# CSE 332
# Introduction to Visualization

# Scientific Visualization

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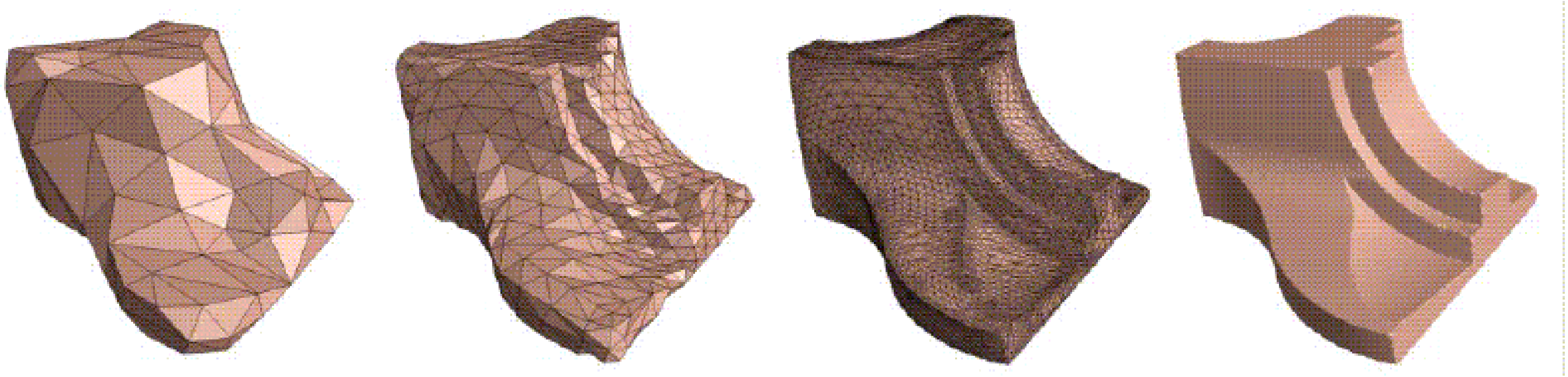
| Lecture | Topic | Projects |
|---|---|---|
| 1 | Intro, schedule, and logistics | |
| 2 | Applications of visual analytics, data, and basic tasks | |
| 3 | Data preparation and reduction | Project 1 out |
| 4 | Data preparation and reduction | |
| 5 | Data reduction and similarity metrics | |
| 6 | Dimension reduction | |
| 7 | Introduction to D3 | Project 2 out |
| 8 | Bias in visualization | |
| 9 | Perception and cognition | |
| 10 | Visual design and aesthetics | |
| 11 | Cluster and pattern analysis | |
| 12 | High-Dimensional data visualization: linear methods | |
| 13 | High-D data vis.: non-linear methods | Project 3 out |
| 14 | High-D data vis.: categorical data | |
| 15 | Principles of interaction | |
| 16 | Visual analytics and the visual sense making process | |
| 17 | VA design and evaluation | |
| 18 | Visualization of graphs and hierarchies | Project 4 out |
| 19 | Midterm | |
| 20 | Visualization of time-varying and time-series data | |
| 21 | Maps and geo-vis | |
| 22 | Computer graphics and volume rendering | |
| 23 | Techniques to visualize spatial (3D) data | Project 4 halfway report due |
| 24 | Scientific and medical visualization | |
| 25 | Non-photorealistic rendering | |
| 26 | Memorable visualizations, visual embellishments | Project 5 out |
| 27 | Infographics design | |
| 28 | Projects Hall of Fame demos | |

# Rendering Volumes as Surfaces

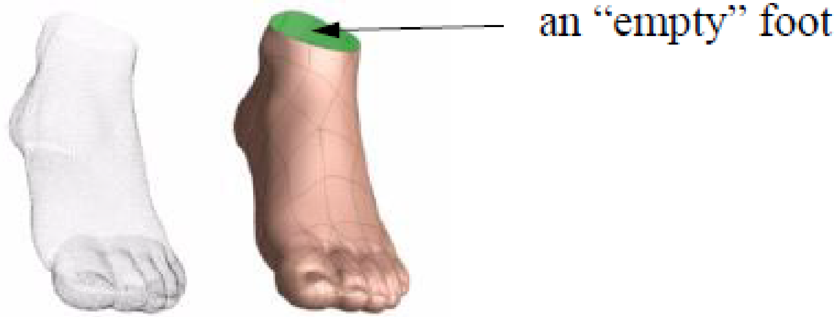
- Objects are explicitely defined by a surface or boundary representation (explicit inside vs outside)
- This boundary representation can be given by:

  - a mesh of polygons:



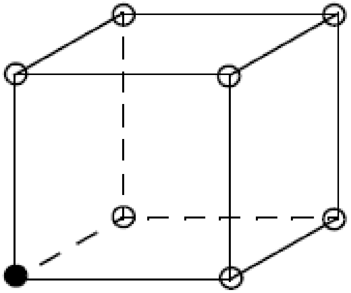
200 polys 1,000 polys 15,000 polys

  - a mesh of spline patches:

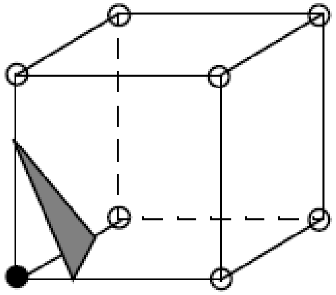


# The Marching Cubes Polygonization Algorithm

- 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:

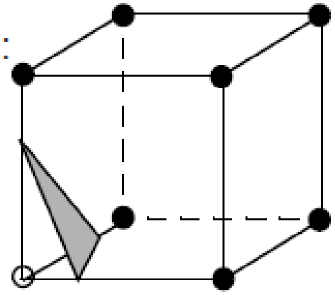


only 1 voxel > iso-value



the polygon that separates
inside from outside

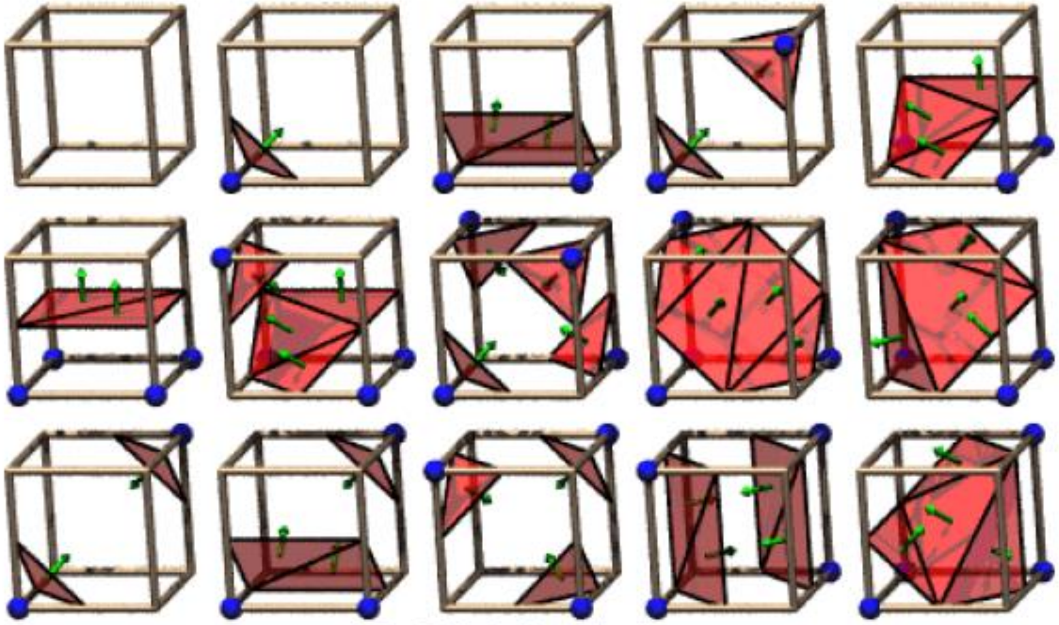
the reverse case:



7 voxels > iso-value
the same polygon results

# Marching Cubes (2)

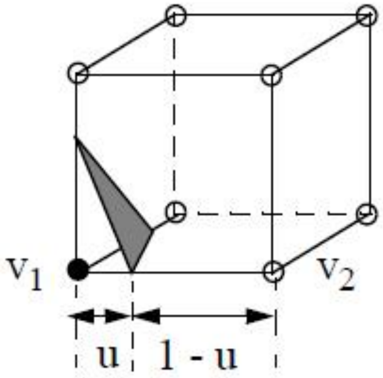
- One can identify 15 base cases
  - Use symmetry and reverses to get the other 241 cases



The 15 Cube Combinations

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

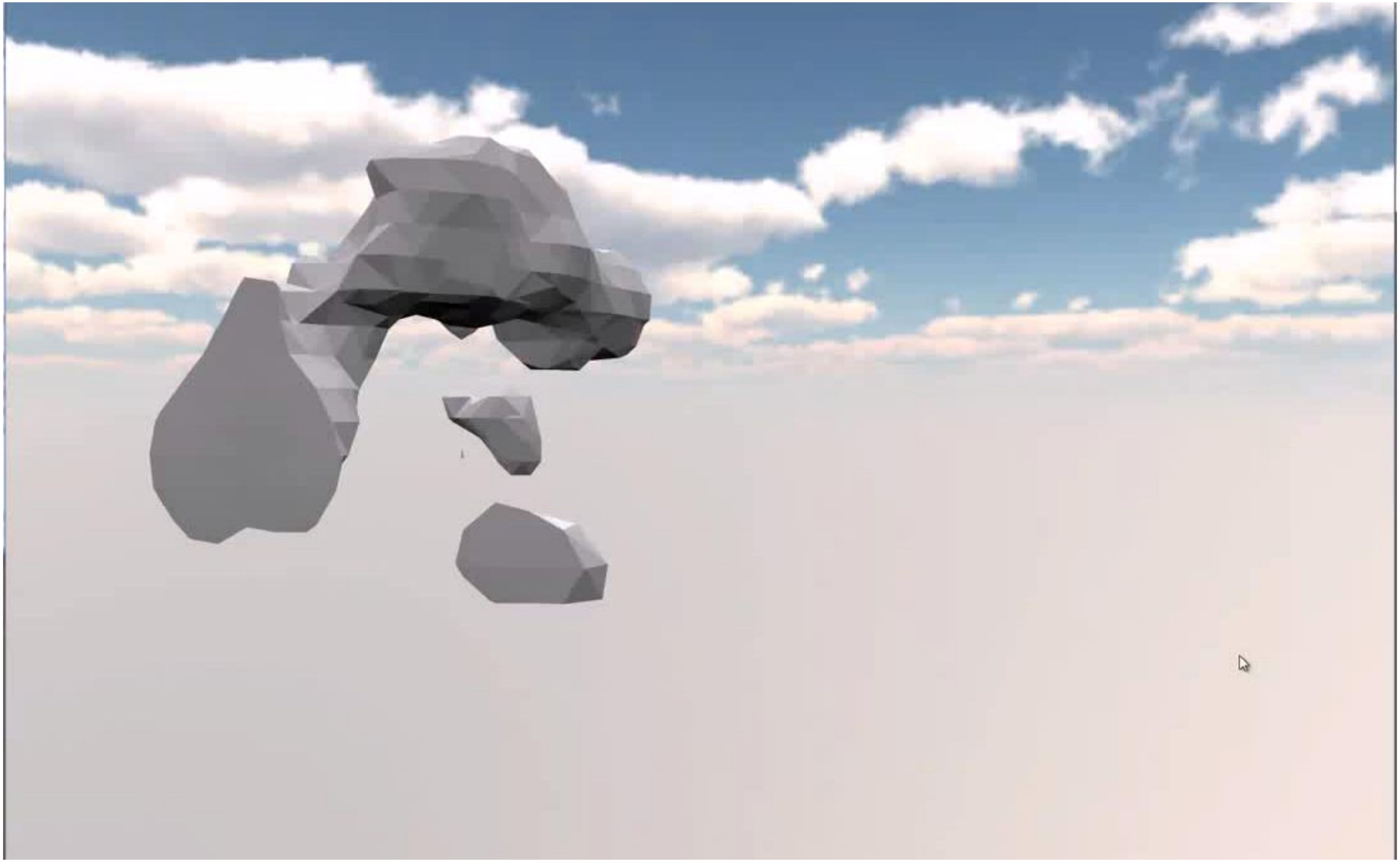
$$iso = v_1 \cdot (1-u) + v_2 \cdot u \longrightarrow u = \frac{v_1 - iso}{v_1 - v_2}$$



- Now interpolate the vertex color by: $c_1 = uc_2 + (1-u)c_1$
- Interpolate the vertex normal by: $\boldsymbol{n}_1 = u\boldsymbol{g}_\mathbf{2} + (1-u)\boldsymbol{g}_\mathbf{1}$

(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

# 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 two 22-core IBM Power9 processors and six NVidia Tesla V100 GPIUs

# What Does it Do?

Compute, compute, compute

Examples:

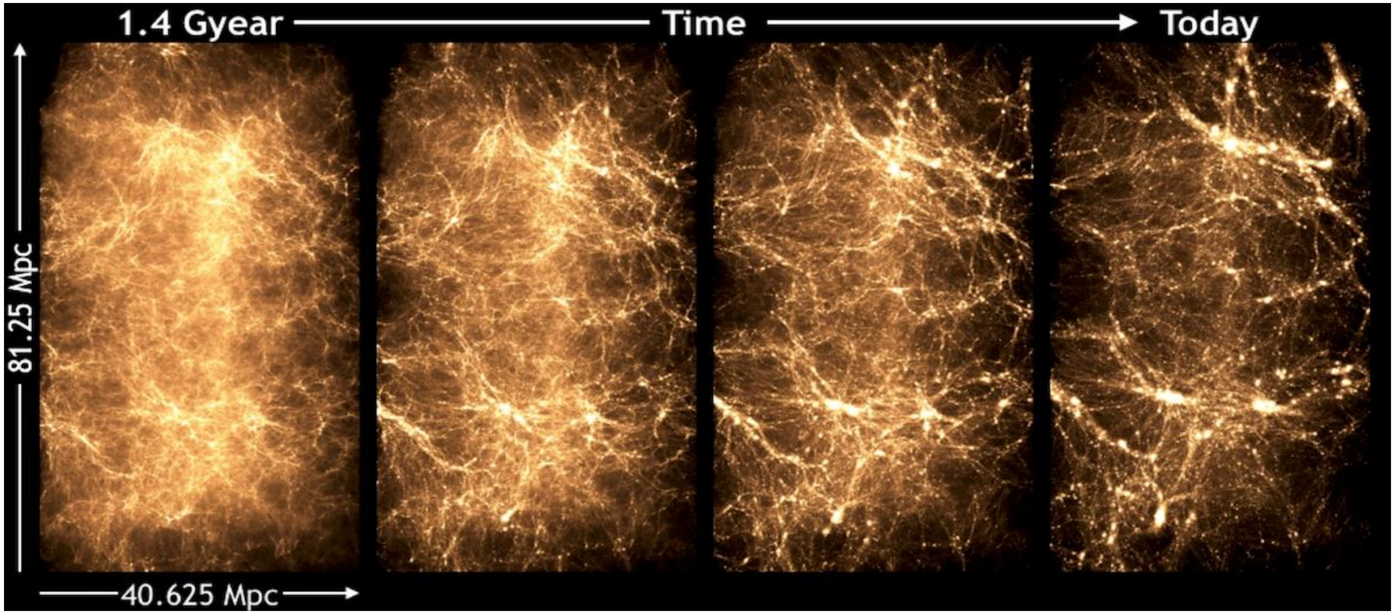
- S3D, a project that models the molecular physics of combustion, aims to improve the efficiency of diesel and biofuel engines
- Denovo simulates nuclear reactions with the aim of improving the efficiency and reducing the waste of nuclear reactors
- WL-LSMS simulates the interactions between electrons 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

