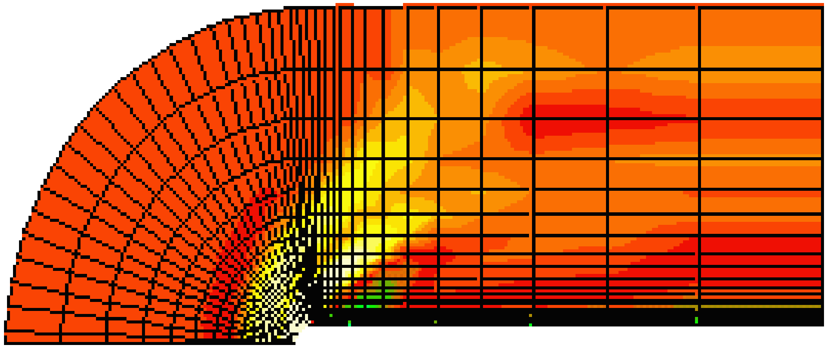
Say, you want to simulate the airflow around an airplane wing

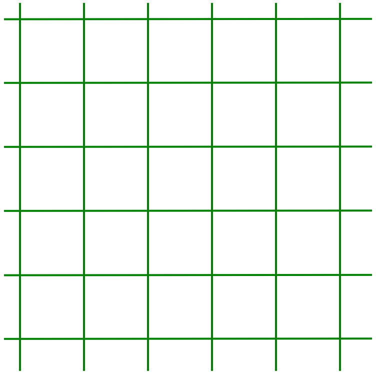
- where is the flow most interesting?

