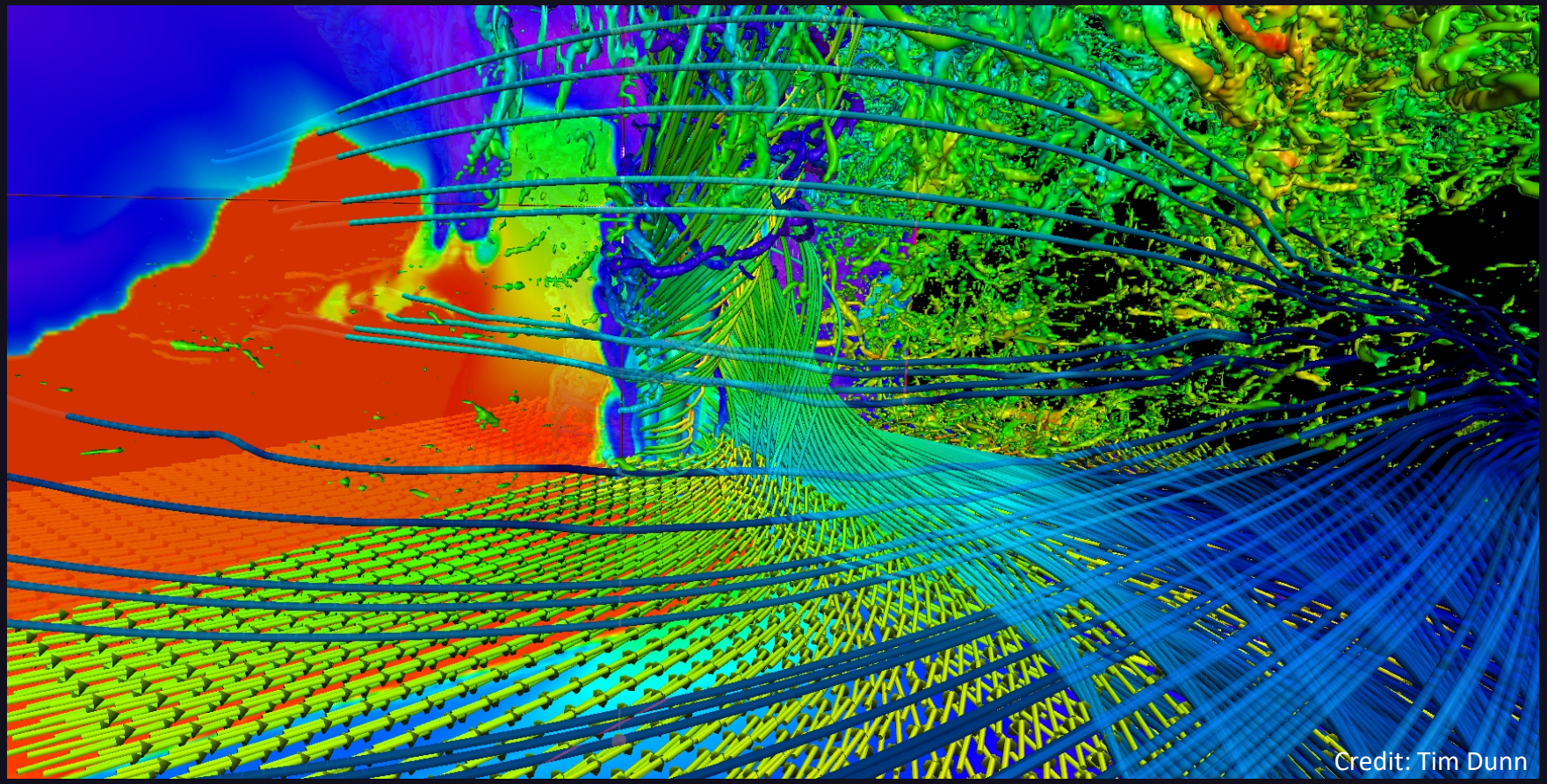
An Introduction to Scientific Visualization



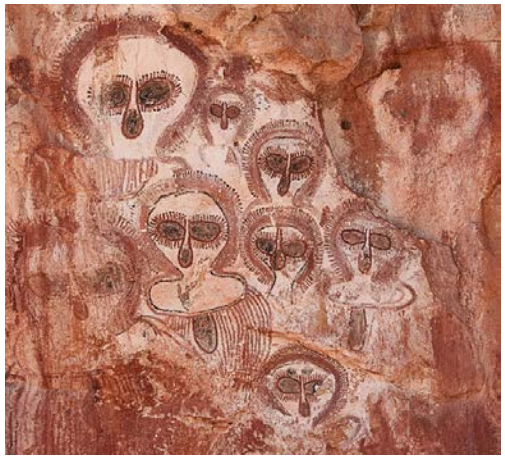
Visualize

vi·su·al·ize

- 1. To form a mental image of
- 2. To make visible

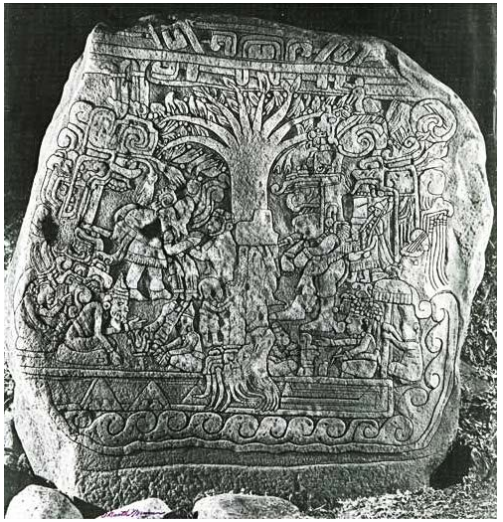
[Websters Dictionary]