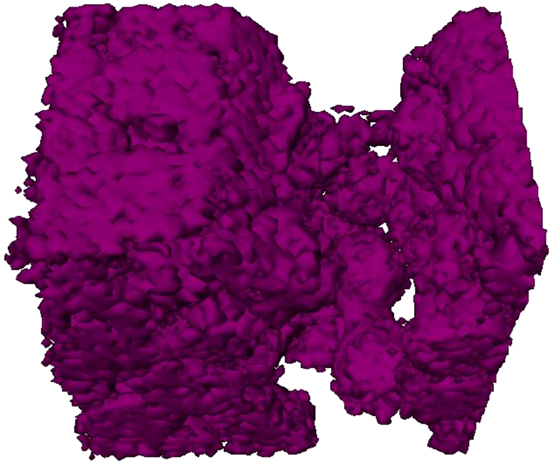
Numbers, lots of them

- 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

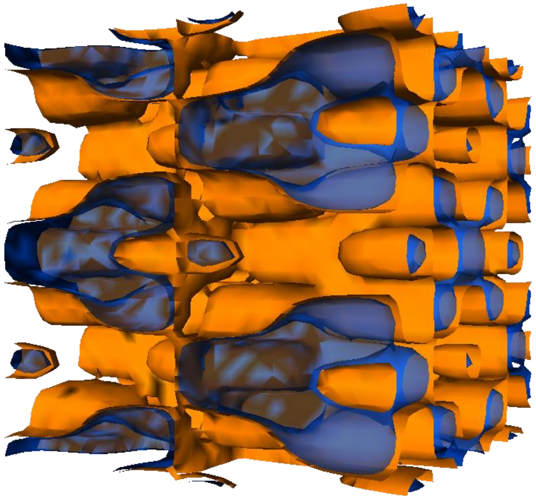


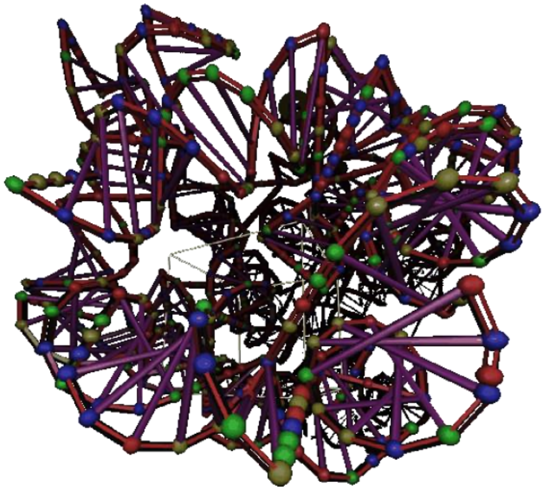
# More Examples



Nuclear, Quantum, and Molecular Modeling

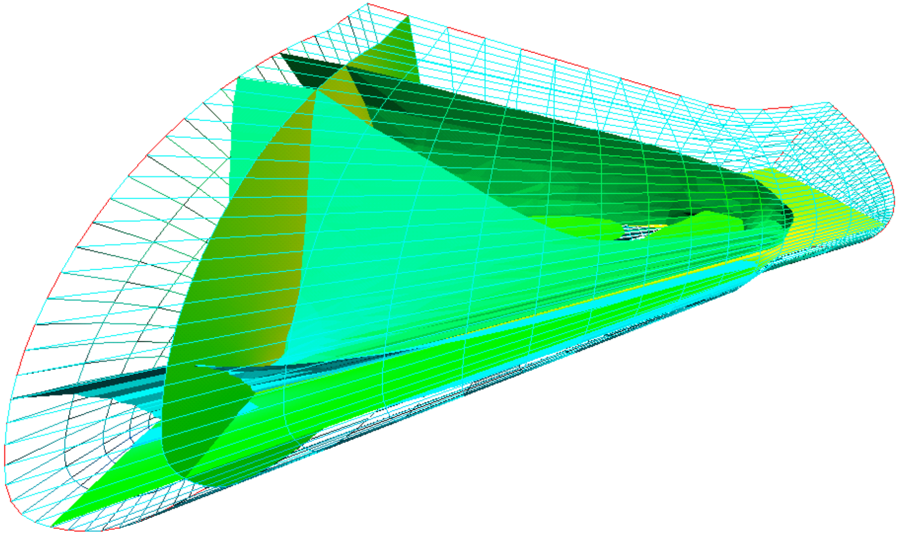
Structures, Fluids and Fields



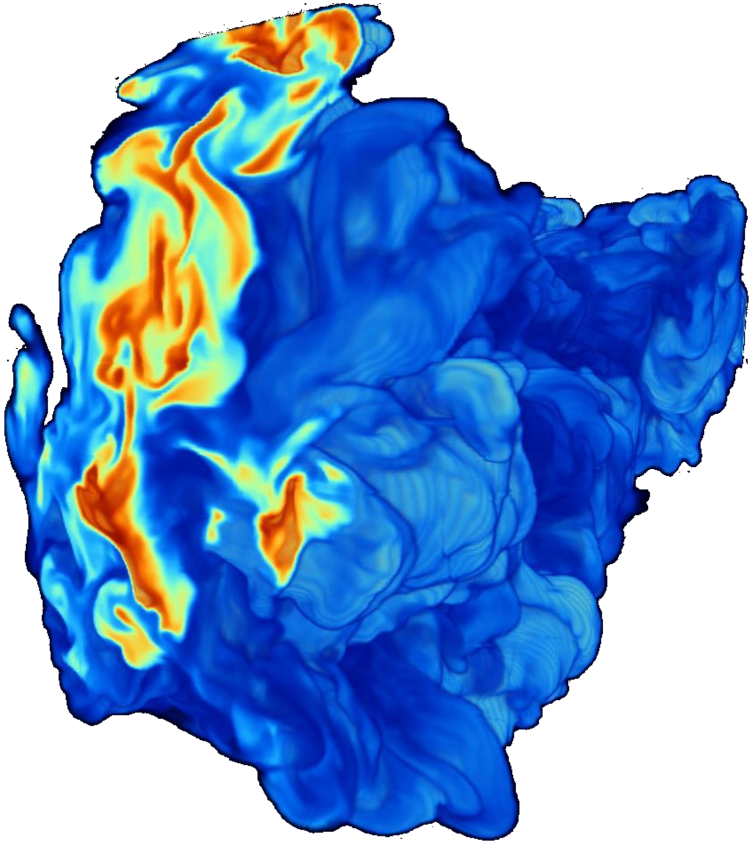


Advanced Imaging and Data Management

# More Examples



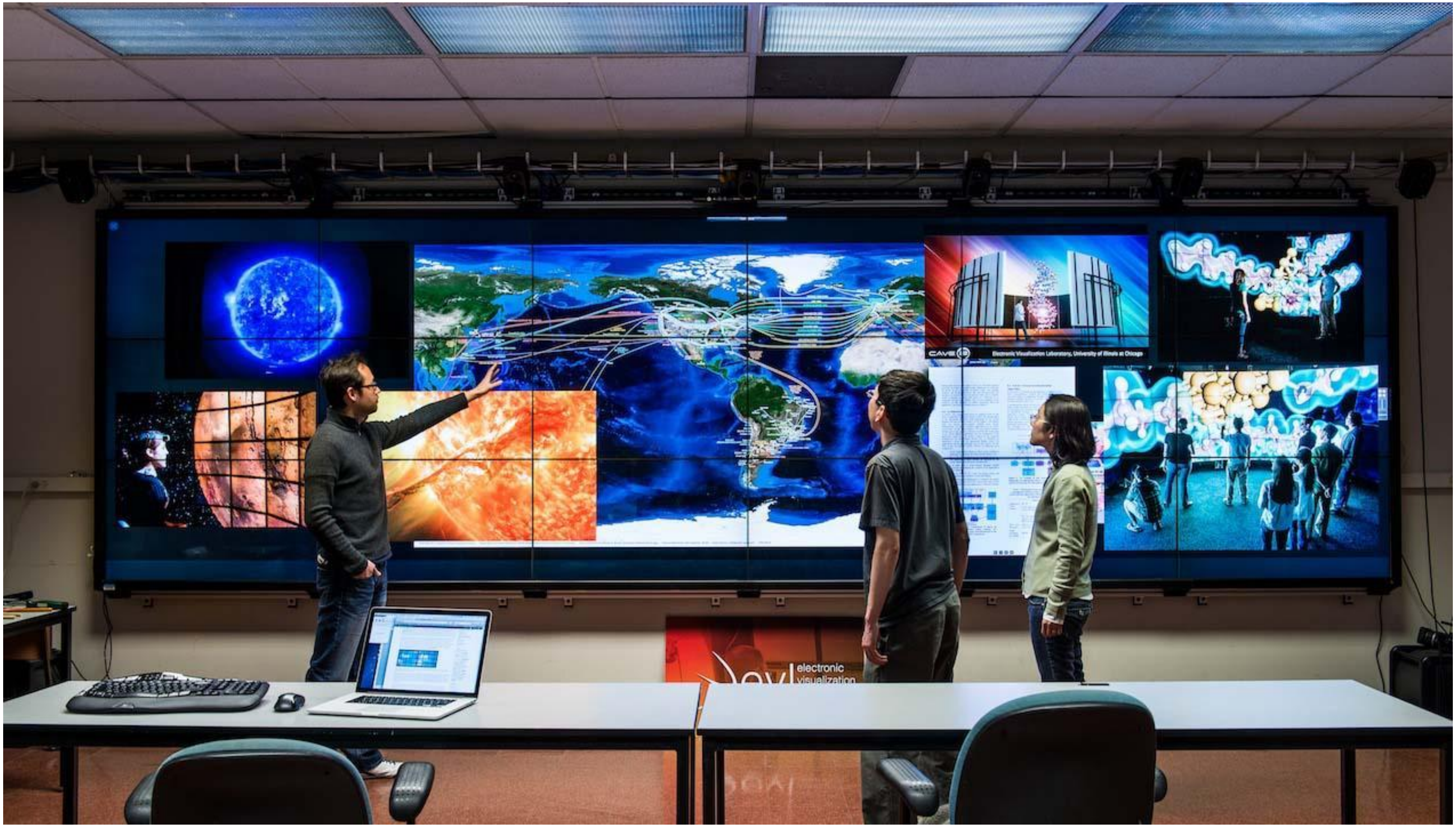
Surface Rendering with vTK
(The Visualization Toolkit