- right, close to the surface

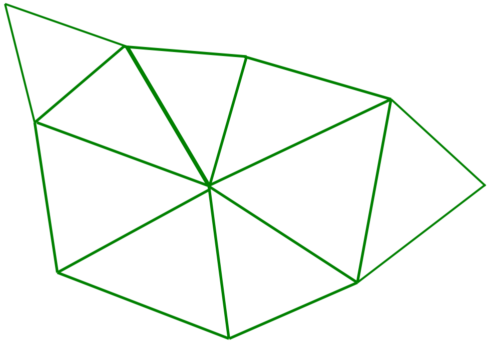
Simulation lattice

Make the simulation lattice densest along the surface





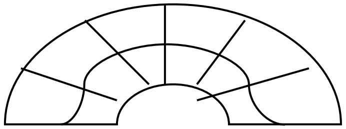
Regular → irregular grids



GRIDS

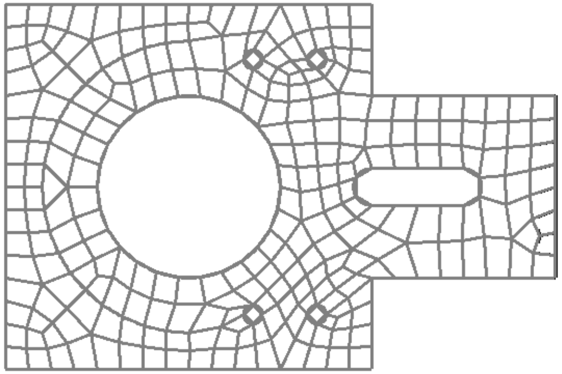
Structured grid

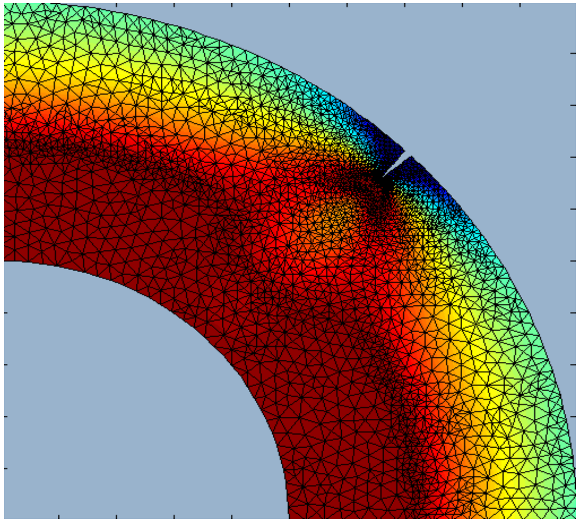
- more or less a bent regular grid

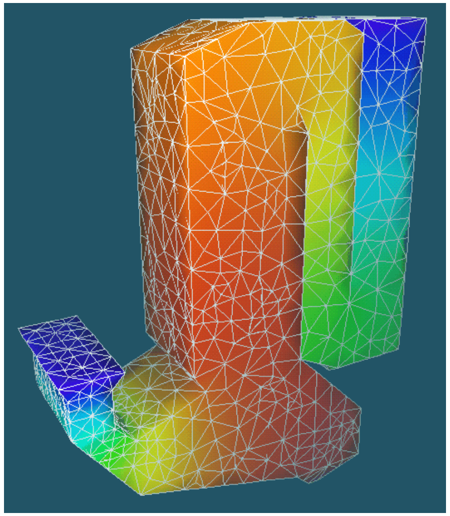


Unstructured grid

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





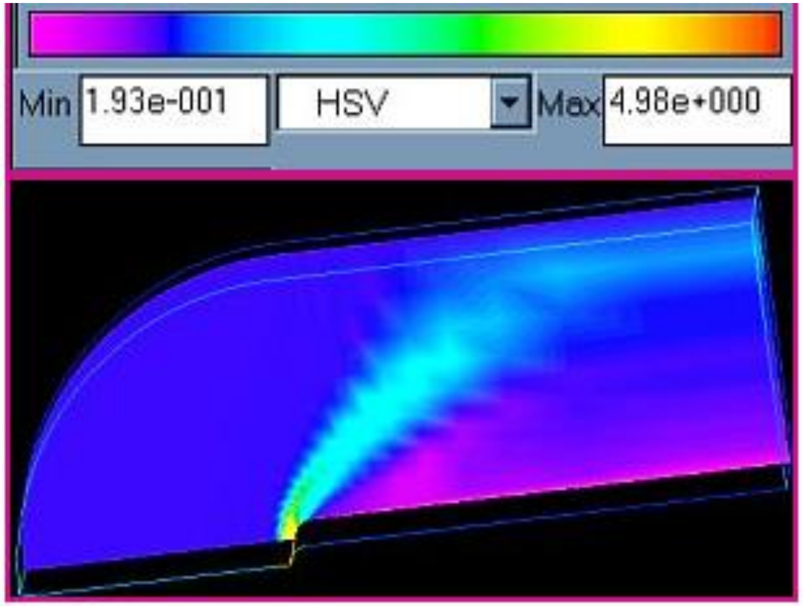


THE BLUNTFIN DATASET

Mapping flow strength to color

Rendering by cell traversal

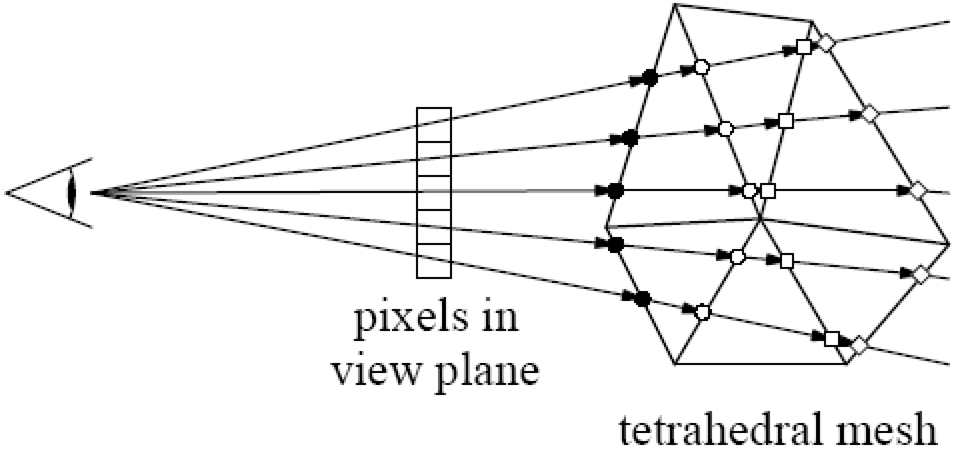
- go from cell to cell
- composite colors and opacities