History of Visualization



Credit: Graeme Churchard

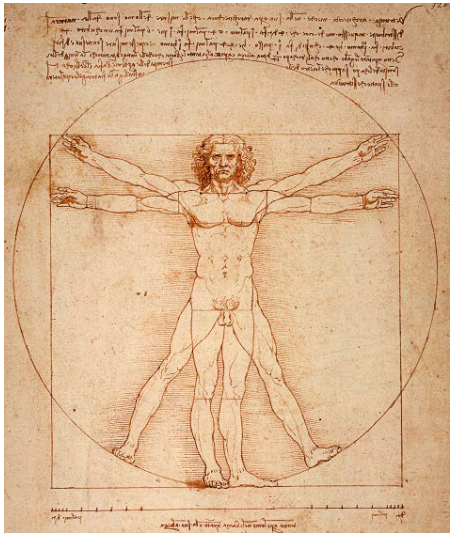
Credit: N. Aujoulat @MCC-CNP



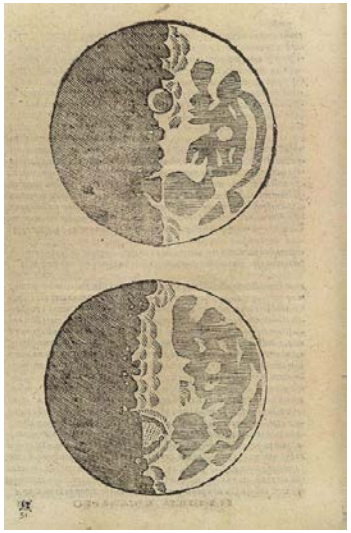
Credit: V. Garth Norman

Credit: Karen Dunn

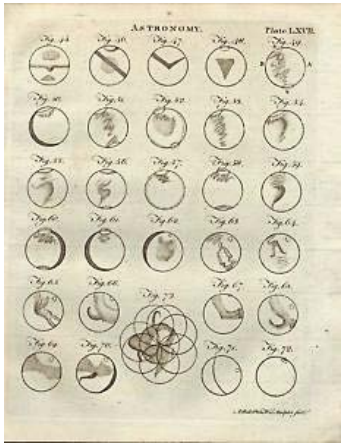
History of Visualization



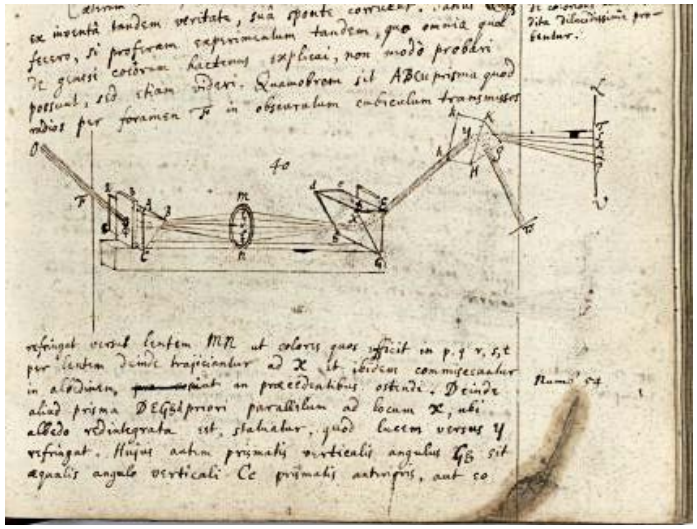
Leonardo da Vinci



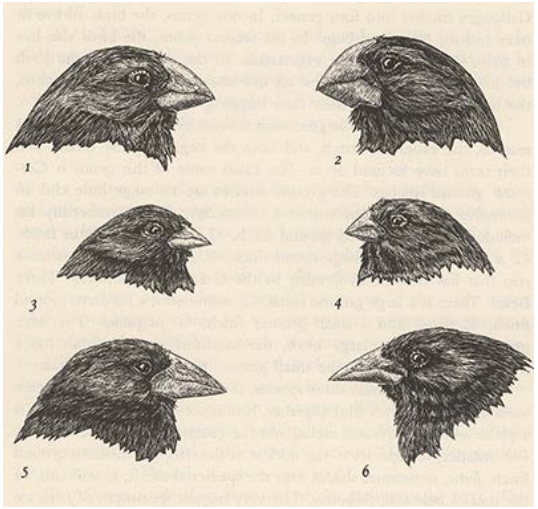
Galileo Galilei



William Herschel



Isaac Newton



Charles Darwin

History of Visualization

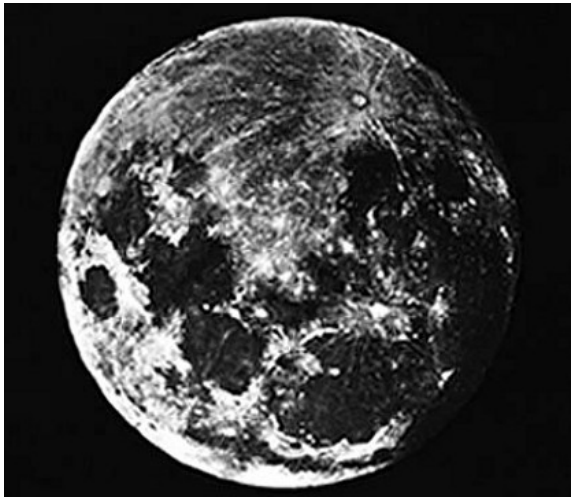


Photo: John W. Draper (1839)

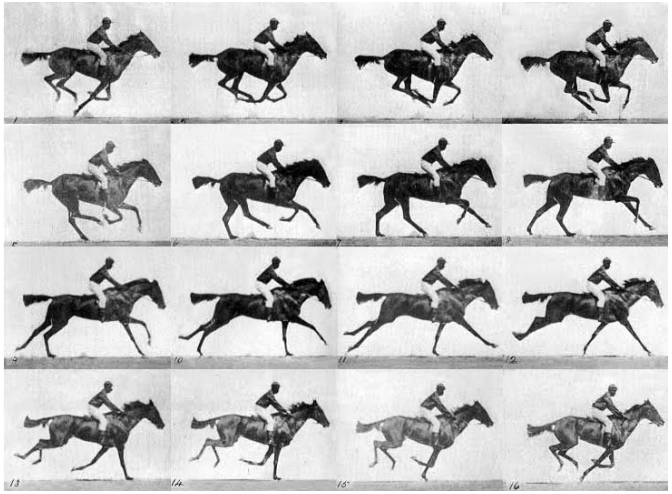
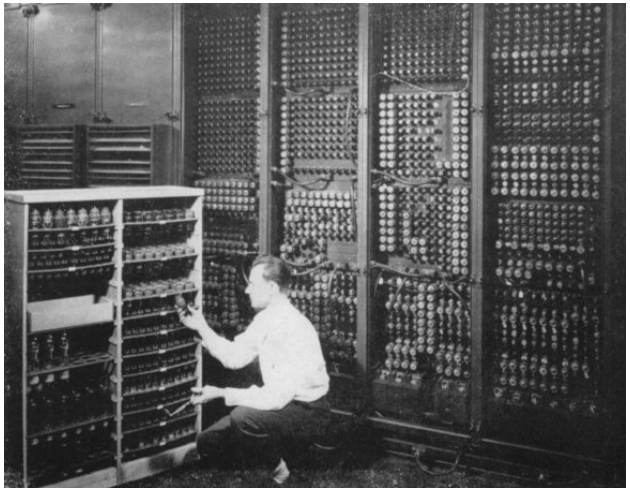
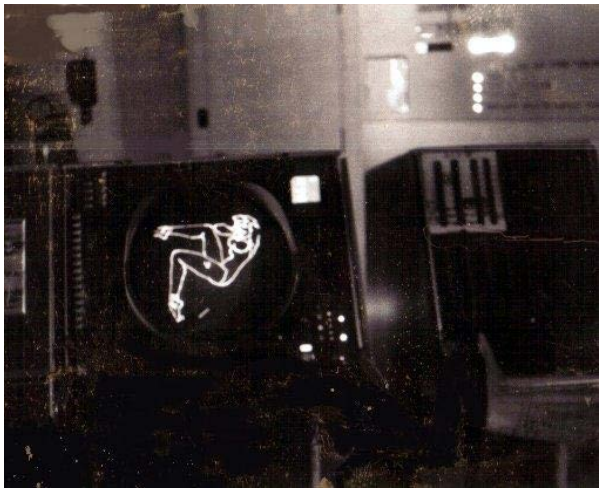


Photo: Eadweard Muybridge (1878)

Photo: Wilhelm Ronton (1895)



Credit: Lawrence A. Crowl



Credit: Lawrence A. Tipton

History of Visualization

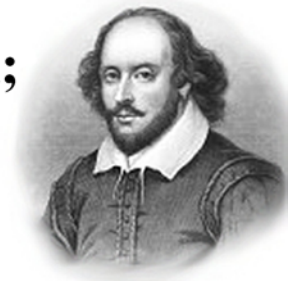
Credit: British Museum

Credit: Oland Karlevistenen

Credit: Dead Sea Scrolls Foundation

"Ignorance is the curse of God;
Knowledge is the wing
wherewith we fly to heaven."

William Shaksepeare



Credit: Tim Dunn

$$\frac{1}{Pr}\left(\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u}\cdot\nabla)\boldsymbol{u}\right) = -\nabla\sigma + \nabla^2\boldsymbol{u} + T_z$$

$$\frac{\partial T}{\partial t} + (\boldsymbol{u}\cdot\nabla)T = \nabla^2 T + Ra\boldsymbol{u}_z$$

$$\nabla\cdot\boldsymbol{u} = 0$$

What is Modern Scientific Visualization?

Scientific Visualization: **"The use of computers or techniques for comprehending data or to extract knowledge from the results of simulations, computations, or measurements"**

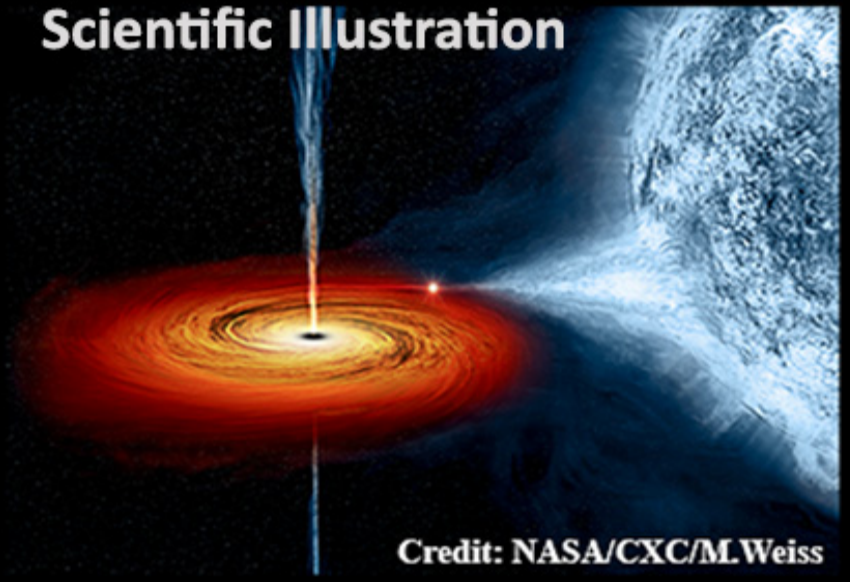
[McCormick *et al.*, 1987]

Our Definition of Scientific Visualization

A 2D or 3D visualization which, as accurately as possible, describes scientific data which has an inherent continuous spatial embedding and may or may not have a temporal component.