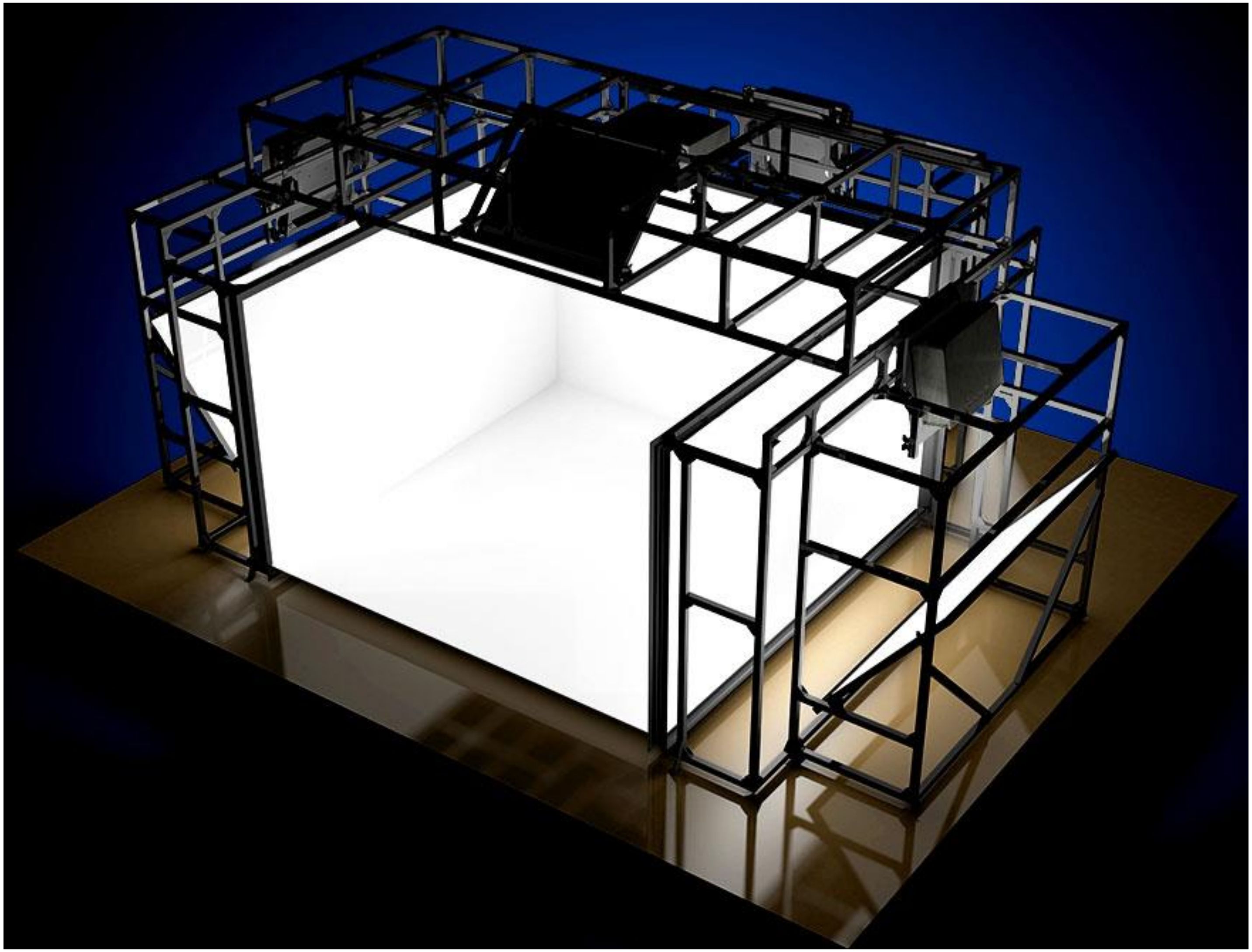
Volume Rendering

# Where to Visualize All This?

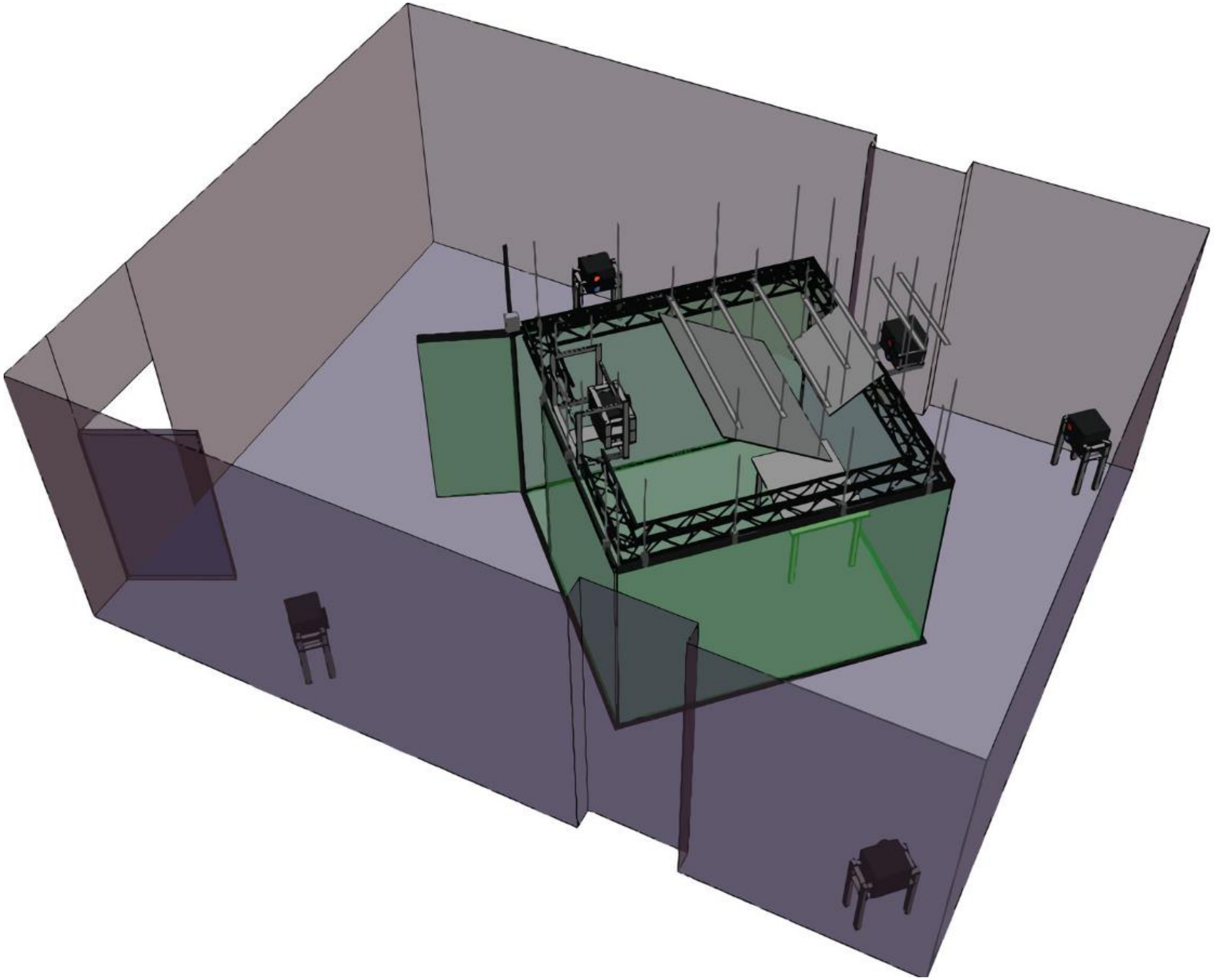
# Display Wall



# CAVE



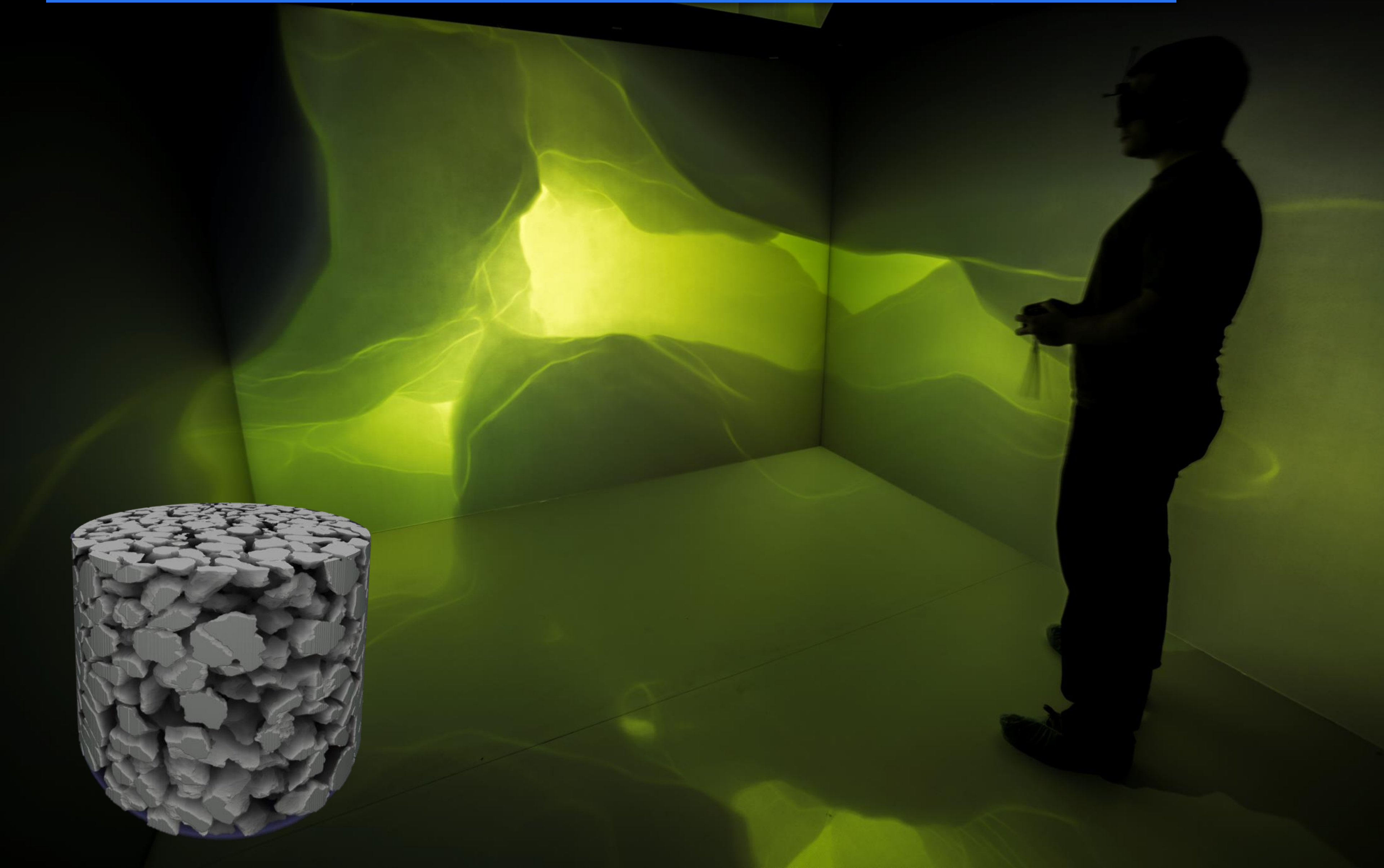
# The Stony Brook Immersive Cabin



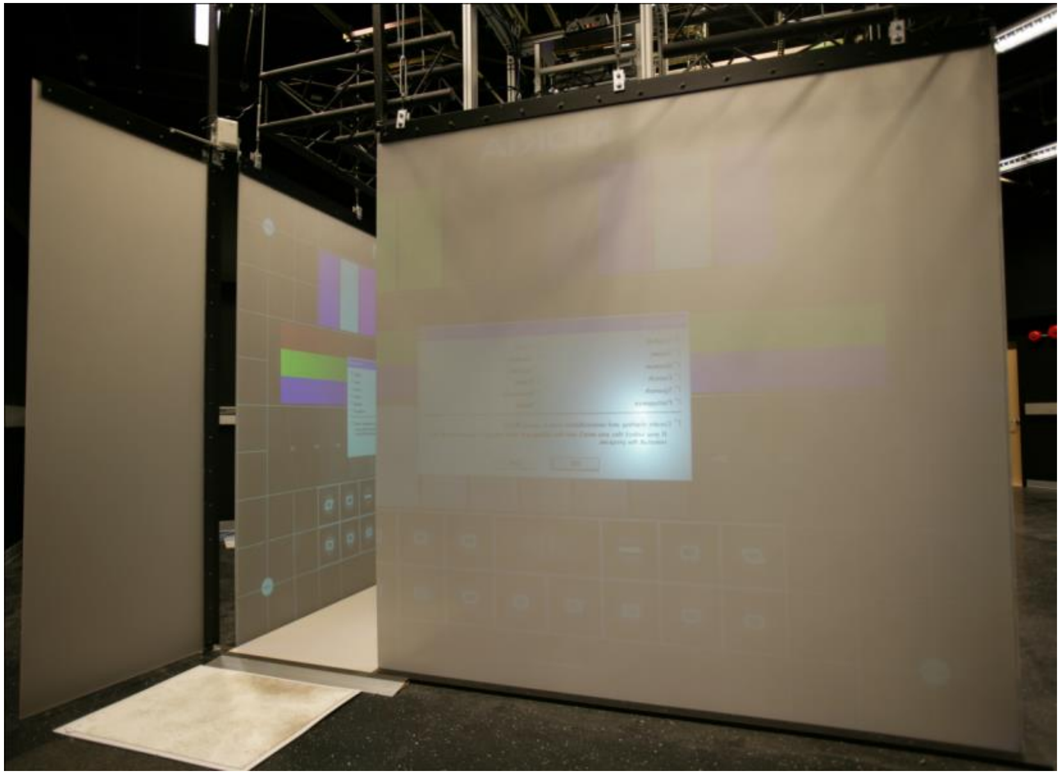
# CAVE

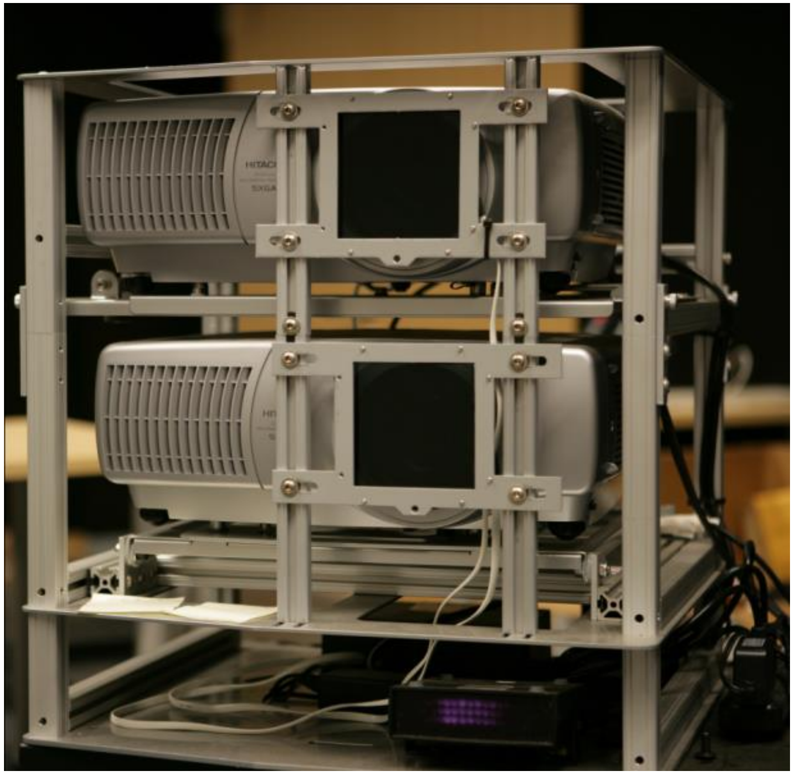
# Microtomography

*(BNL, soil sample)*



# The Stony Brook Immersive Cabin





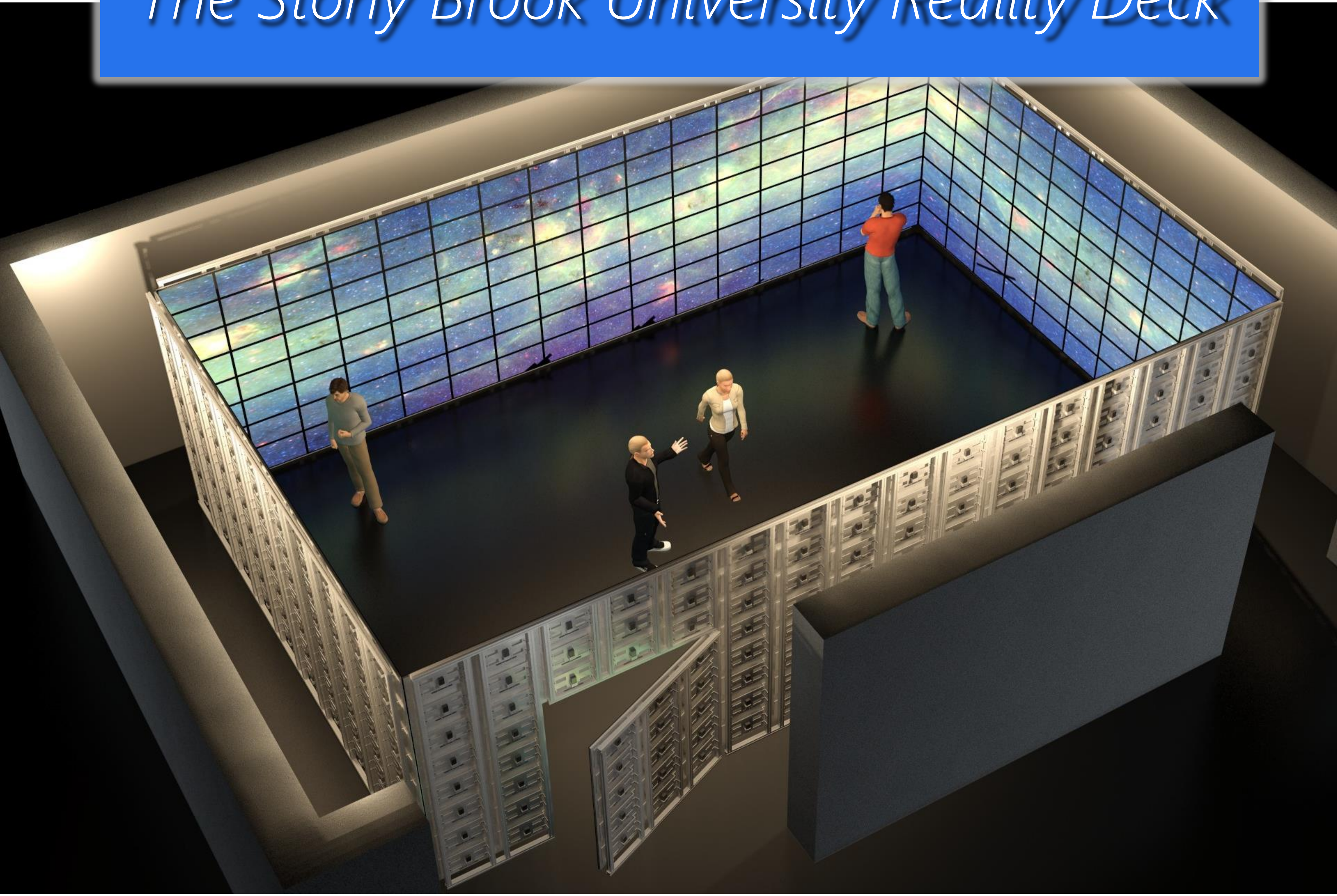
Projector based system

- 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

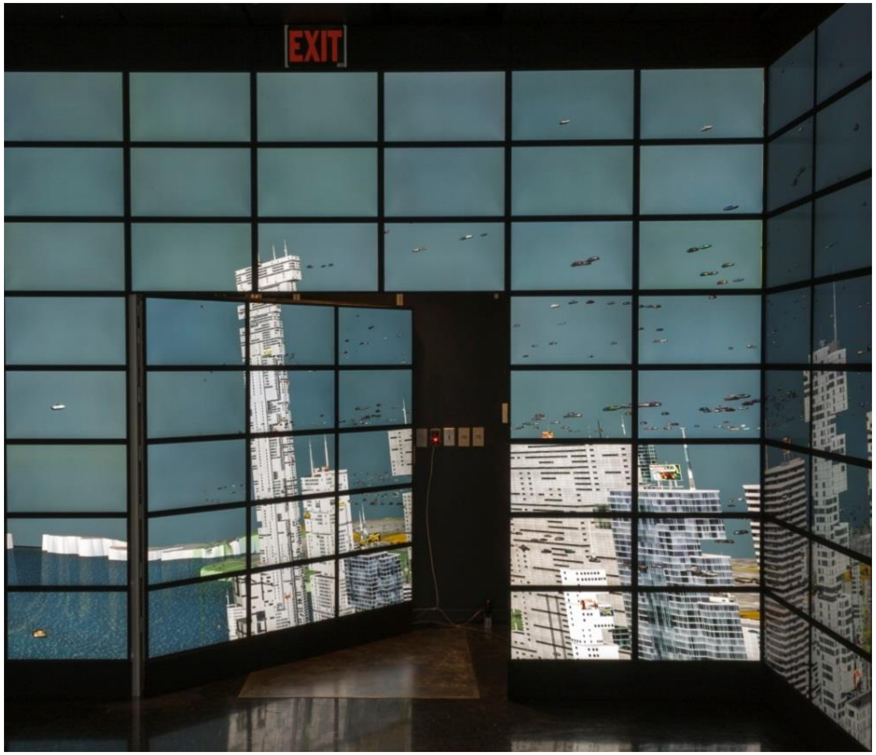
- 30′×40′×11′ environment
- 416 UQXGA LCD Displays
  - 2,560×1,440 resolution over 50’-100’ DisplayPort cables
  - fast response time, wide viewing angles, good dynamic range
- 20-node GPU cluster, each node equipped with:
  - 2× Six-core CPUs, 48 GB Ram
  - 4× AMD FirePro V9800 with 4GB Ram and 6 DisplayPort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