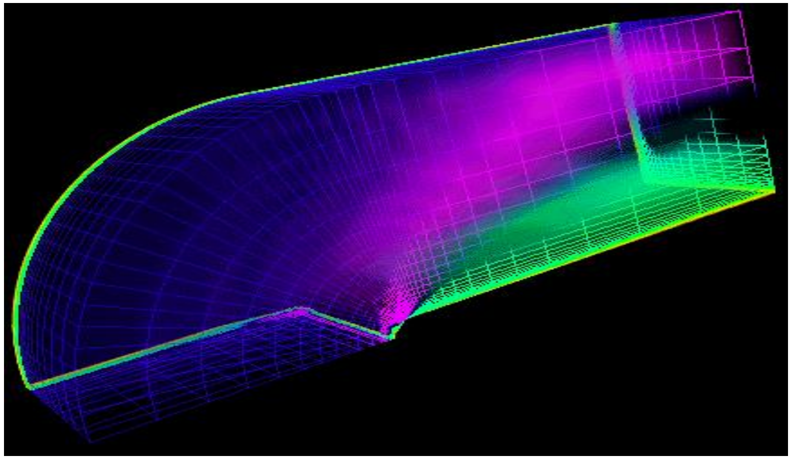


Min 1.93e-001

HSV

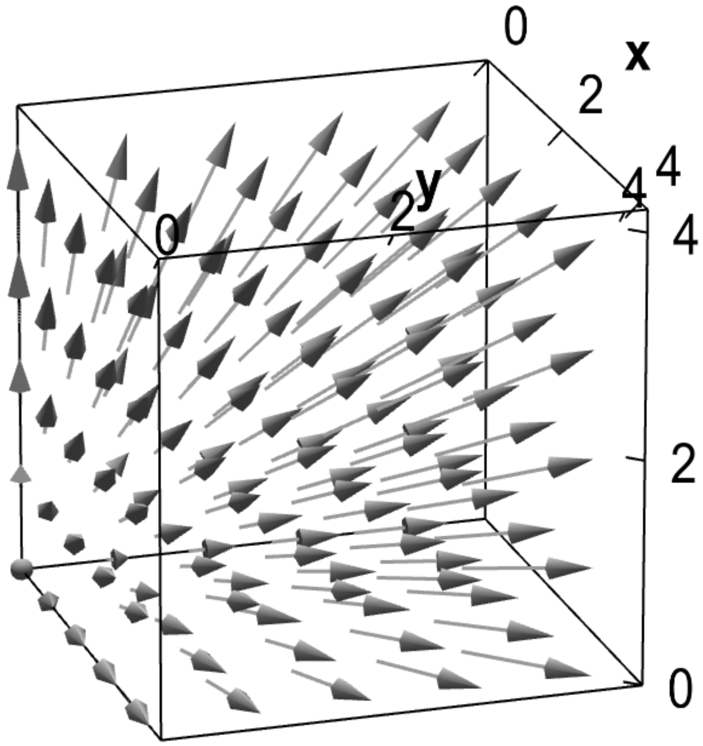
Max 4.98e+000

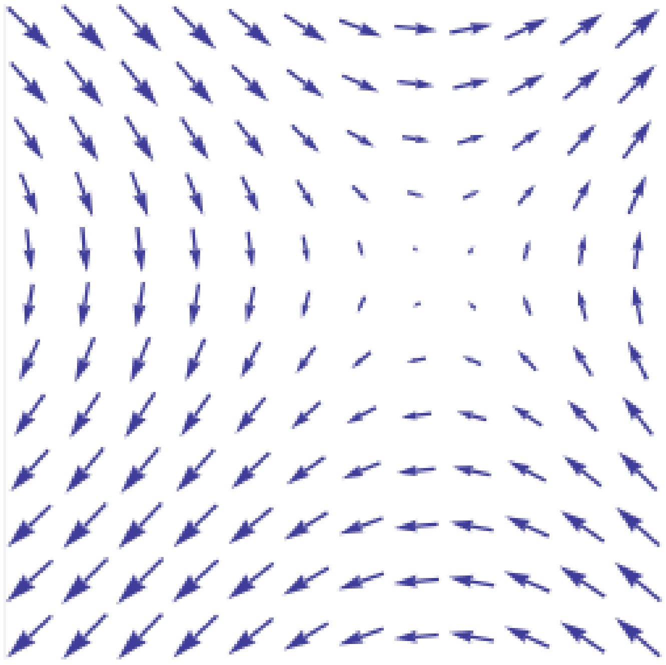




FLOW VISUALIZATION

Also called vector field visualization

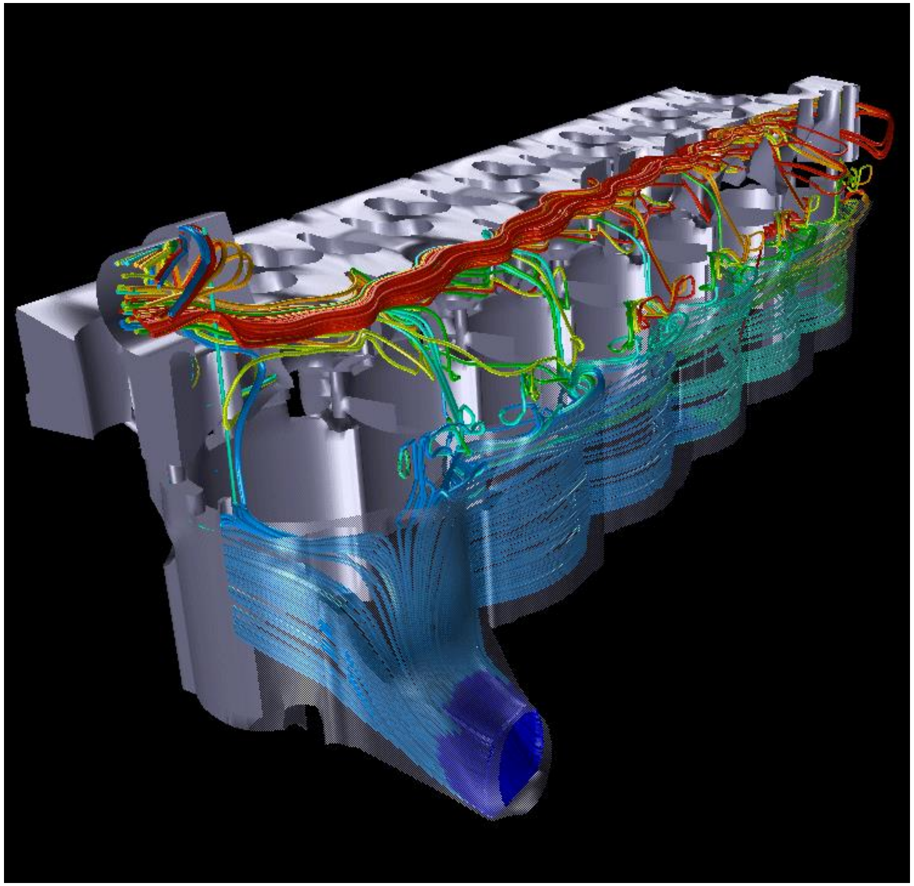