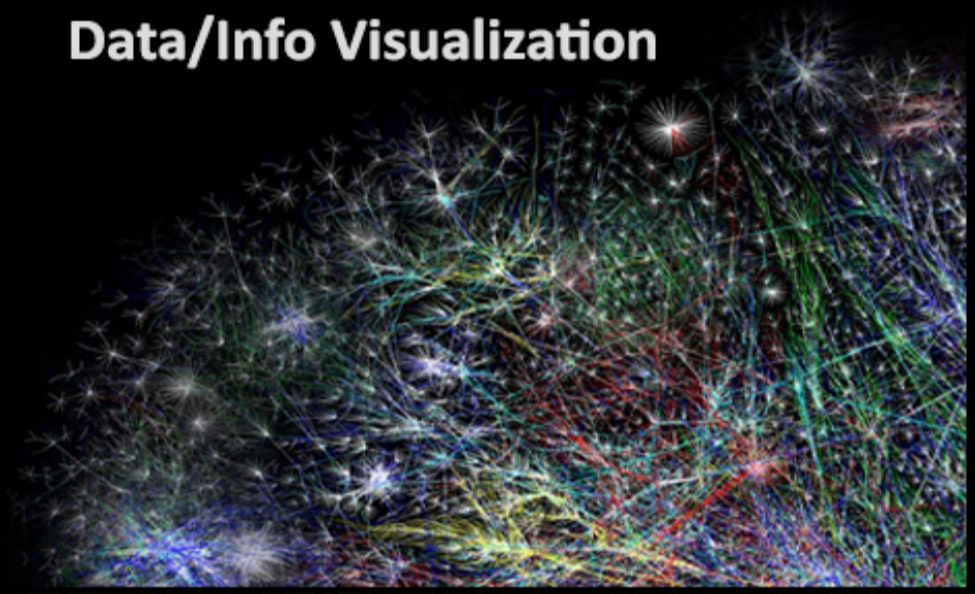
Subsets of Scientific Visualization

Scientific Illustration



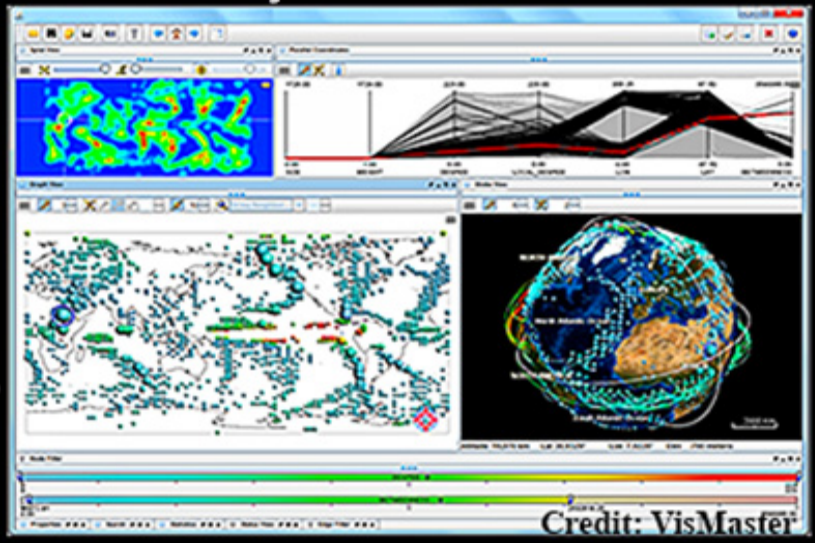
Credit: NASA/CXC/M.Weiss

Data/Info Visualization



Credit: Tim Dunn

Data Analytics



Credit: VisMaster

Scientific Visualization Data

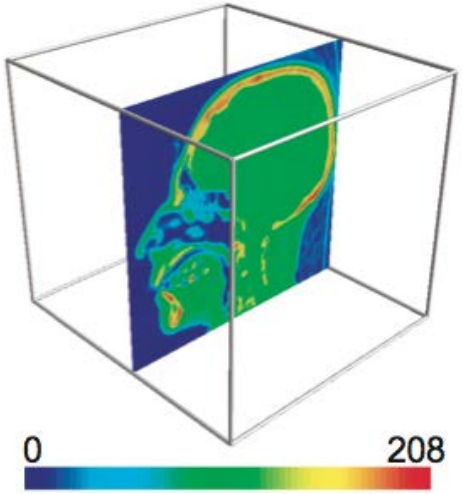
Data may be real or complex and is continuous in both range and domain and maps out a spatial domain;

$$f: R^{2+n} \rightarrow R \qquad \ni n >= 0$$

Scientific Visualization Data Examples

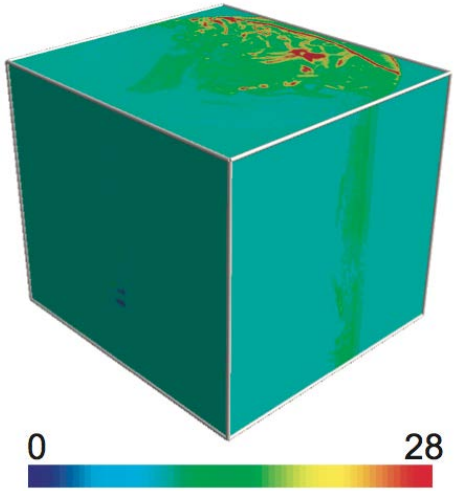
$f : \mathbf{R}^2 \rightarrow \mathbf{R}$

a planar slice



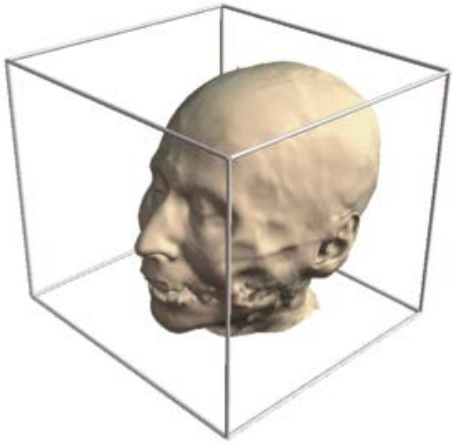
$f : \mathbf{R}^3 \rightarrow \mathbf{R}$

a volume



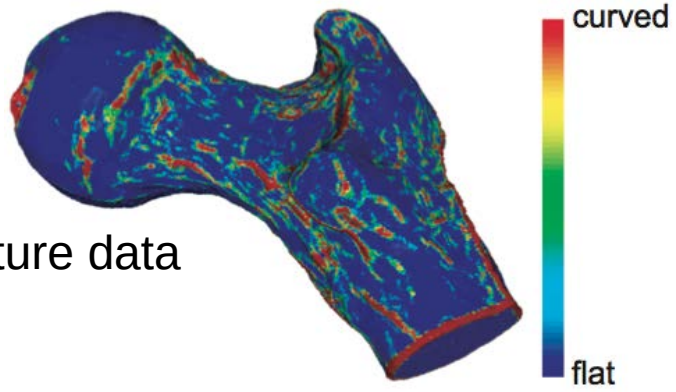
$f : \mathbf{R}^2 \rightarrow \mathbf{R}^0$

a surface



$f : \mathbf{R}^2 \rightarrow \mathbf{R}$

a surface
with curvature data



Credit: ***Data Visualization: Principles and Practice***, Second Edition, CRC Press, by Alexandru C. Telea (2014)