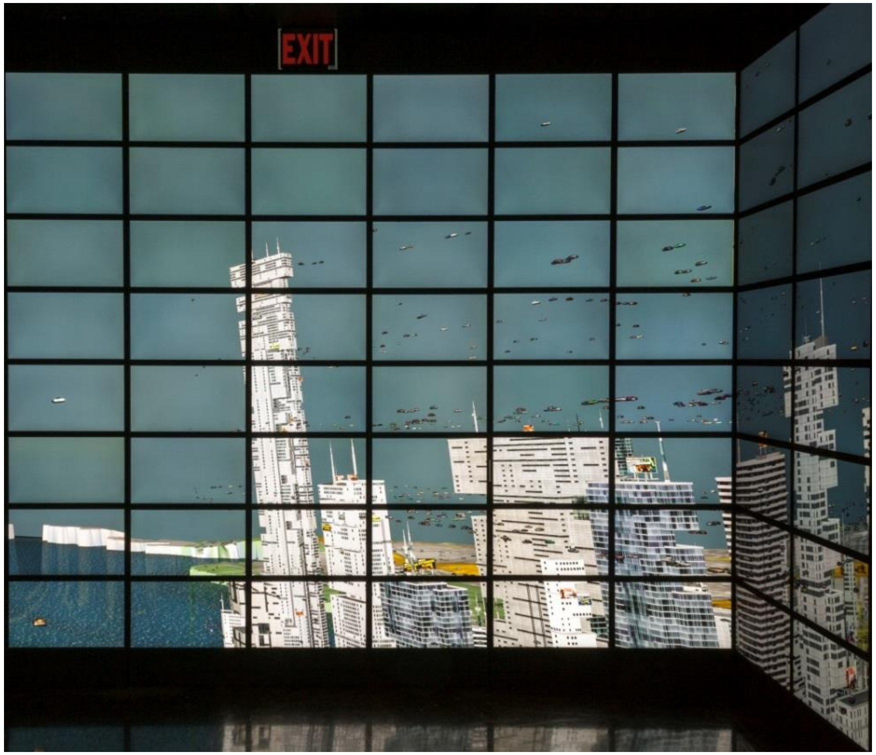
# Automatic Door

3×5 section of displays

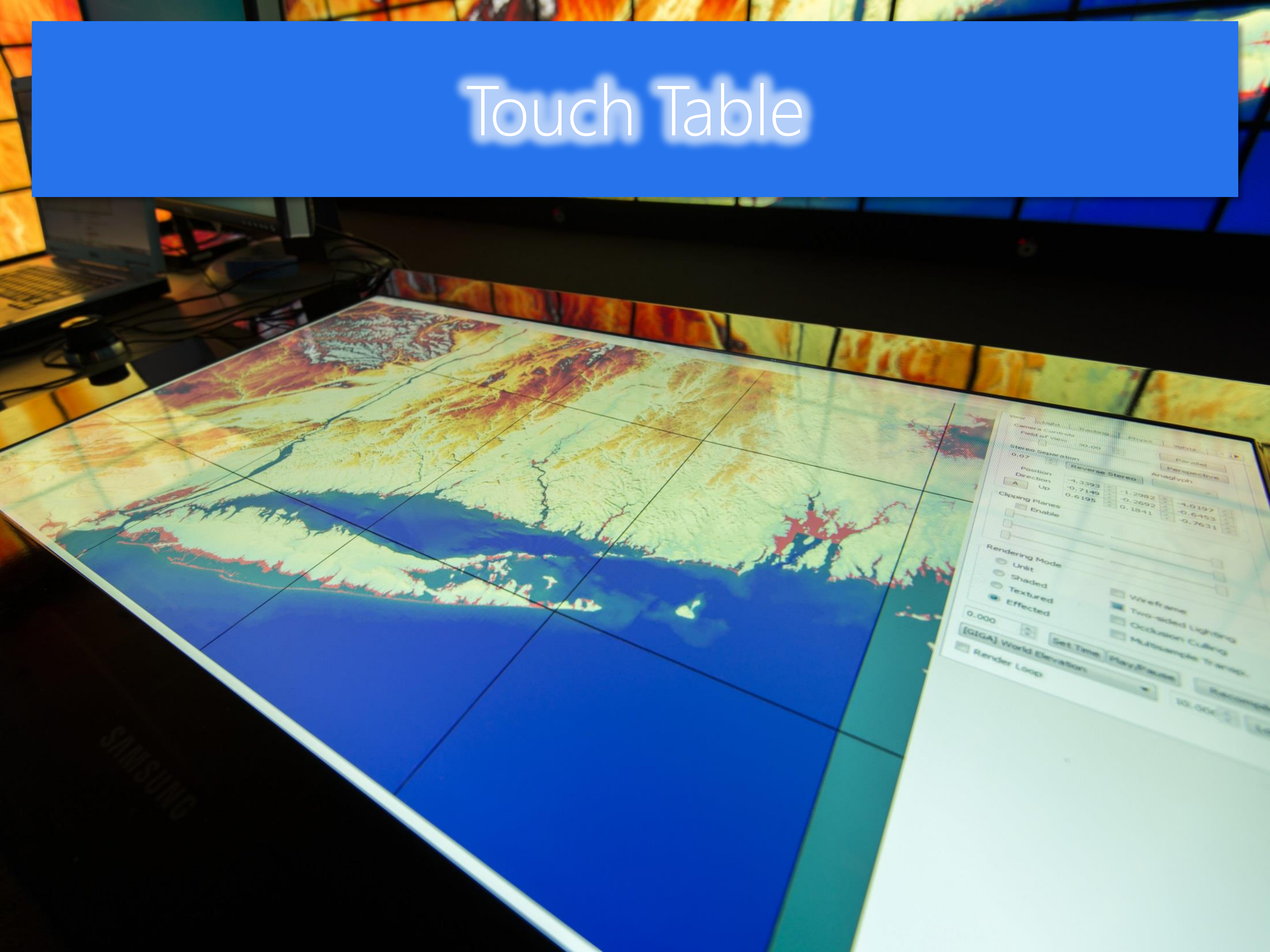
Visually indistinguishable from rest of display