STREAM LINES

Perform an integration through the vector field

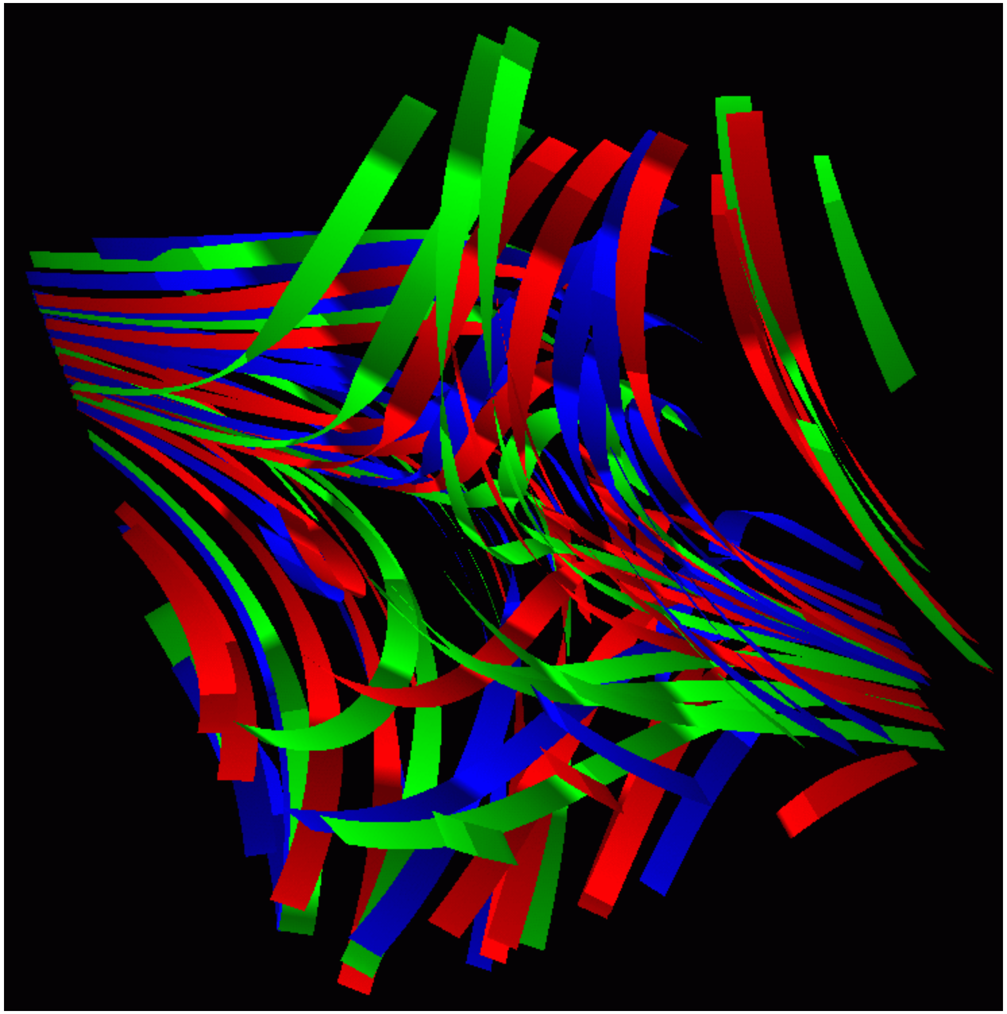
- color maps to temperature



STREAM RIBBONS

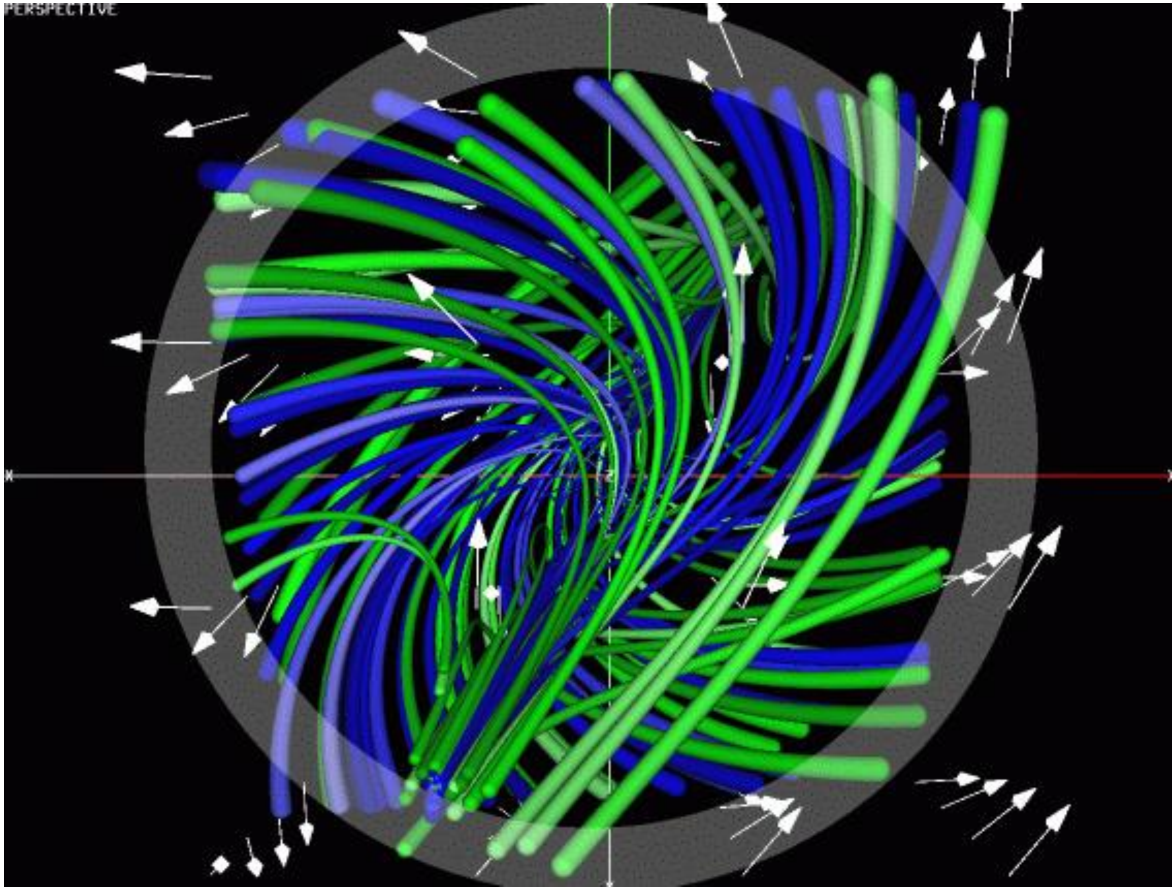
Connect two streamlines

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