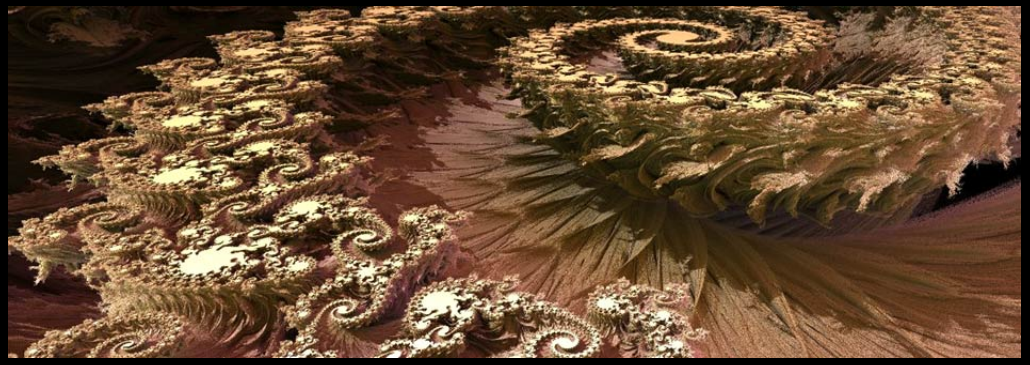
Scientific Visualization Data

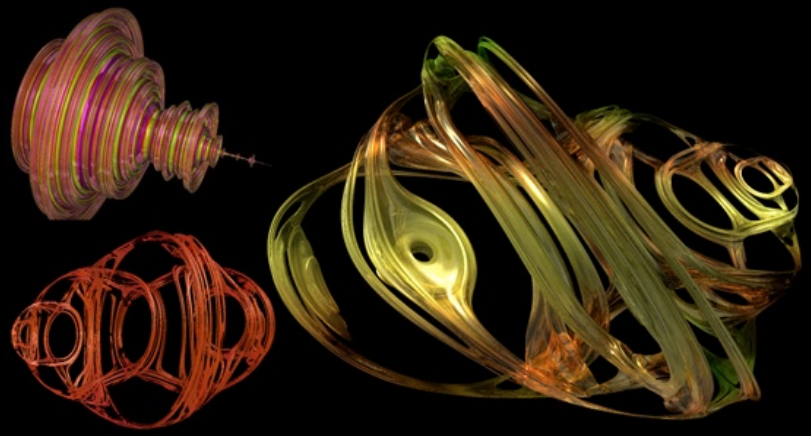
Data may be real or complex and is continuous in both range and domain and maps out a spatial domain;

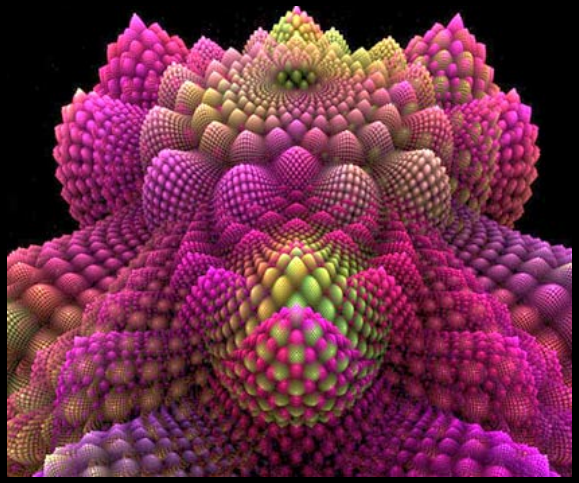
$$f: R^{2+n} \rightarrow R \qquad \ni n >= 0$$

Does *n* have to be an integer?

n with non-integer values!



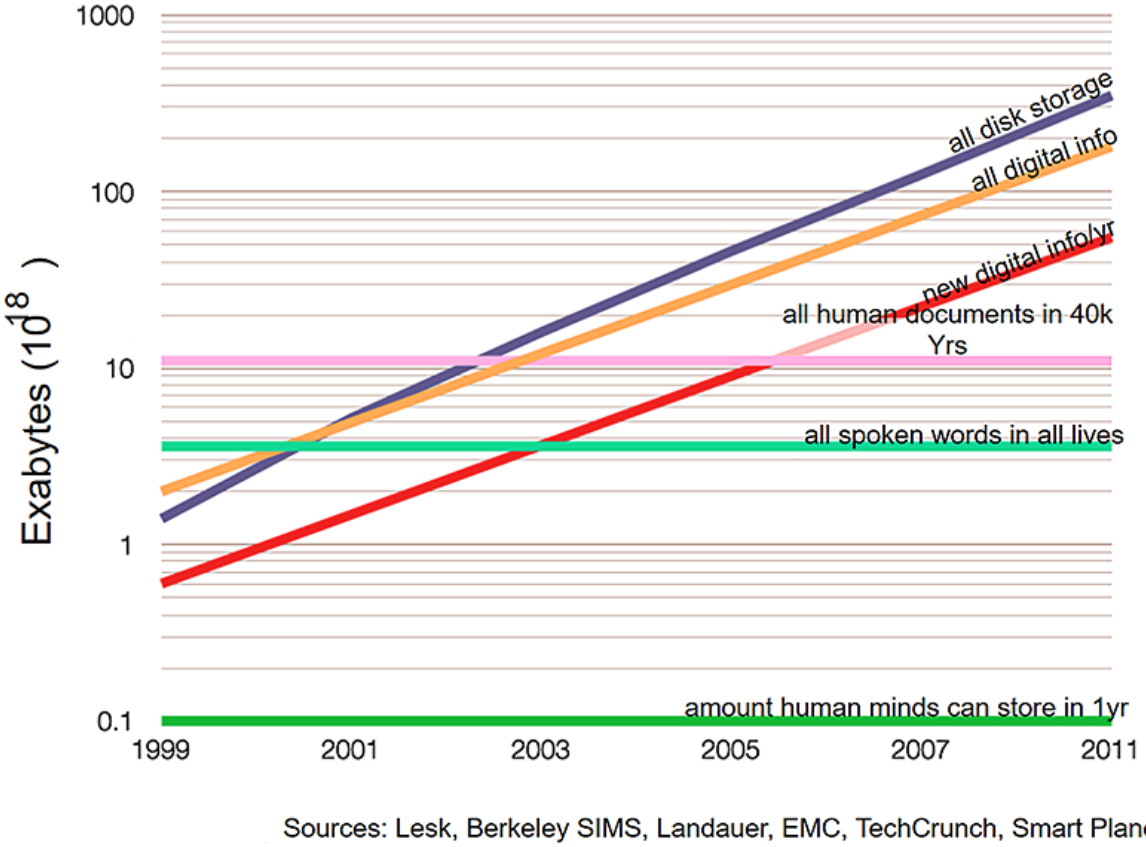




Credit: http://www.miqel.com/fractals_math_patterns/3d_fractals_mandelbulb.html

Scientific Visualization Is All About The Scientific Data!

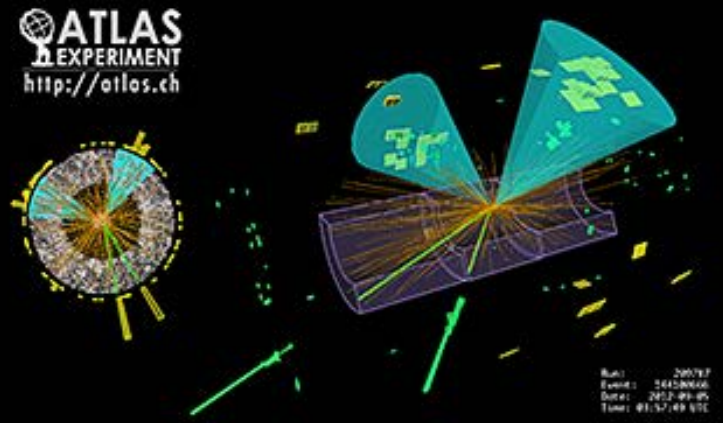
The Data Explosion



Sources: Lesk, Berkeley SIMS, Landauer, EMC, TechCrunch, Smart Planet

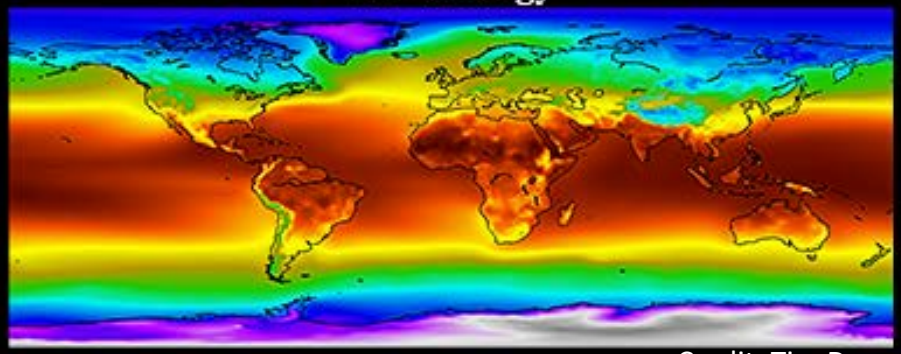
"There was 5 exabytes of information created between the dawn of civilization through 2003, but that much information is now created every 2 days, and the pace is increasing... "

Eric Schmidt –Techonomy 2010



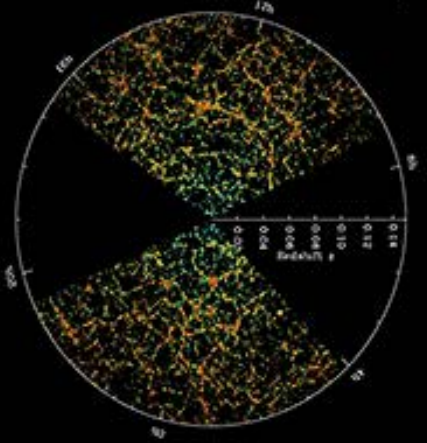
The Connectome Project

Climatology



Credit: Tim Dunn

The Sloan Digital Survey



How Do We Generate Data Used In Visualization?