- allows for a fully enclosed visualization environment



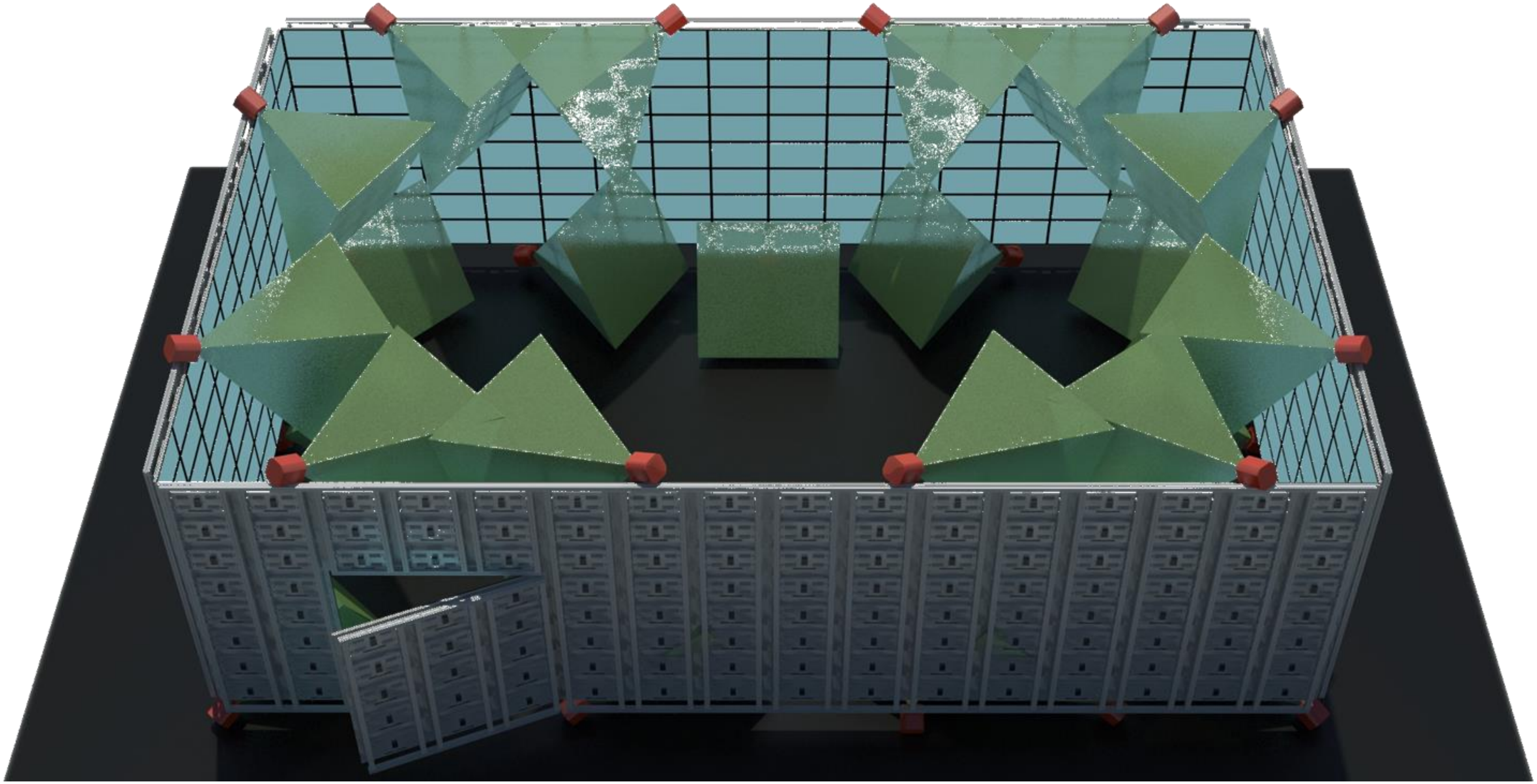


# Touch Table



# Reality Deck Tracking System

24-camera infrared optical system from OptiTrack

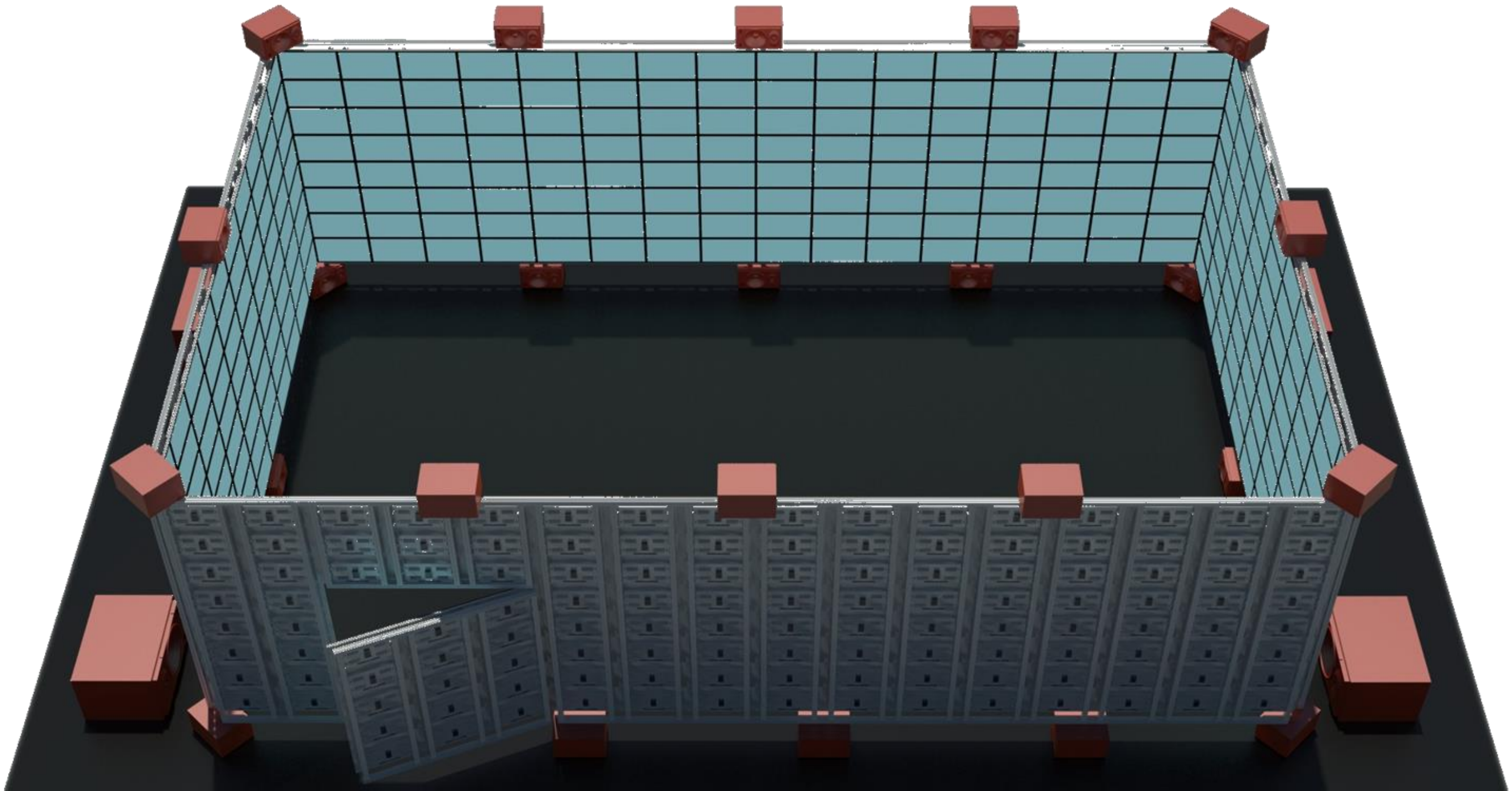


# Reality Deck Sound System

24.4 channel professional-grade system

Positional audio with real-time ambisonics

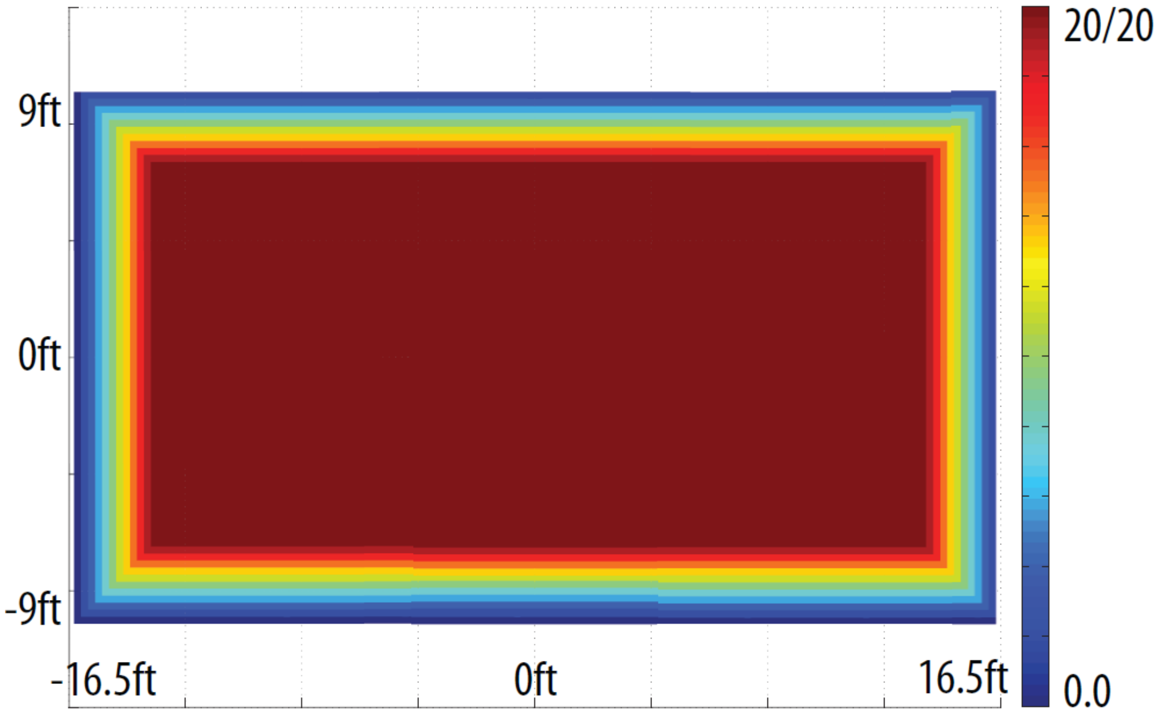
- using the Rapture3D OpenAL driver



# Uniformly High Visual Acuity

User can make visual queries at an instant

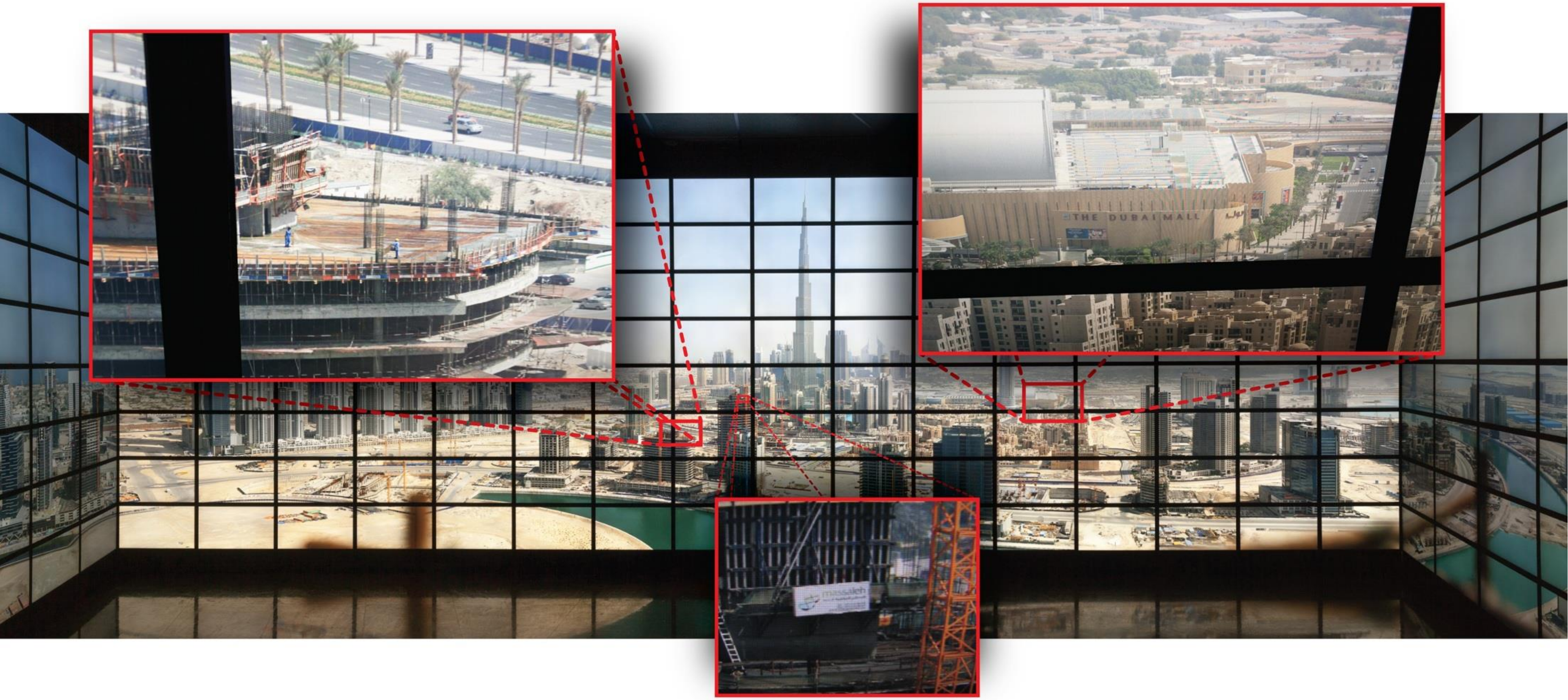
- walk up to obtain more detail
- just like in real life – hence the Realty Deck
- 20/20 visual acuity at 1.5′-2′ away