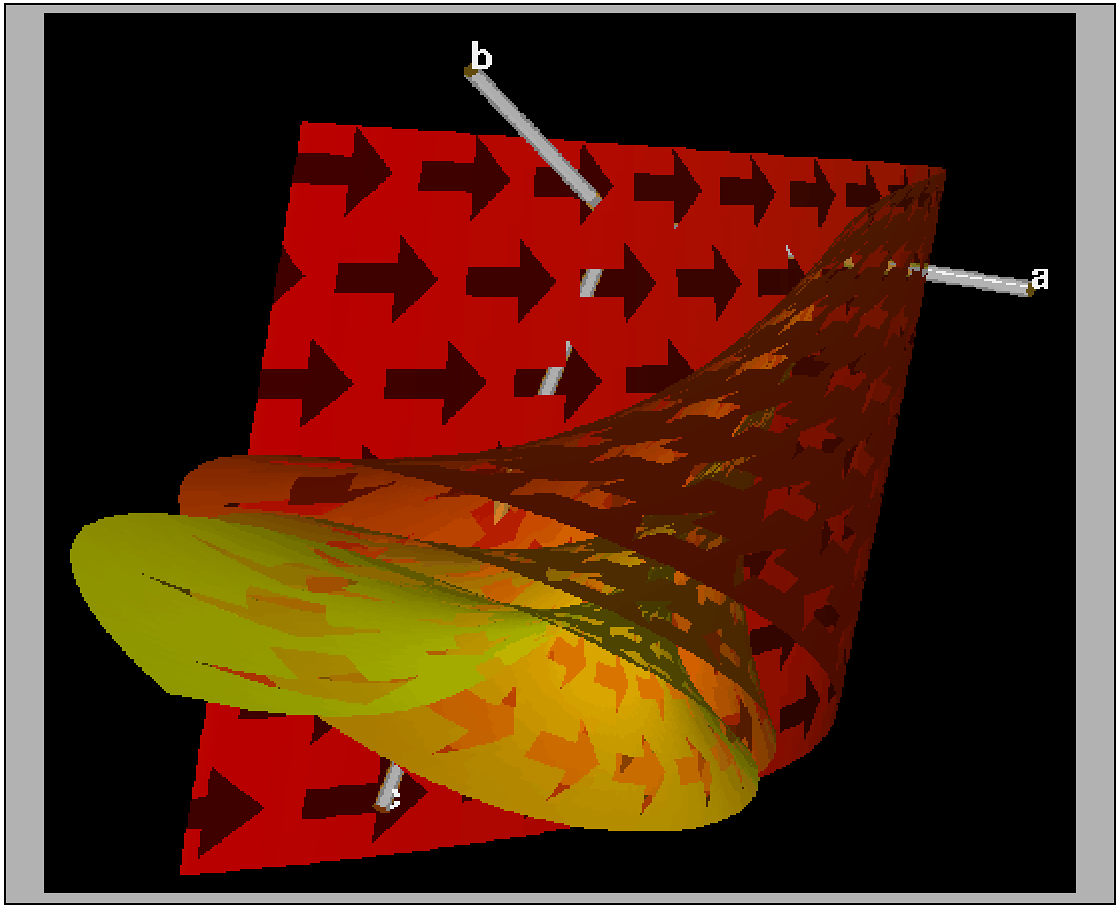
STREAM TUBES

Connect three or more streamlines



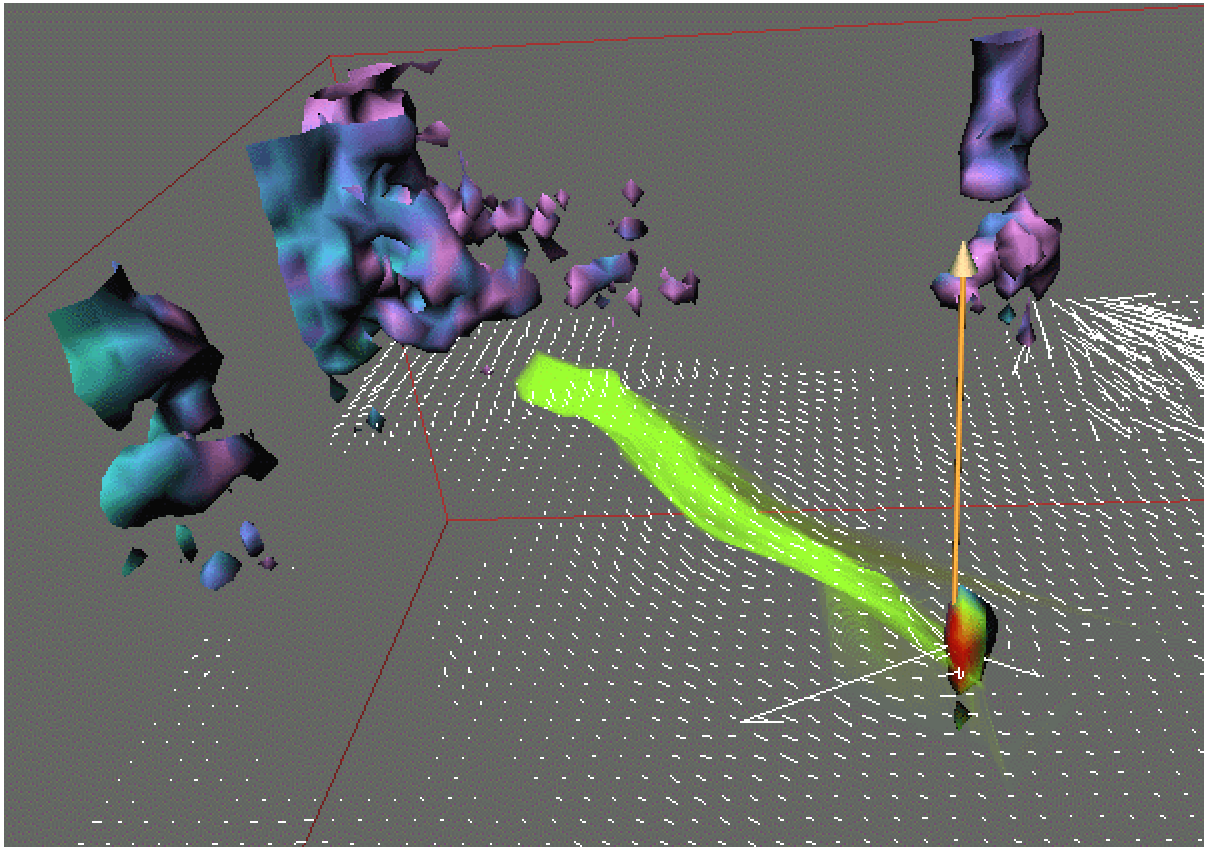
STREAM SURFACES

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

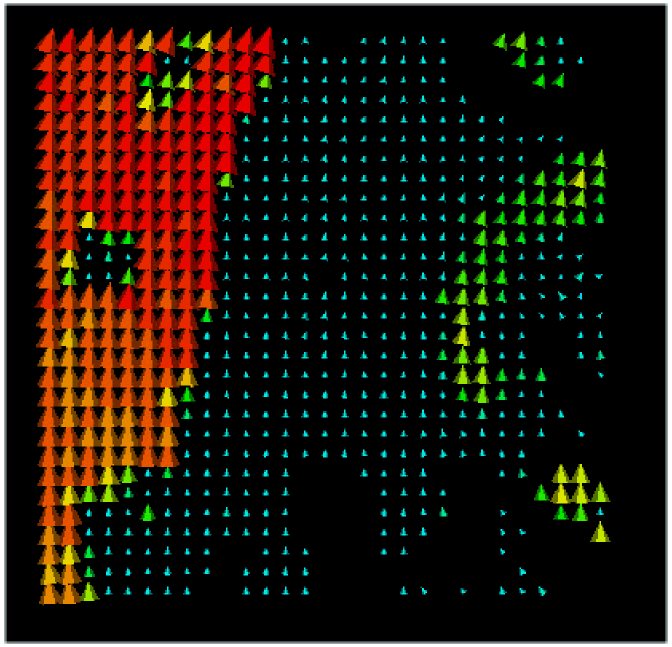
Seek to give a more global view of the vector field