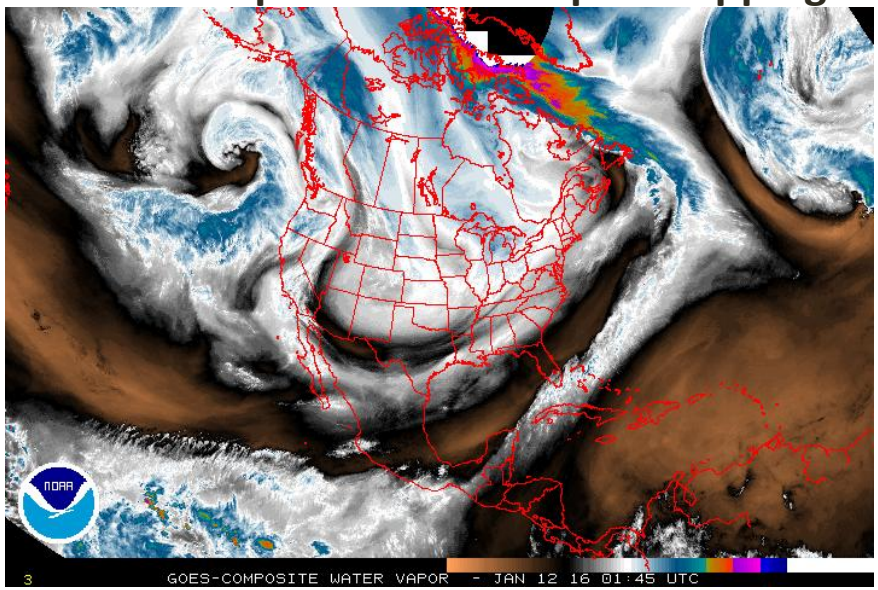
How Do We Generate Data used in Visualization?

3 Main Methods

- **Observations**
- **Simulations**
- **Hybrid combination of the first two.**

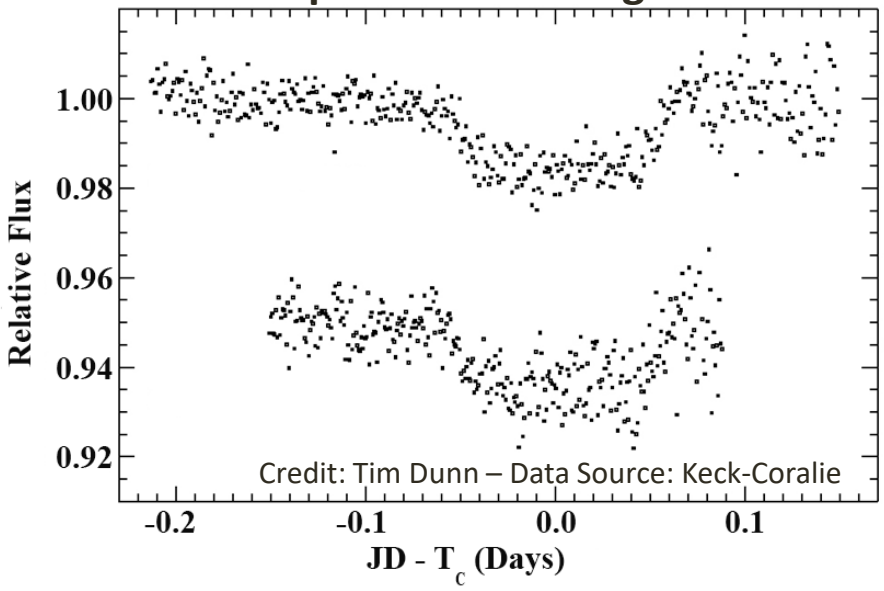
Observation

GOES Composite Water Vapor Mapping

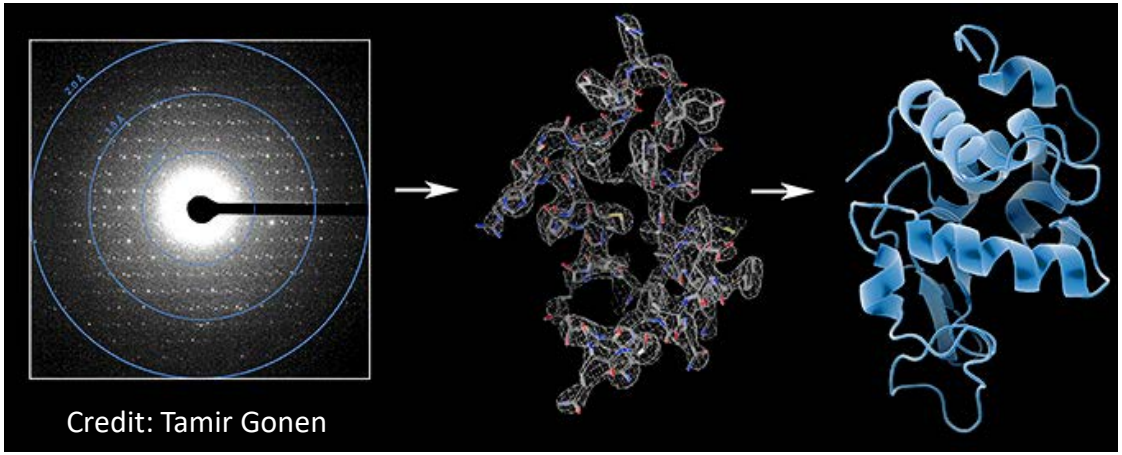


Credit: NOAA Geostationary Satellite Server

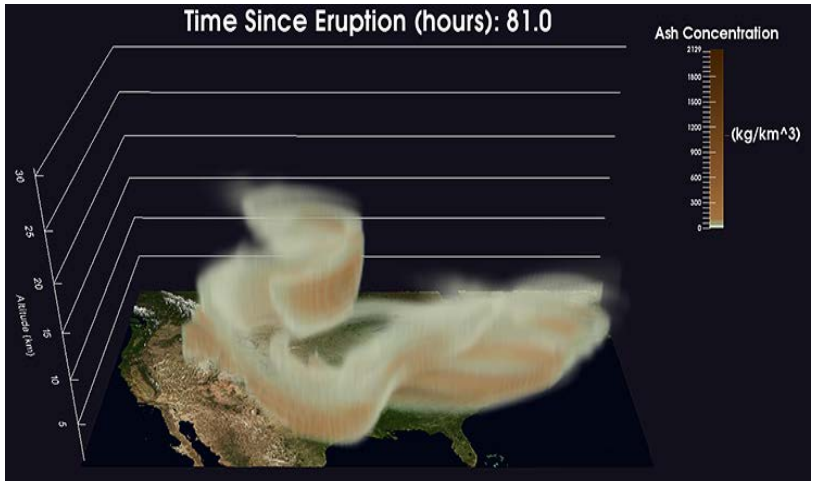
Exoplanet Transit Light Curve

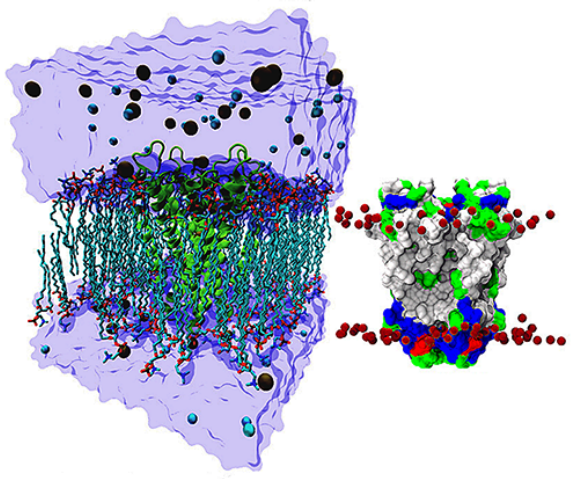


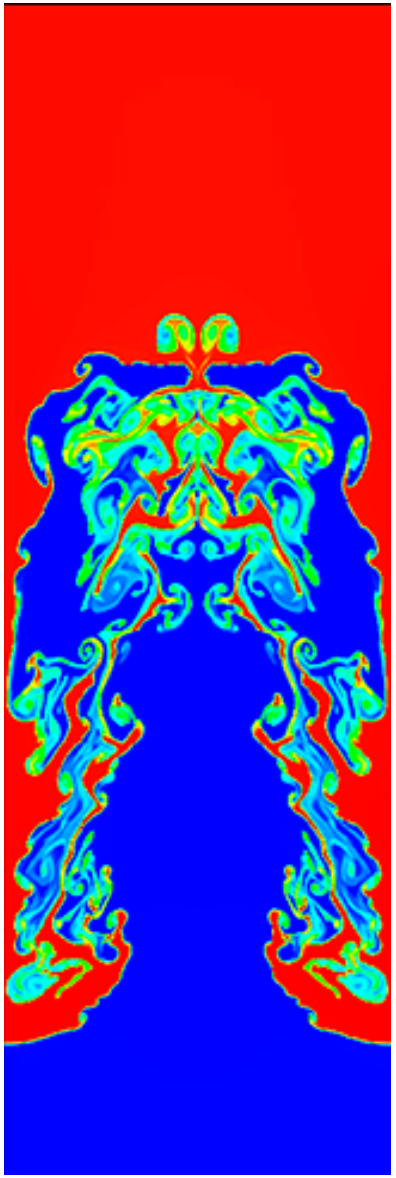
Lysozyme structure from X-Ray Crystallography