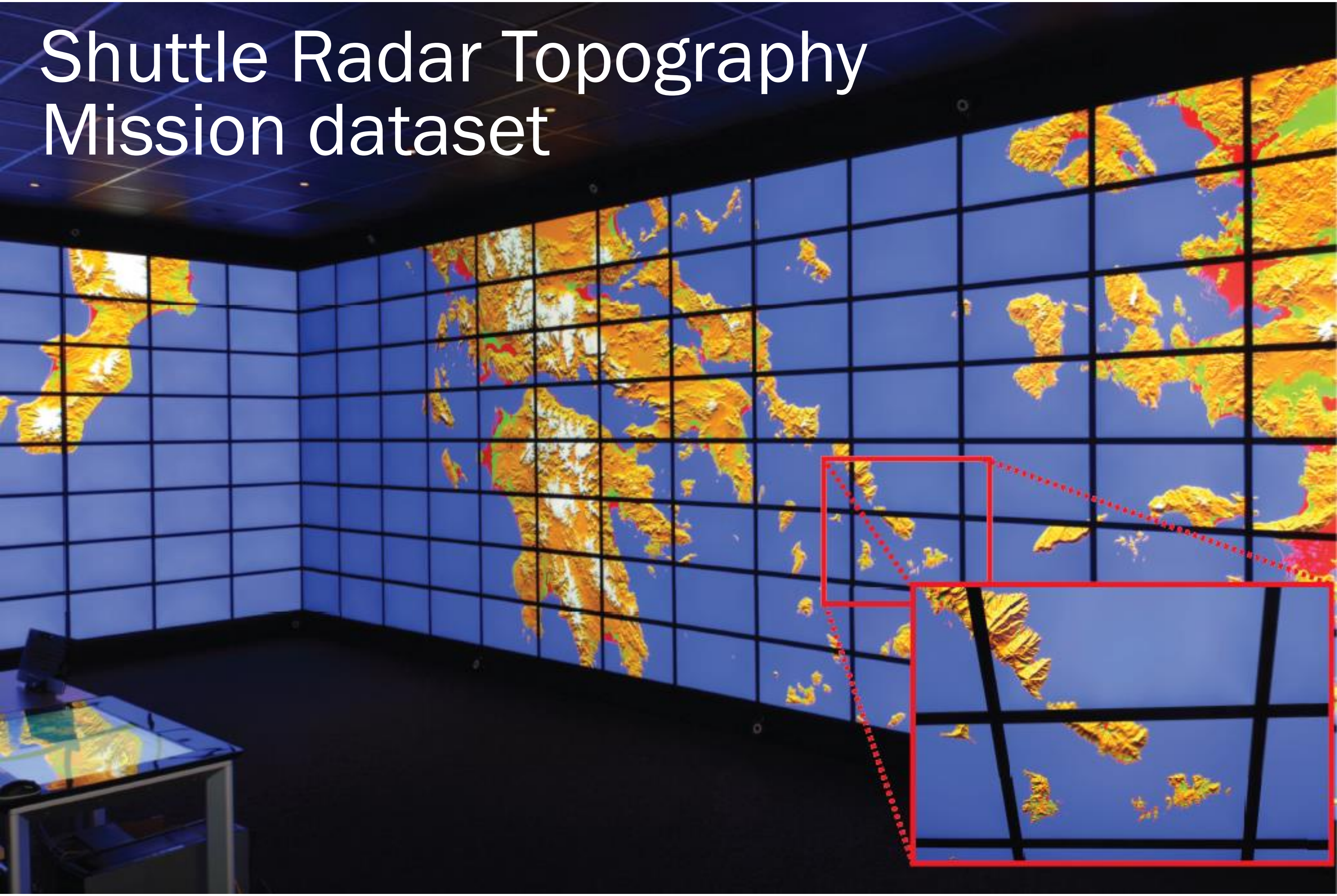
# Gigapixel Visualization

Dubai dataset

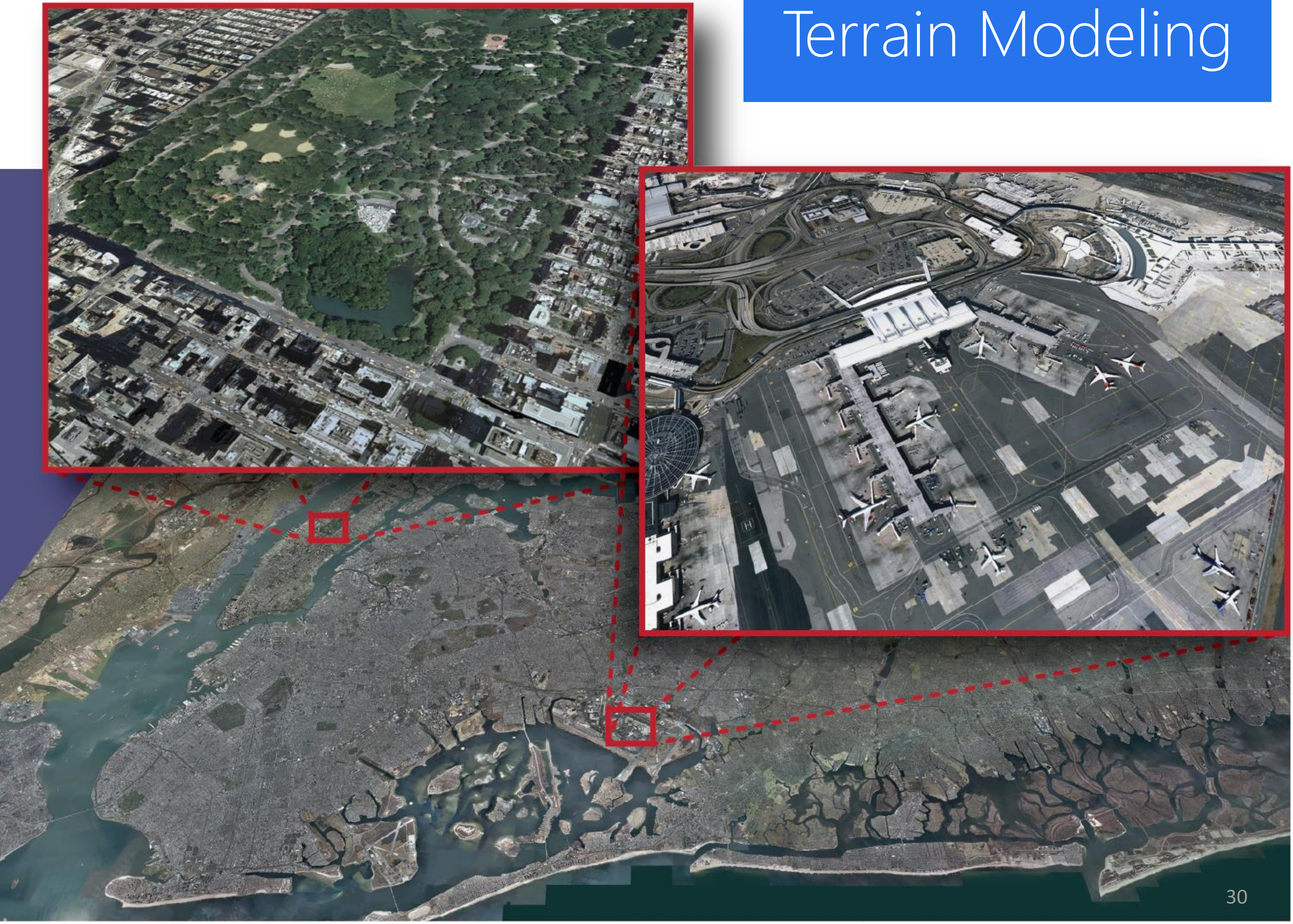
- 45 Gigapixels, 180° field of view



# Shuttle Radar Topography Mission dataset

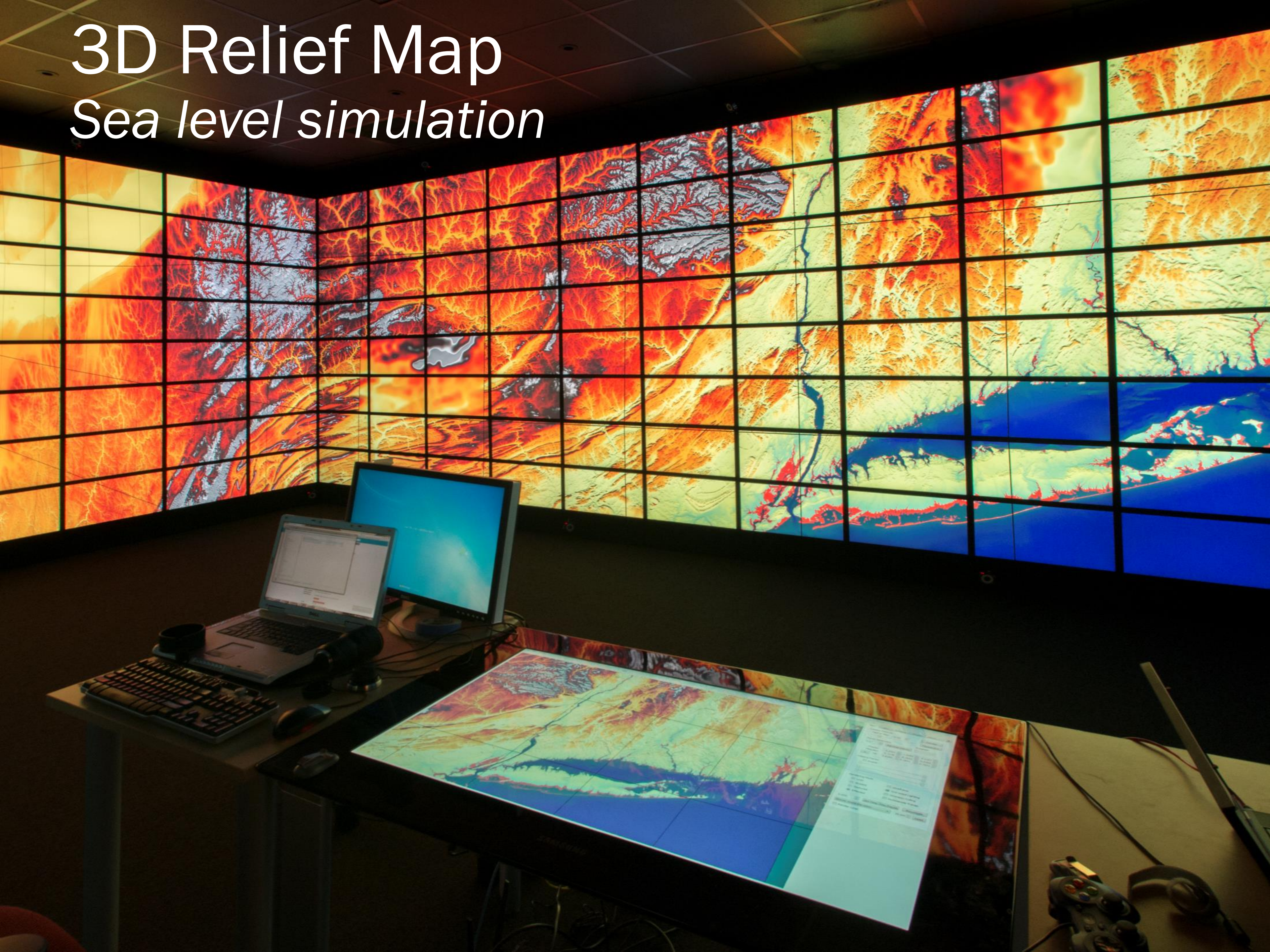


# Terrain Modeling



# 3D Relief Map

*Sea level simulation*



# Protein Visualization

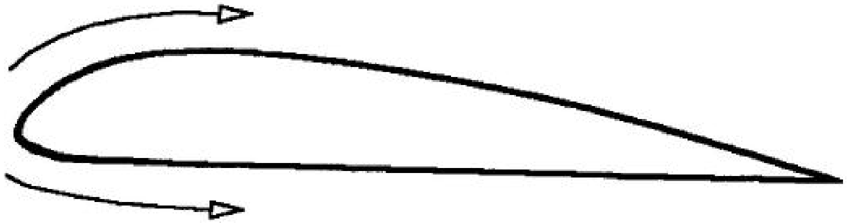
*Reality Deck*

# Scientific Simulation

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

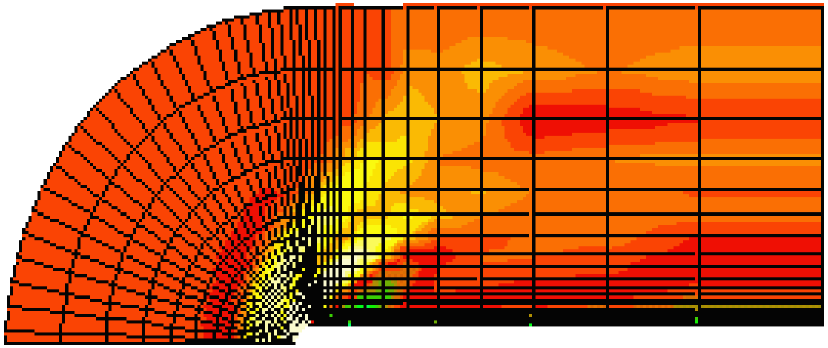
- where is the flow most interesting?