Hedgehogs

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

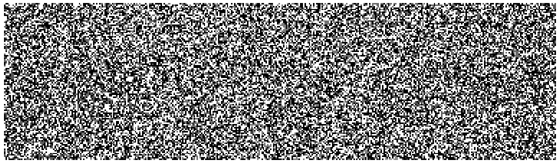
Glyphs, arrows

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



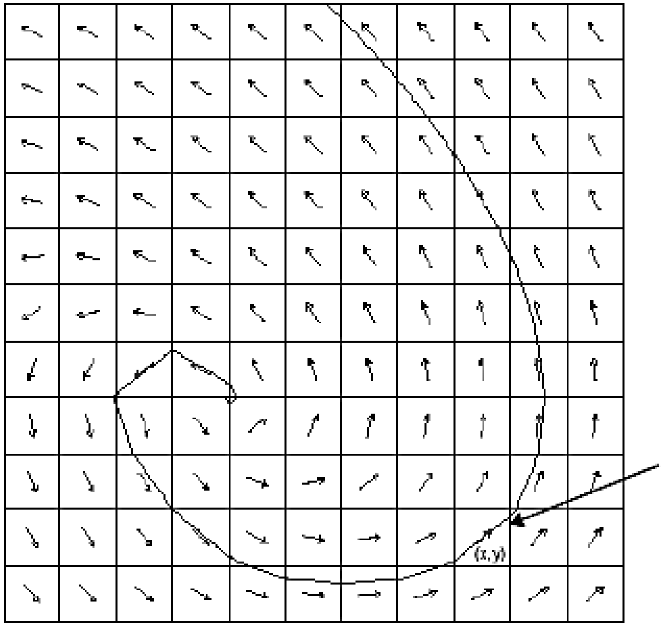
LINE INTEGRAL CONVOLUTION (LIC)