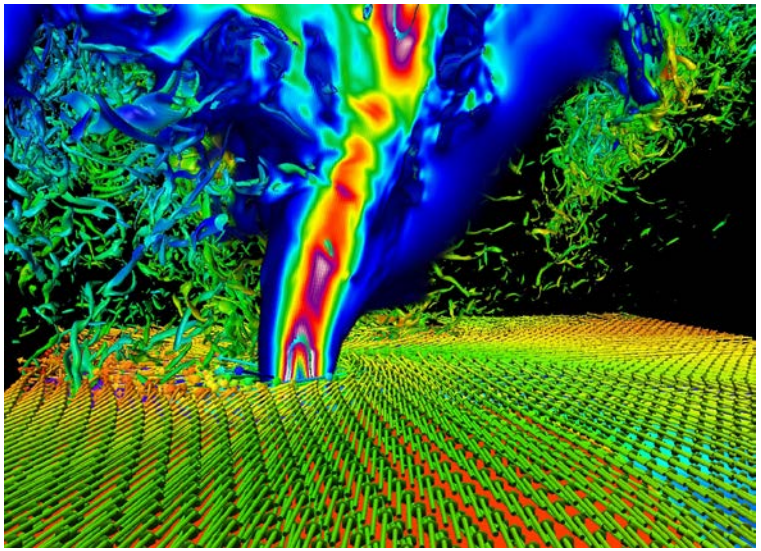


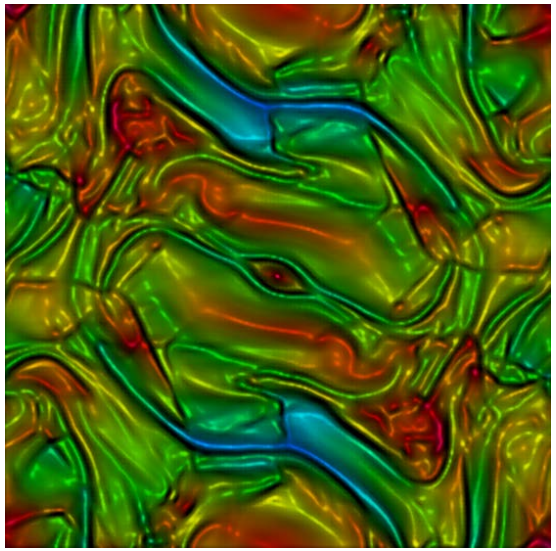
Simulation











Credit All Images: Tim Dunn

What Can Scientific Visualization Be Used For?

What Can Visualization Be Used For?

- Mathematical and Spatial Insight
- Scientific Insight
- Data Exploration
- Validation

Scientific Visualization For Mathematical And Spatial Insight

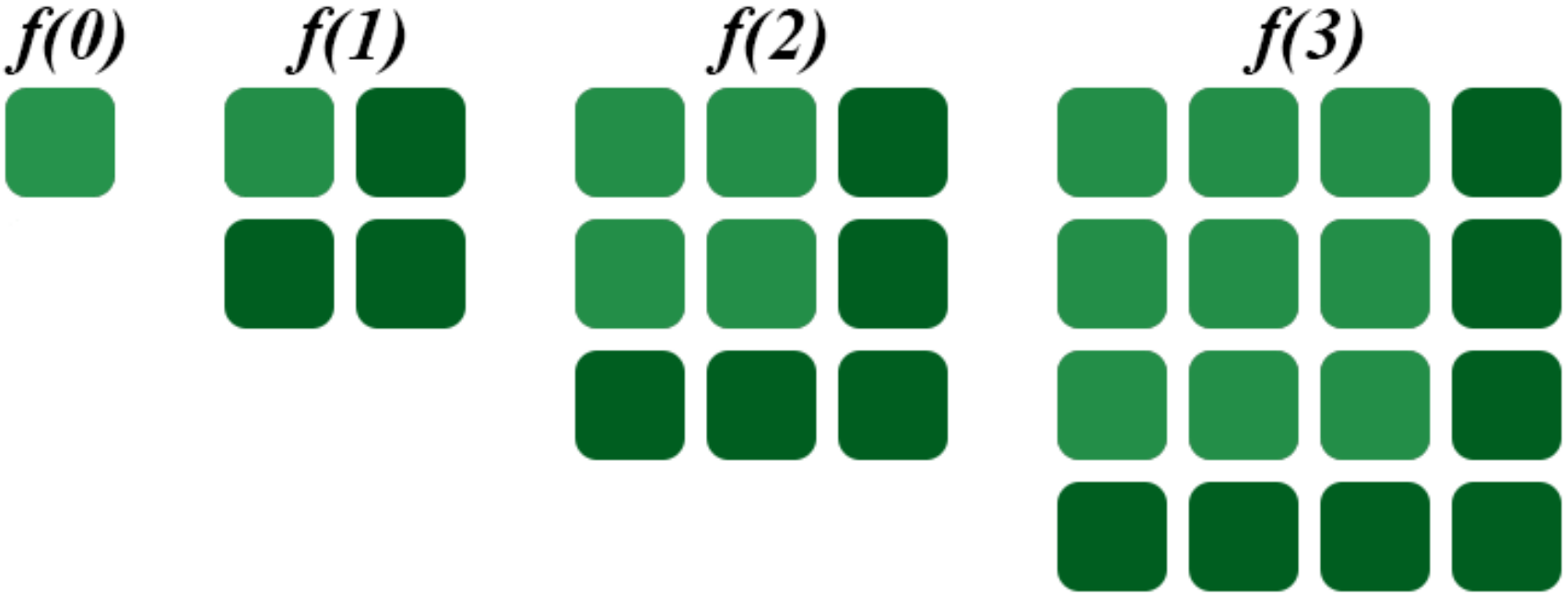
Mathematical and Spatial Insight

$$f(x) = \sum_{x=0}^{n} (2x + 1)$$

Math is a *language* that produces data and *ALL* data can be visualized!!!

Mathematical and Spatial Insight

$$f(x) = \sum_{x=0}^{n} (2x + 1) = (x + 1)^2$$



Scientific Visualization for Scientific Insight

Visualization for Scientific Insight

$$\frac{1}{Pr}\left(\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u}\cdot\nabla)\boldsymbol{u}\right) = -\nabla\sigma + \nabla^2\boldsymbol{u} + T_z$$

$$\frac{\partial T}{\partial t} + (\boldsymbol{u}\cdot\nabla)T = \nabla^2 T + Ra\,\boldsymbol{u}_z$$