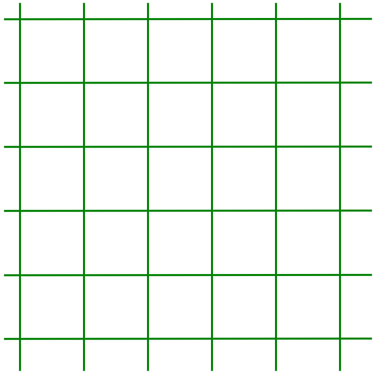
- right, close to the surface



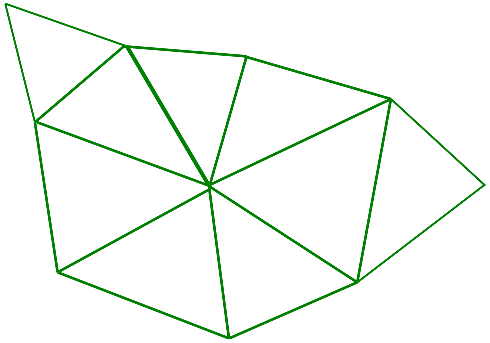
# Simulation lattice

Make the simulation lattice densest along the surface





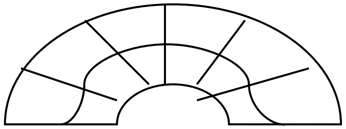
Regular → irregular grids



# Grids

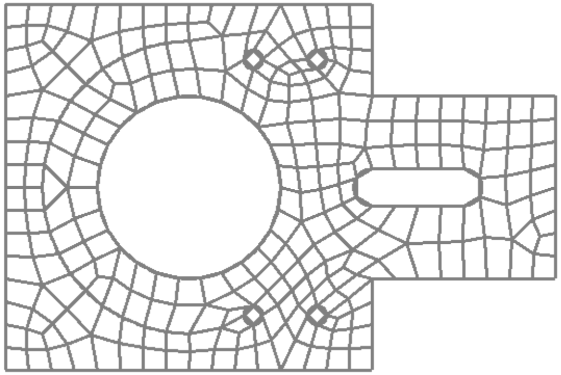
## Structured grid

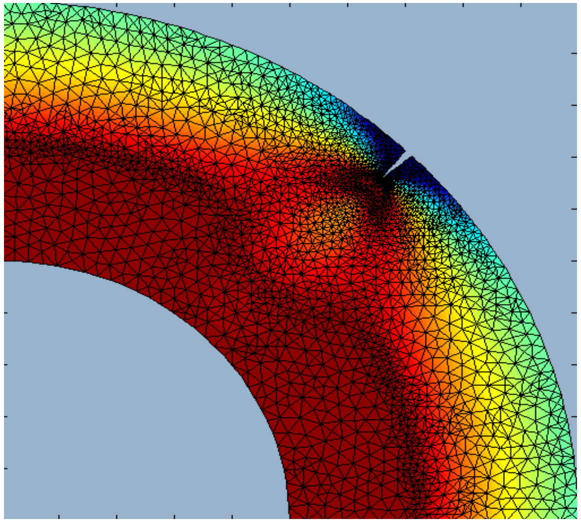
- more or less a bent regular grid

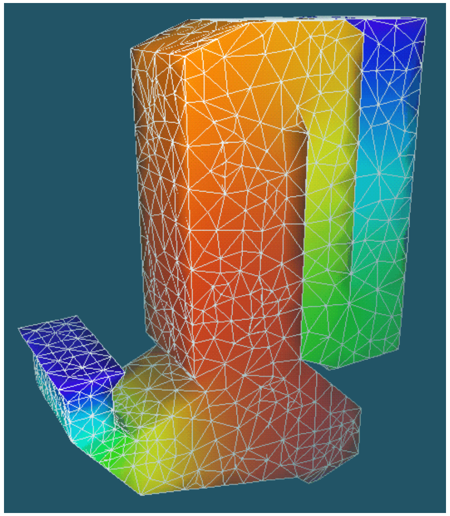


## Unstructured grid

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





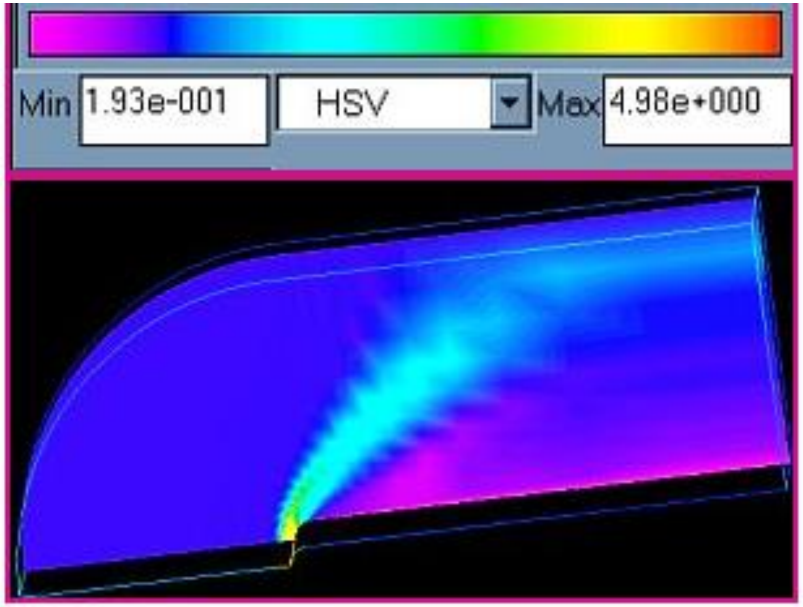


# The Bluntfin Dataset

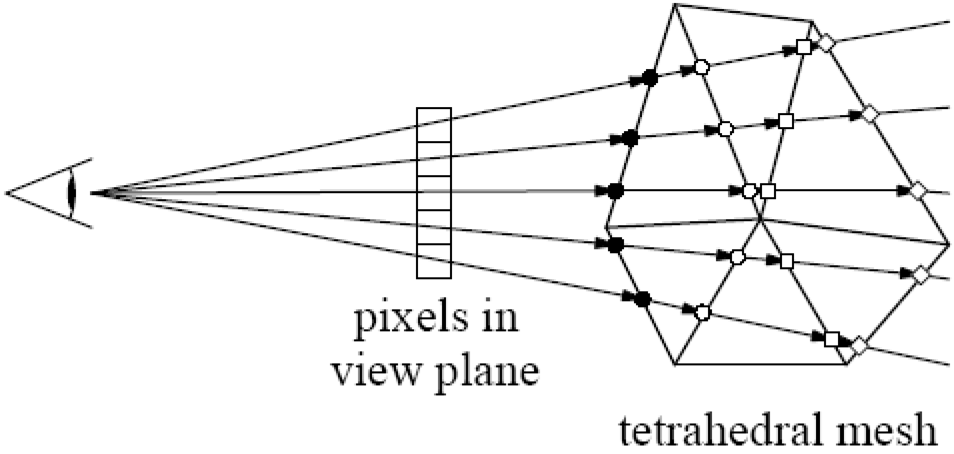
Mapping flow strength to color

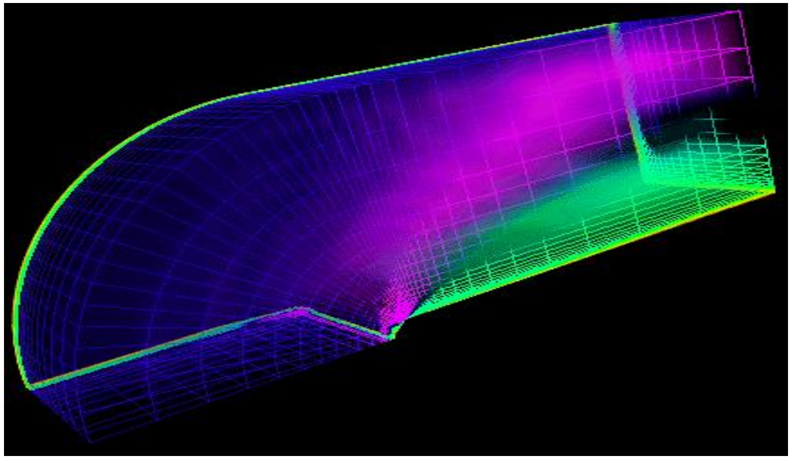
Rendering by cell traversal

- go from cell to cell
- composite colors and opacities



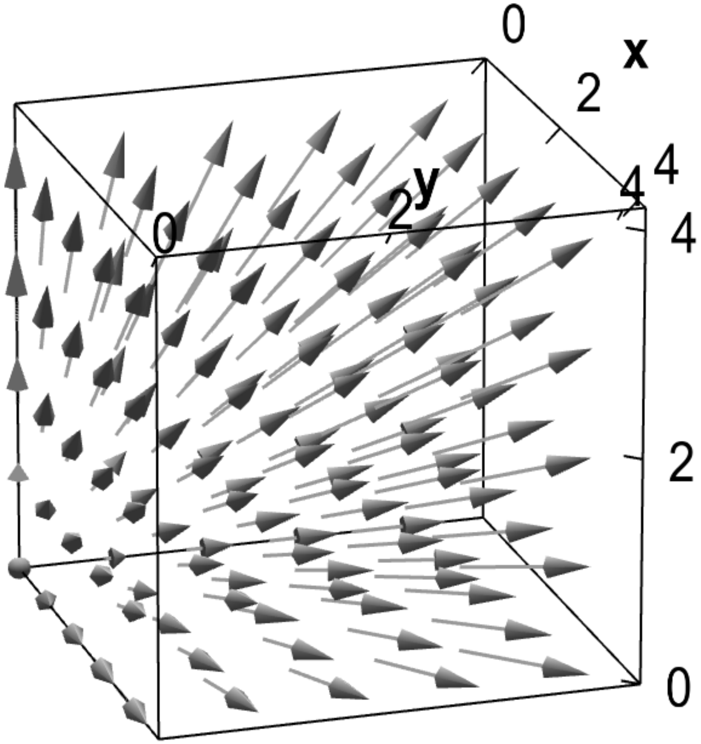
Min 1.93e-001 HSV Max 4.98e+000

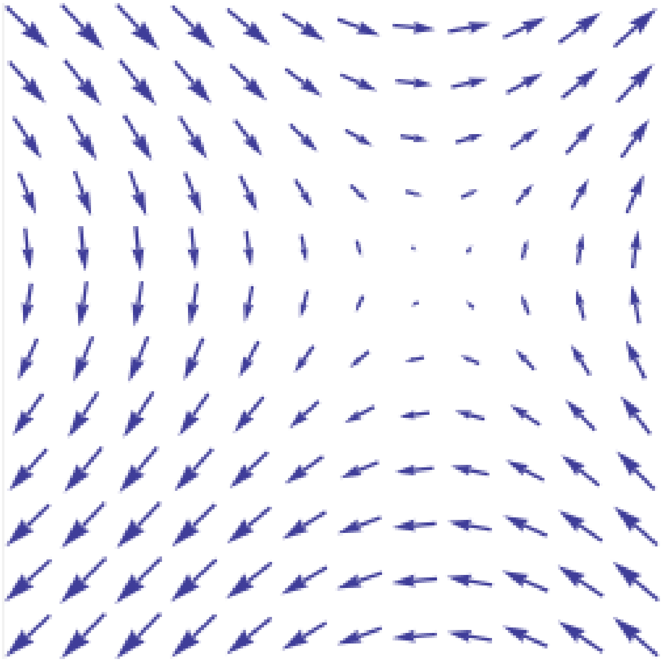




# Flow Visualization

Also called vector field visualization

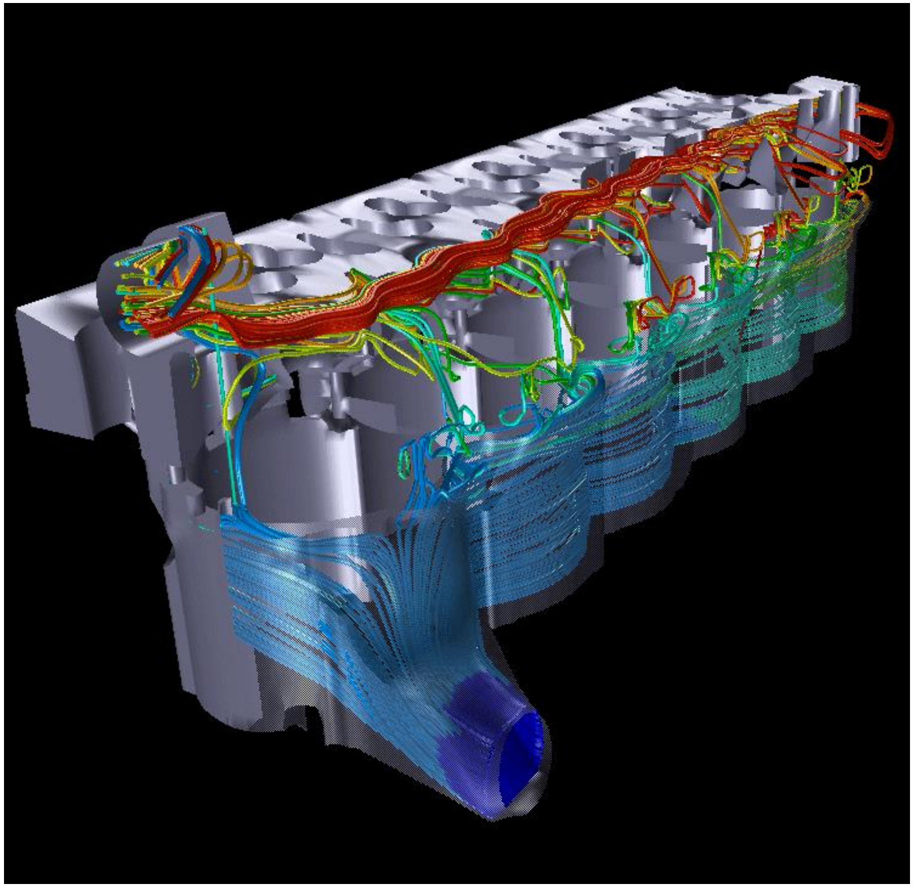




# Stream Lines

Perform an integration through the vector field

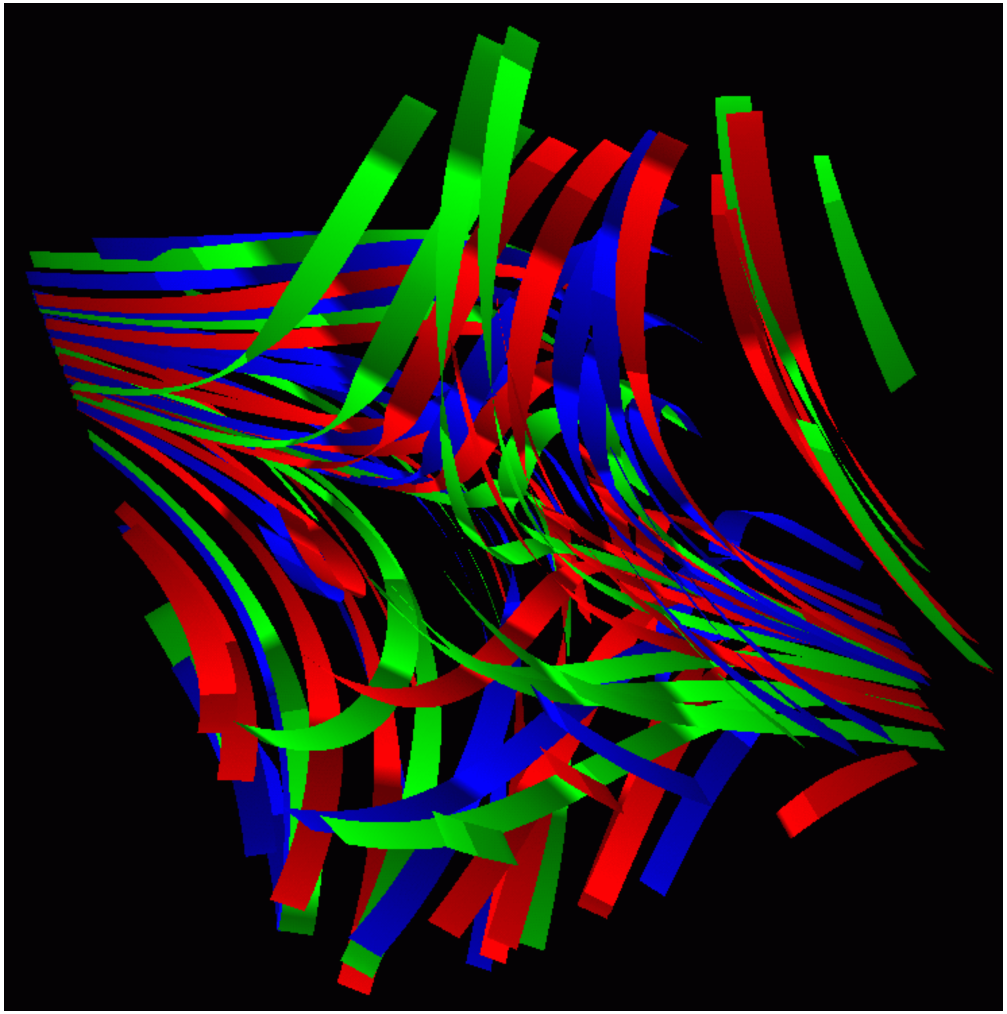
- color maps to temperature



# Stream Ribbons

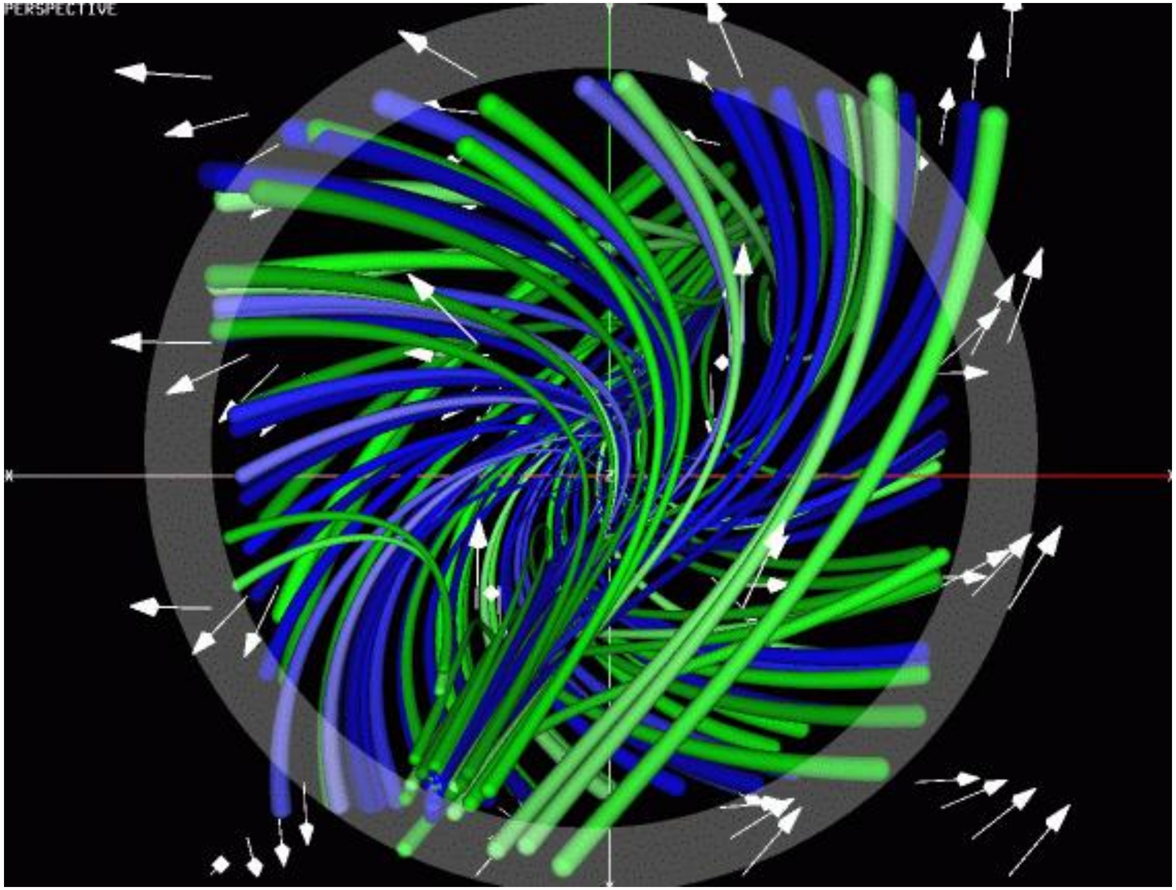
Connect two streamlines

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



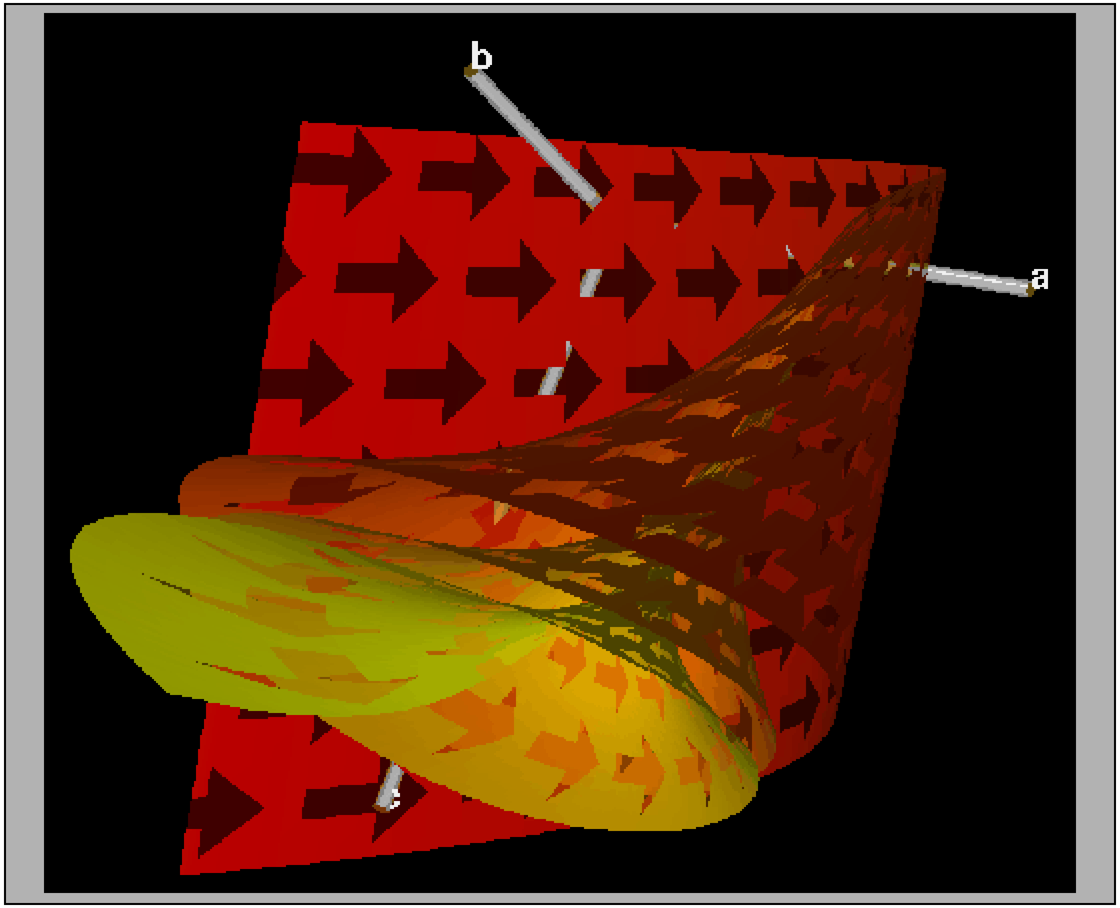
# Stream Tubes

Connect three or more streamlines



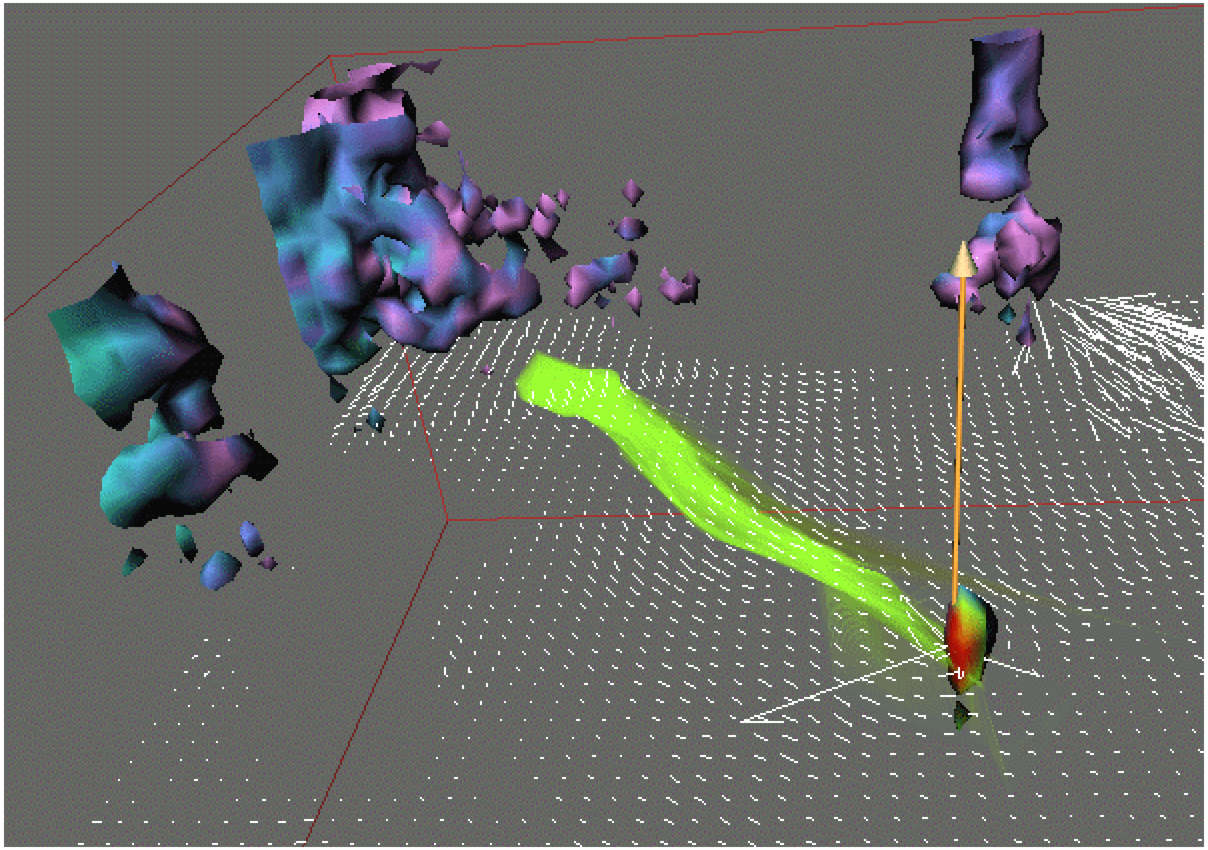
# Stream Surfaces

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

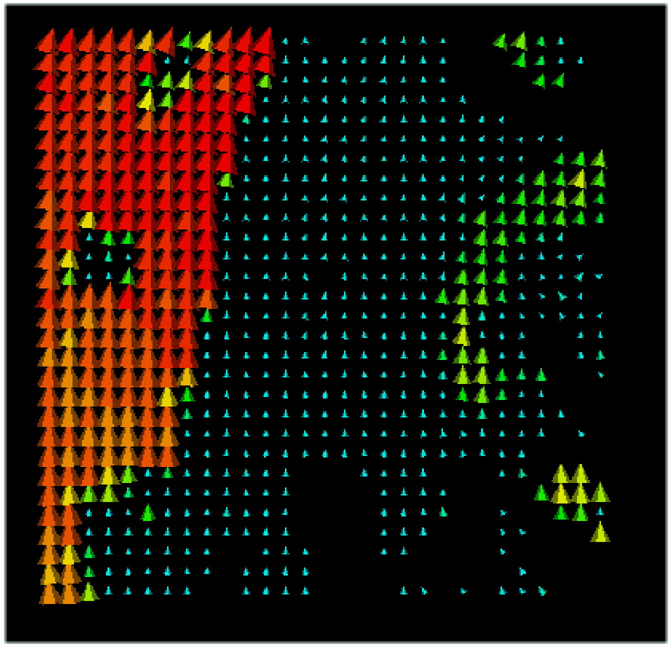
Seek to give a more global view of the vector field