- Input:
  - a 2D vector field



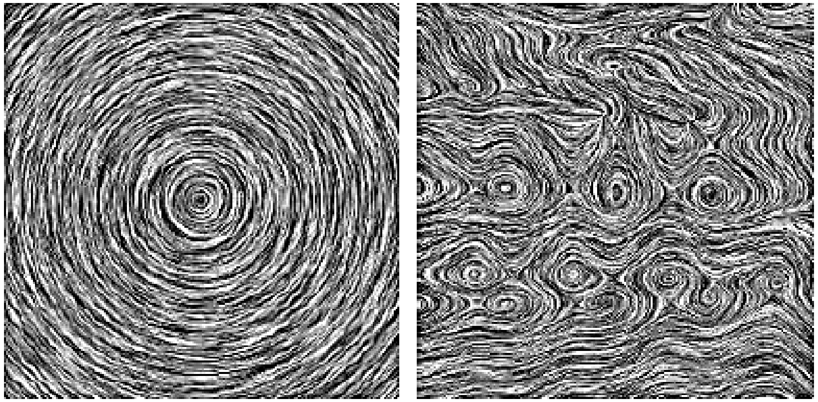
salt+pepper noise

  - 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

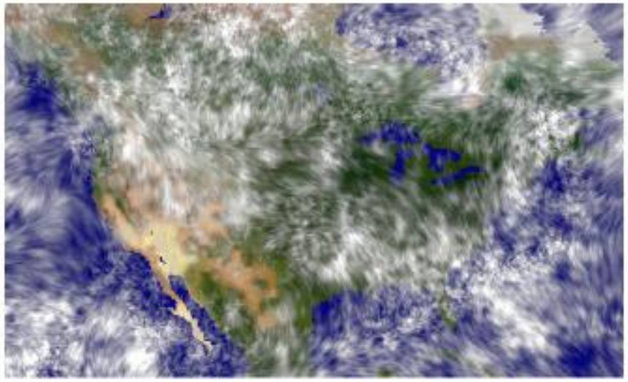
```
For each ouput pixel (x, y)
    Follow the stream line forward for some distance $\Delta s$
    Multiply each pixel value by a 1D filter kernel and add
    Follow the stream line backward for some distance $\Delta s$
    Multiply each pixel value by a 1D filter kernel and add
    Follow the stream line backward for some distance Ds
```

filter aligned with the stream line

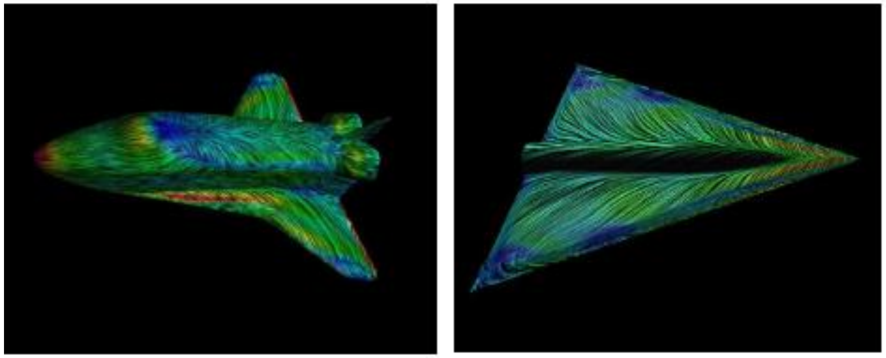
Line Integral Convolution (LIC)

a flower image with different vector fields

a simple motion vector field over the hand



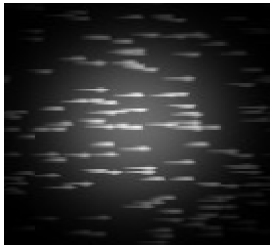
using vector magnitude to determine Δs



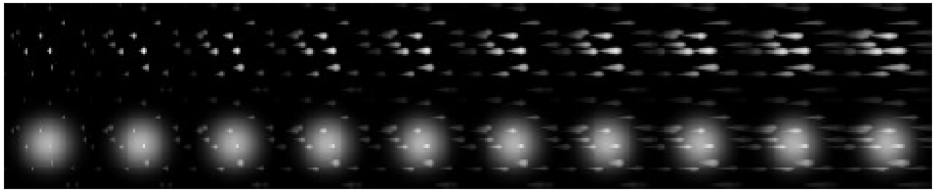
mapping LIC onto an object surface

TEXTURED SPLATS

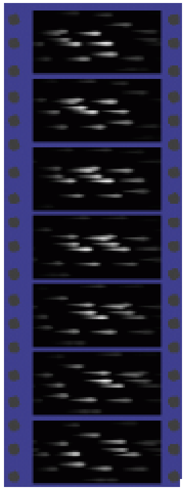
- Embed flow field vector icons into a splat
  - this enables smooth blending of neighboring icons