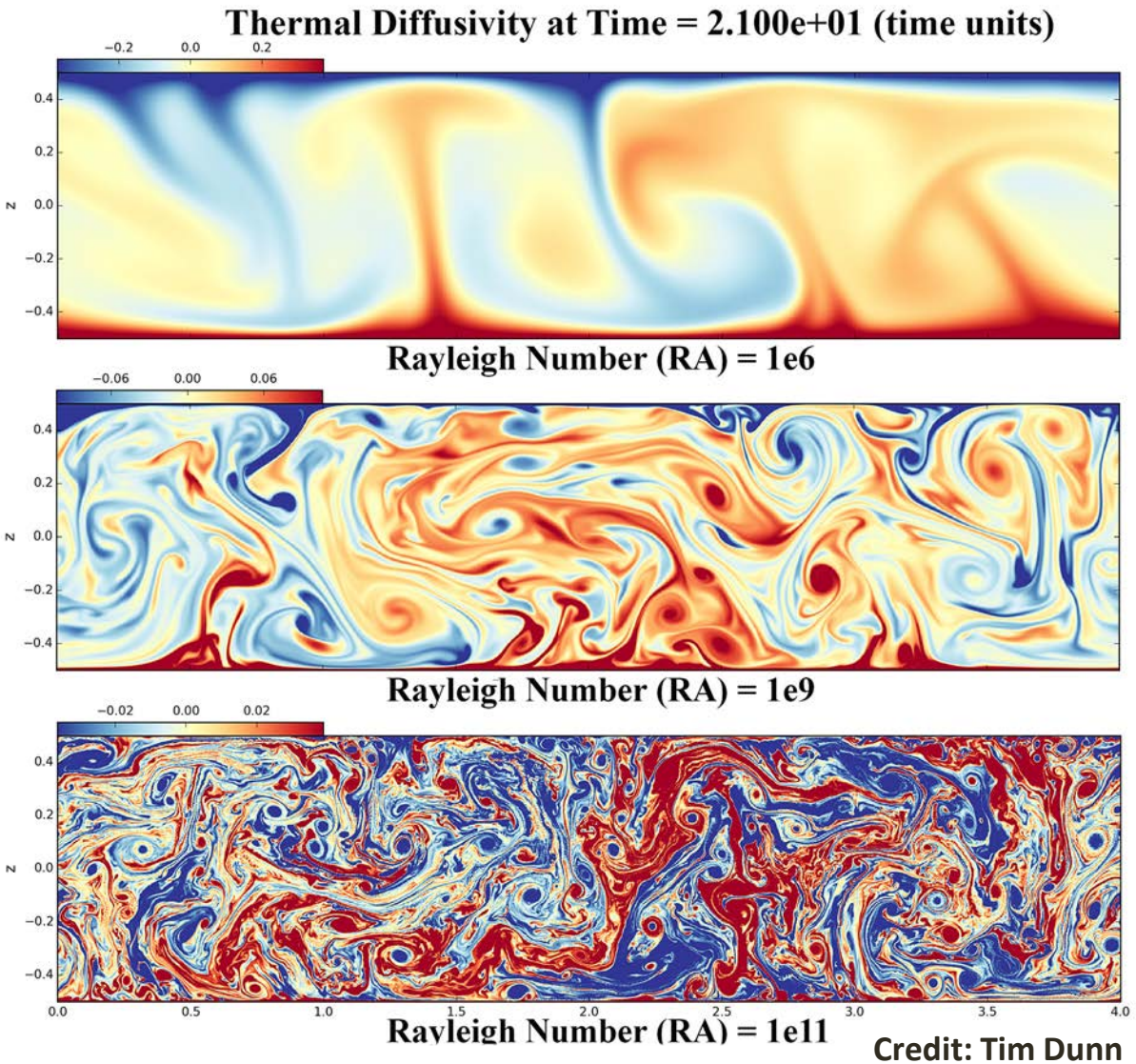
$$\nabla\cdot\boldsymbol{u} = 0$$

Ra = the Rayleigh number which is expresses the balance between the buoyancy and viscosity of a fluid.

Question: What happens to a convective fluid when ***Ra*** changes?

Visualization for Scientific Insight

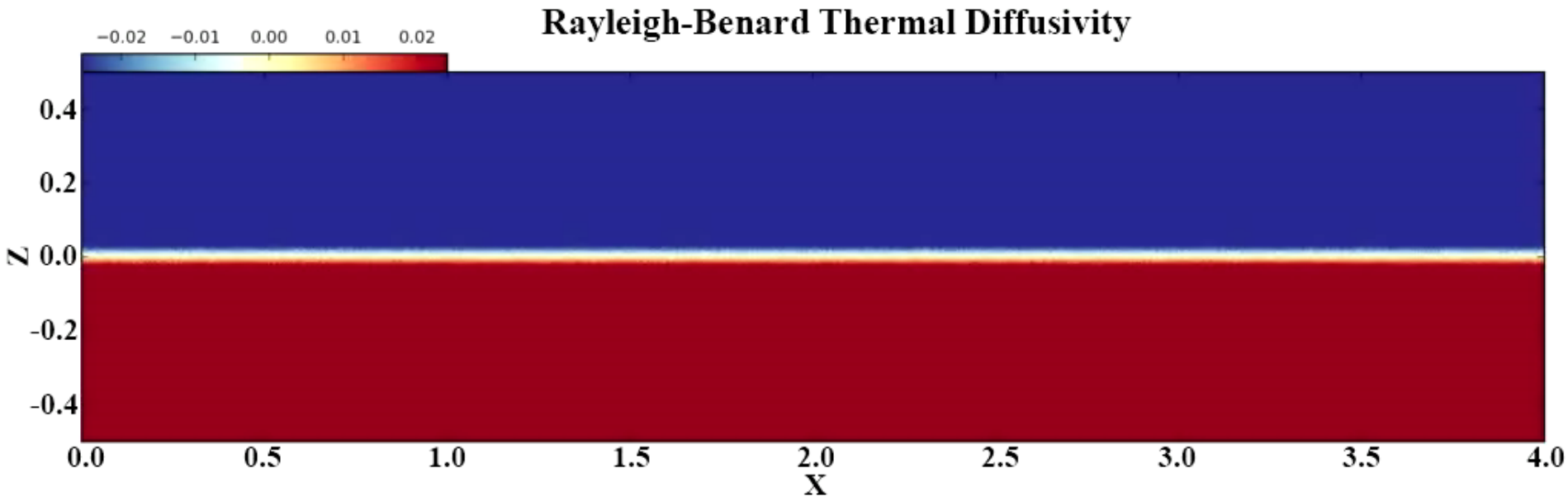
Rayleigh-Benard Convection with Different Rayleigh Numbers