Hedgehogs

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

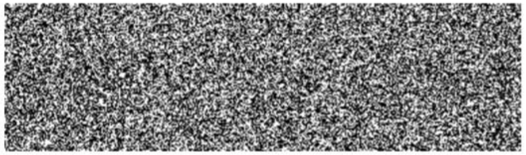
Glyphs, arrows

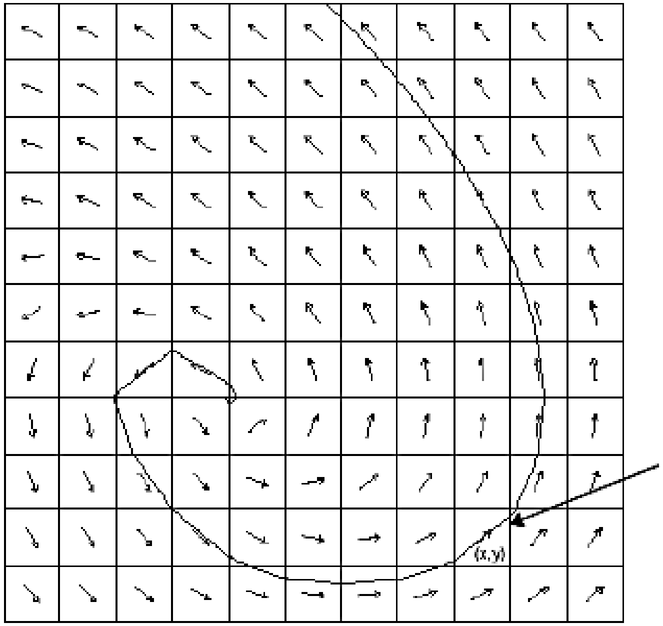
- icons that show directions,
  but tend to clutter the display



# Line Integral Convolution (LIC)

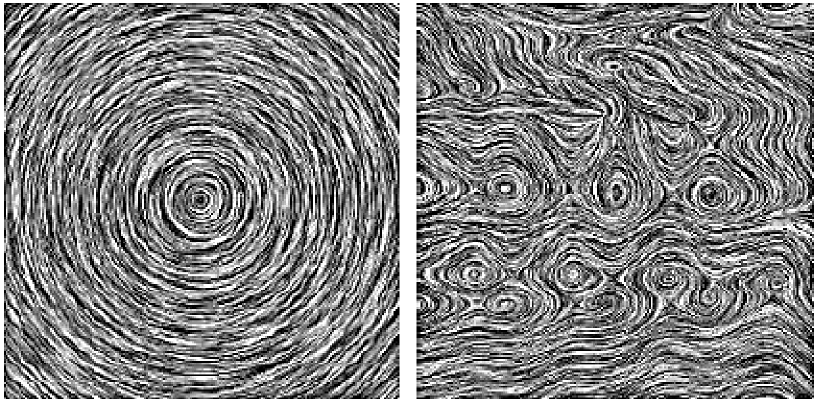
- Input:
  - a 2D vector field
  - an image that will be "smeared" according to the stream lines described by the vector field

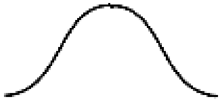

salt+pepper noise



stream line

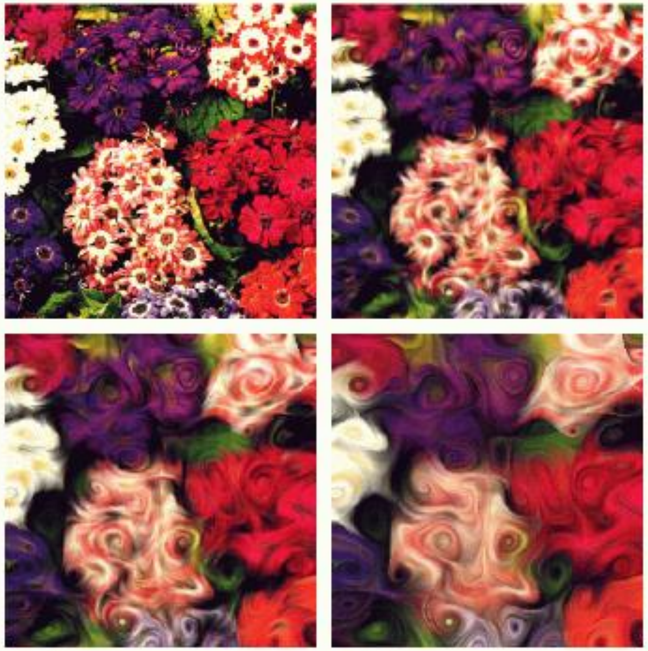
input vector field


output image = line-integrated white noise image


filter aligned with the stream line

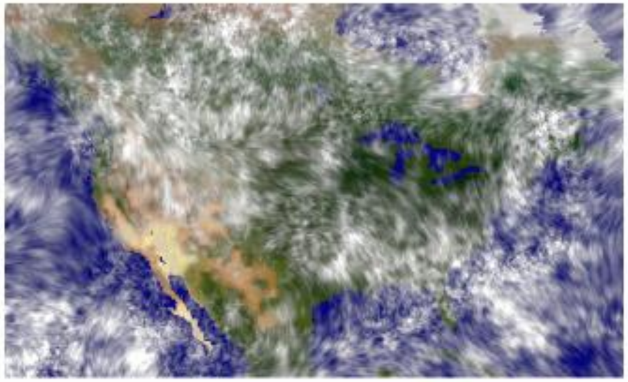
```
For each ouput pixel (x, y)
    Follow the stream line forward for some distance Δs
    Multiply each pixel value by a 1D filter kernel and add
    Follow the stream line backward for some distance Δs
    Multiply each pixel value by a 1D filter kernel and add
    Follow the stream line backward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

# Line Integral Convolution (LIC)

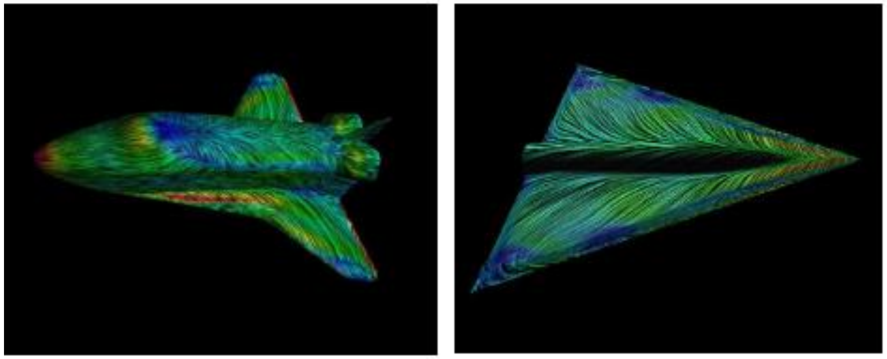


a flower image with different vector fields

a simple motion vector field over the hand



using vector magnitude to determine $\Delta s$

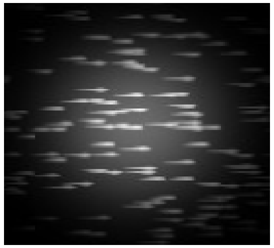


mapping LIC onto an object surface

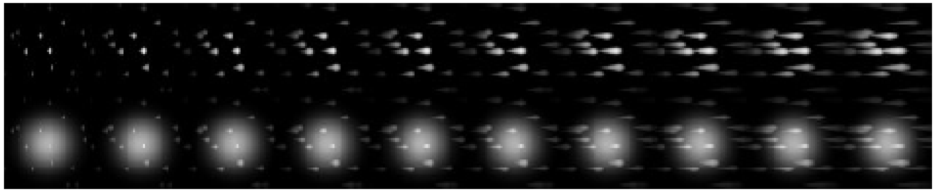
# Textured Splats

- Embed flow field vector icons into a splat

  - this enables smooth blending of neighboring icons



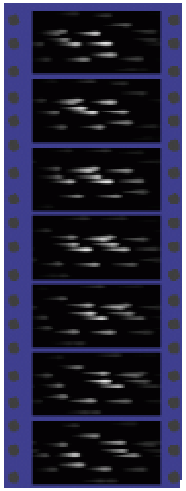
- Create a table of texture splats with varying icon distribution (to prevent regular patters)
- For a given location, select a random splat and rotate corresponding to the flow field direction
- Since the flow field is 3D, the component of the vectors that is parallel to the screen varies
- Need to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



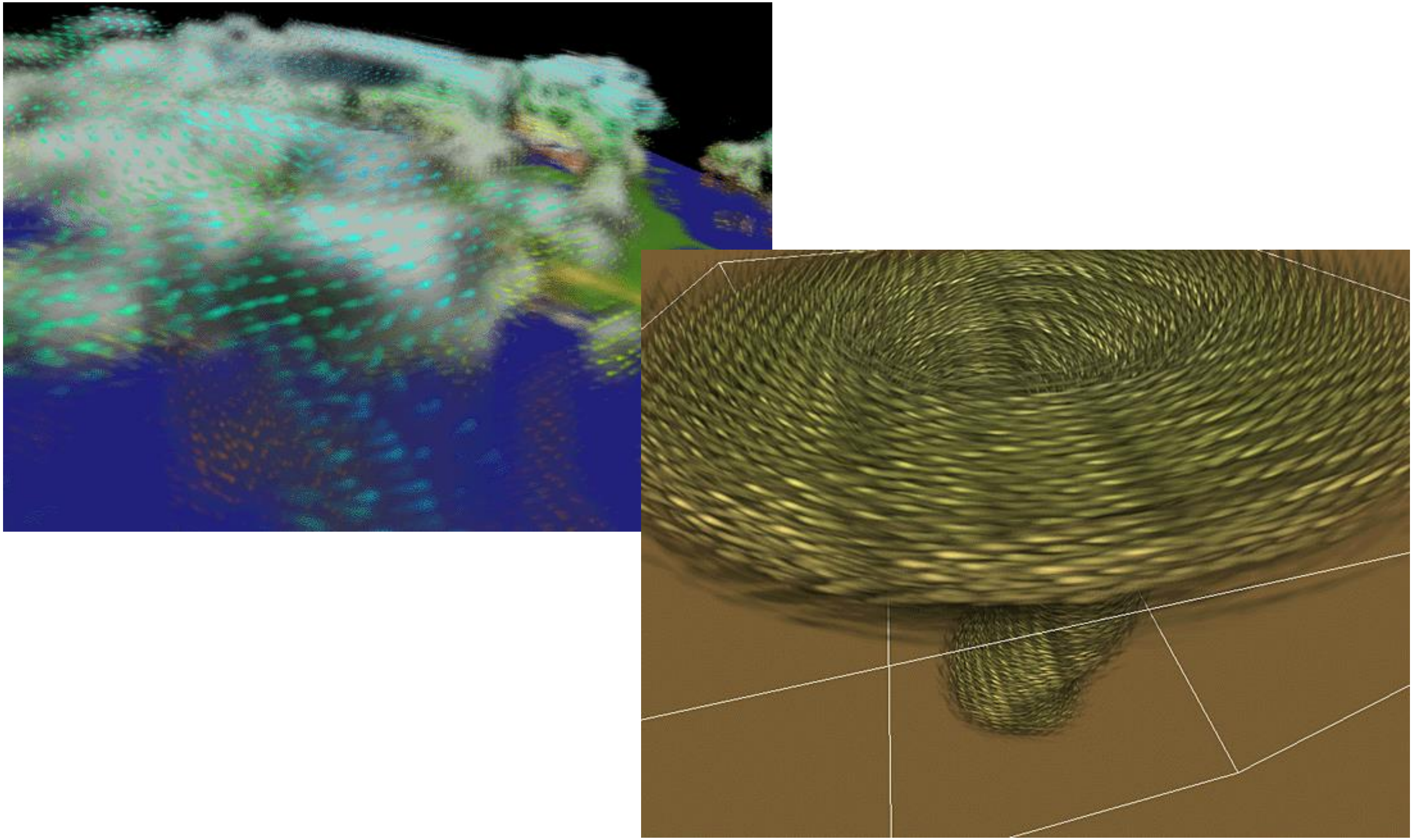
- Animated display

  - 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



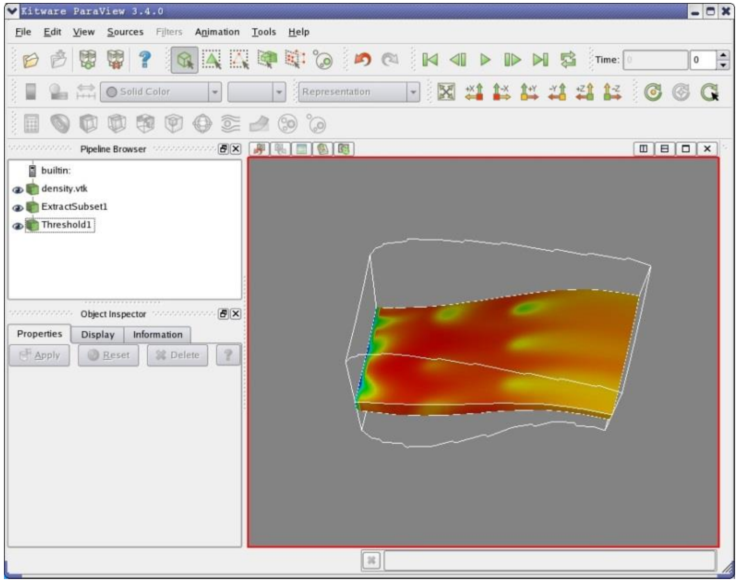
# Popular Software & Libraries

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