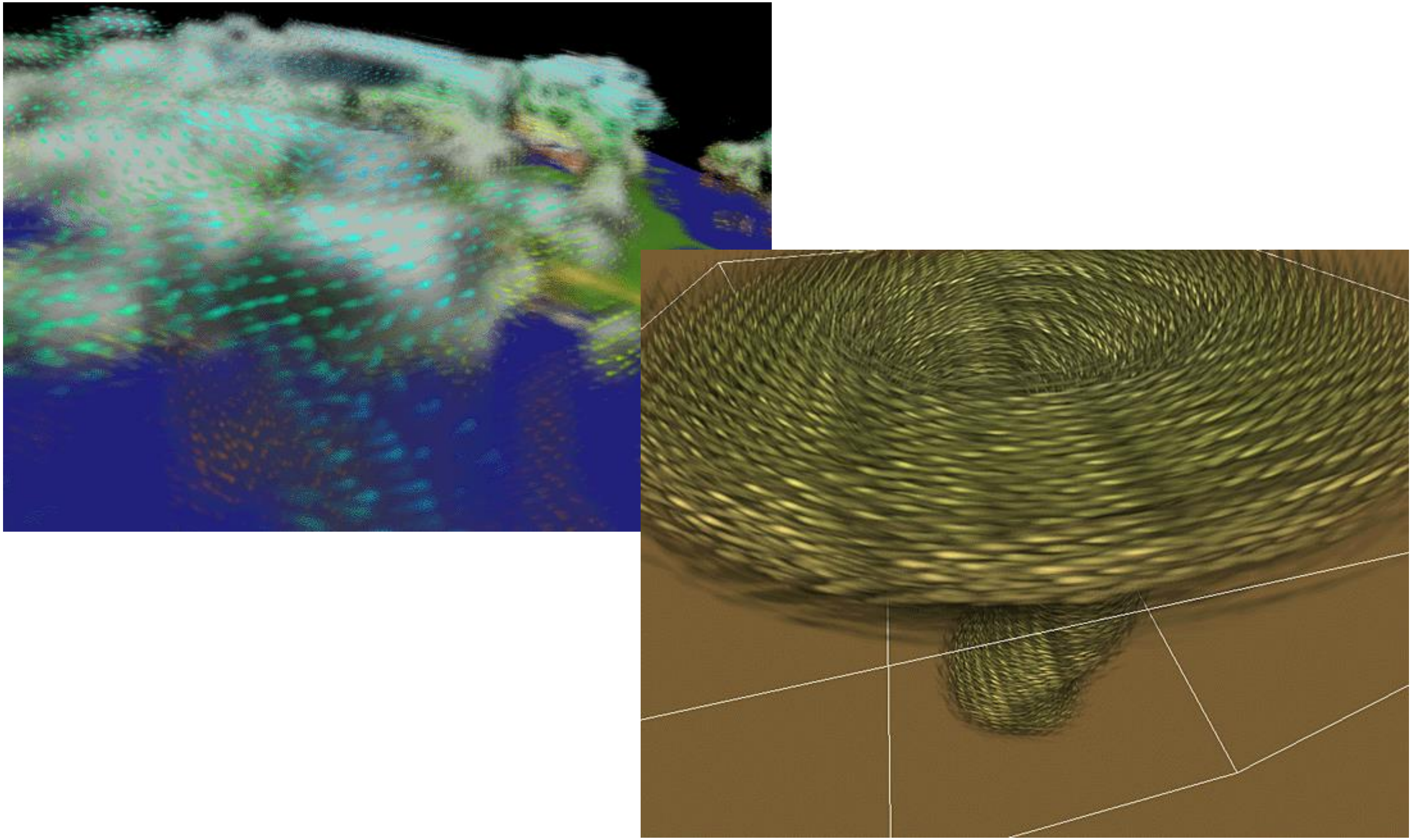
- Create a table of texture splats with varying icon distribution (to prevent regular patters)
- For a given location, select a random splat and rotate corresponding to the flow field direction
- Since the flow field is 3D, the component of the vectors that is parallel to the screen varies
- Need to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

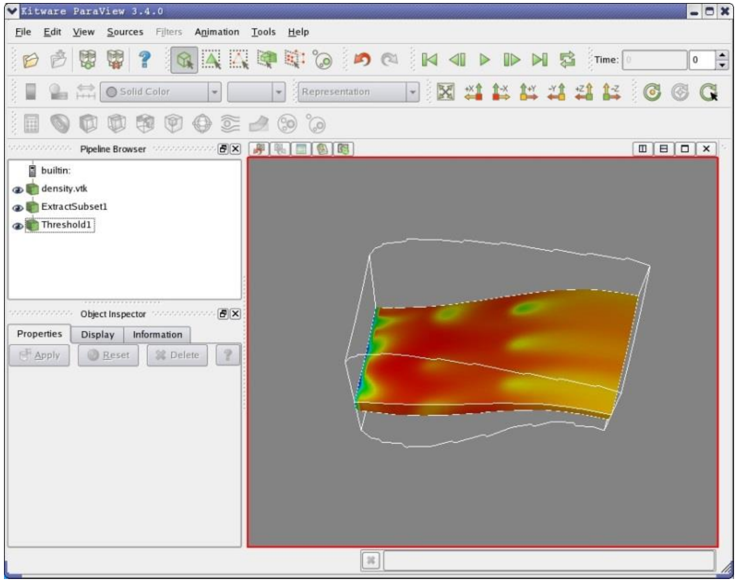


POPULAR SOFTWARE & LIBRARIES

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

SUMMARY

How to render volumetric datasets as polygonal meshes

- convert using the Marching Cubes algorithm

L:arge scale data

- origin -- simulation of large scale phenomena on supercomputers
- collaborative visualization -- display wall, CAVE, SBU Reality Deck

Grids – balancing level of detail and representation complexity

- regular grids, curvilinear grids, unstructured (irregular) grids

Flow and vector field visualization

- stream lines, ribbons, tubes, surfaces, balls
- Line Integral Convolution (LIC), texture splats

Scientific visualization libraries

- VTK, Paraview, VisIt