Credit: Tim Dunn

Visualization for Scientific Insight

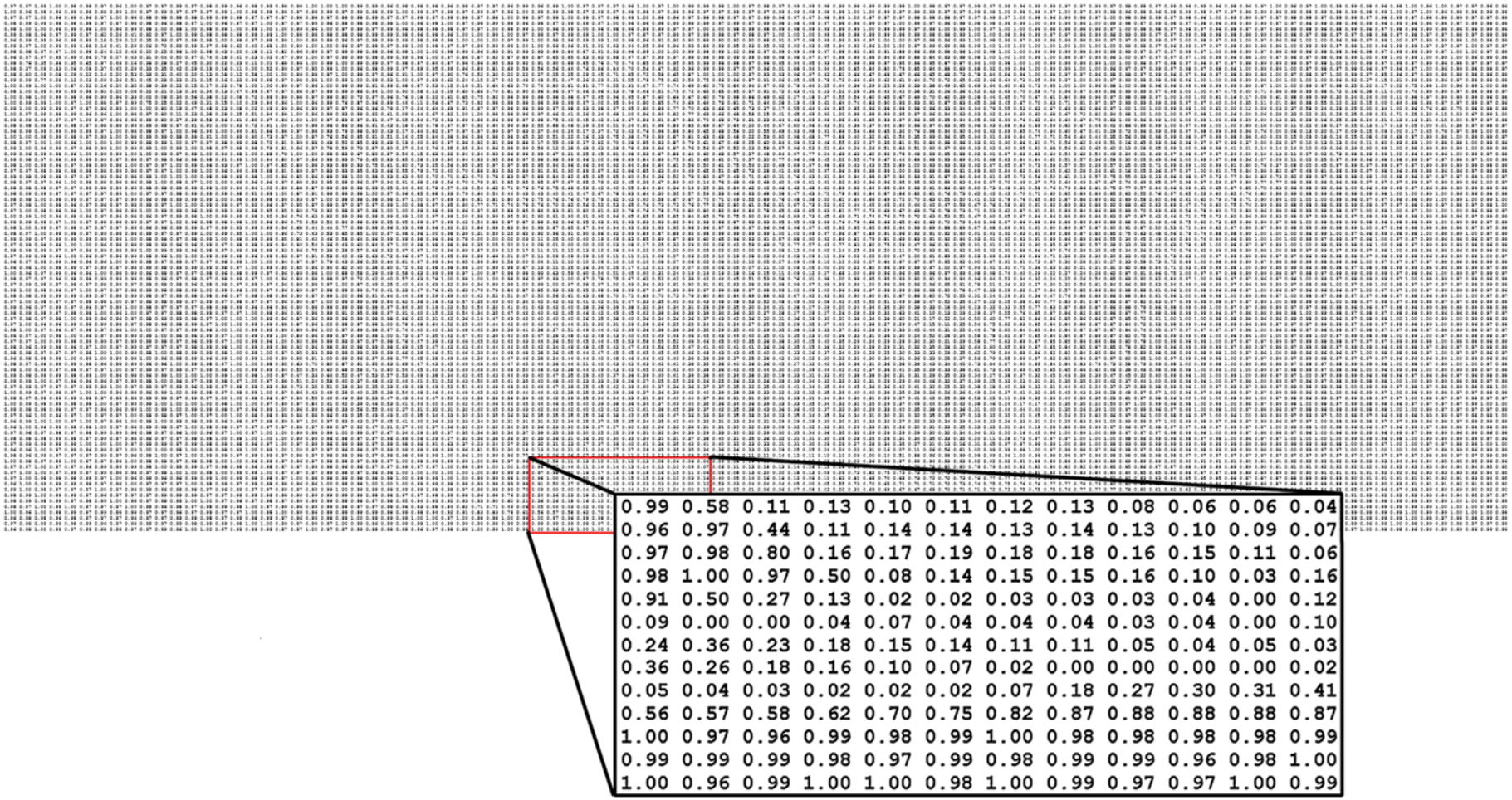
Rayleigh-Benard Convection Over Time



Credit: Tim Dunn

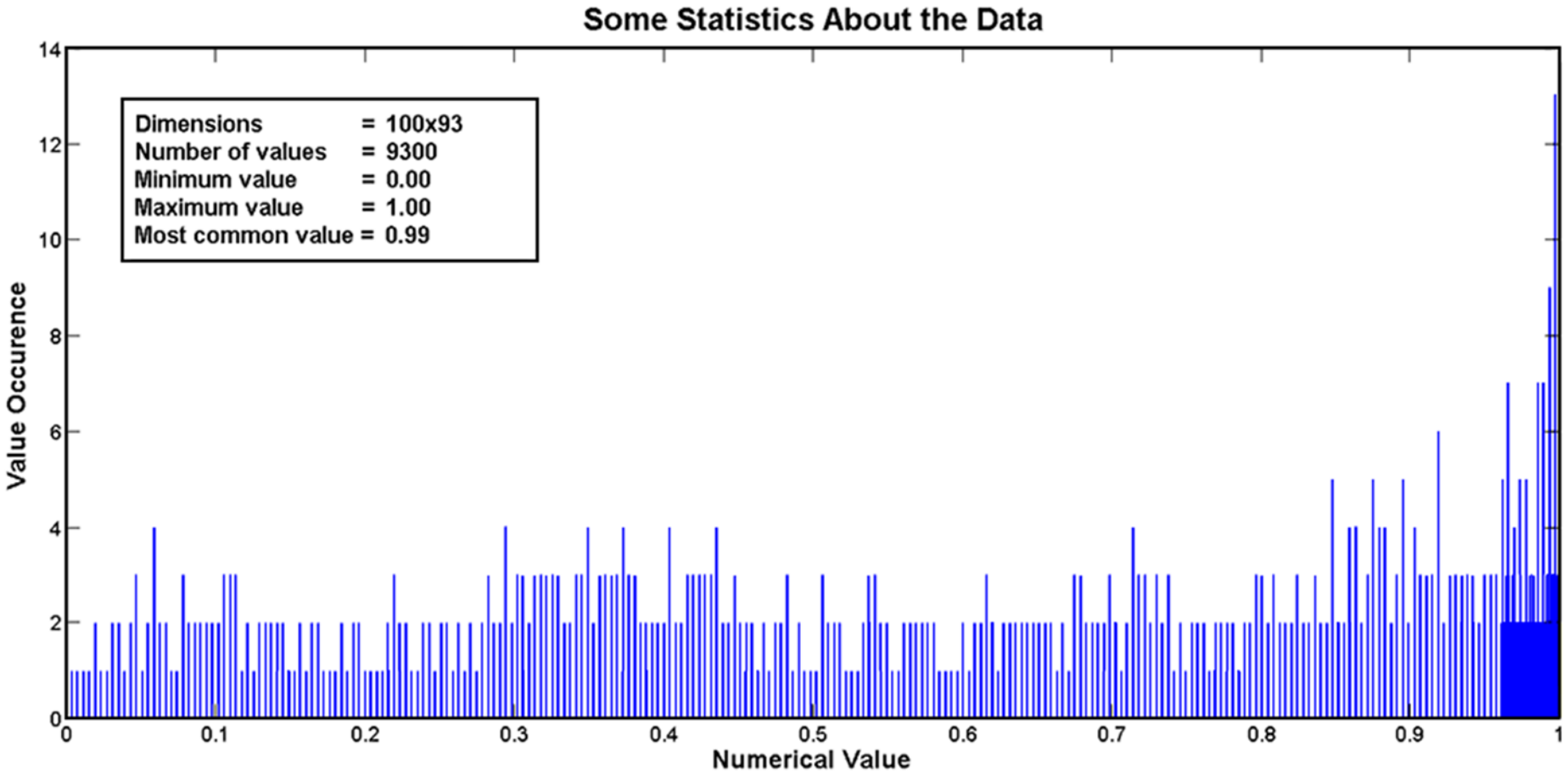
Scientific Visualization for Data Exploration

Visualization as Data Exploration

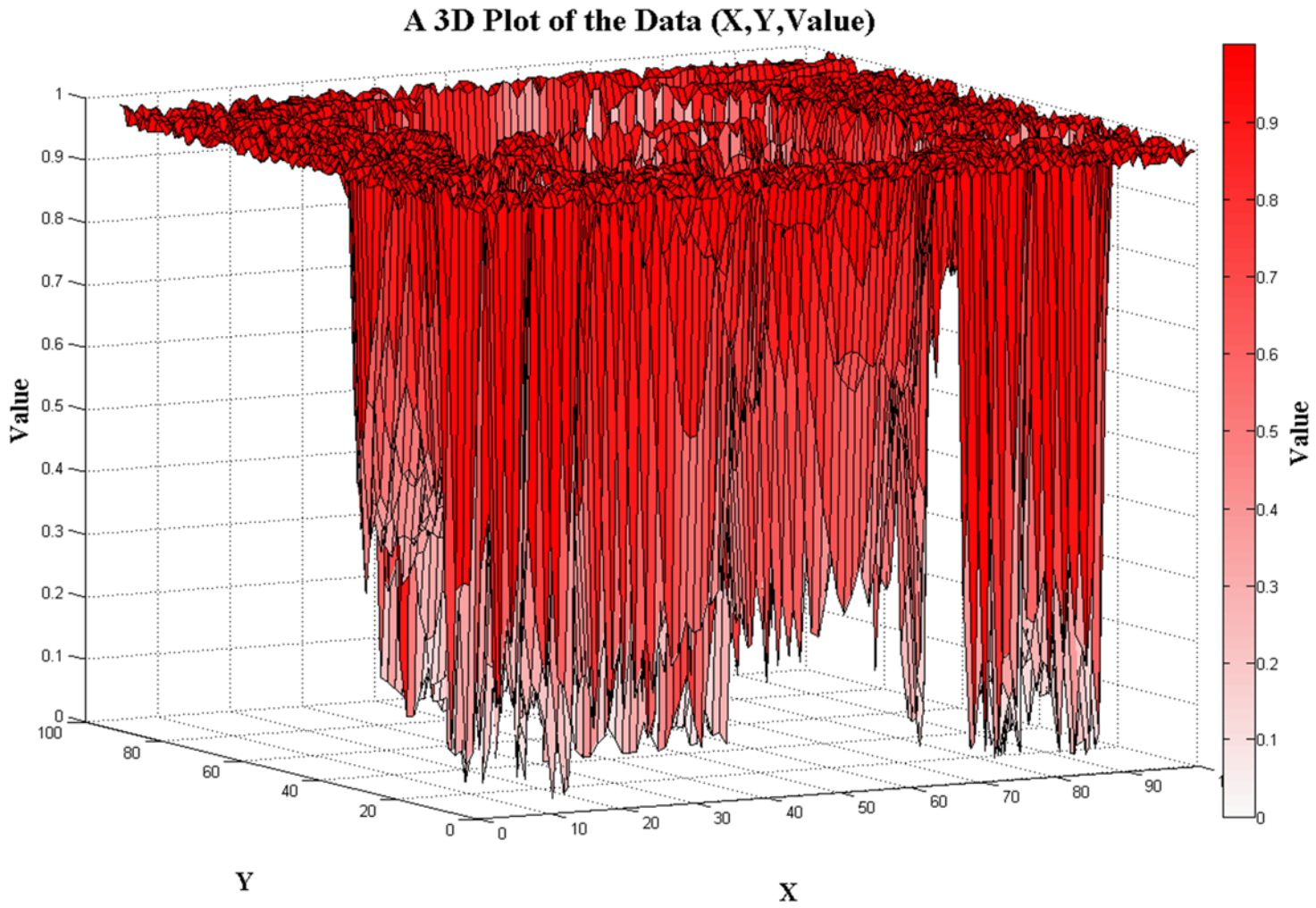


Note: This is only 1/3 of the total data!

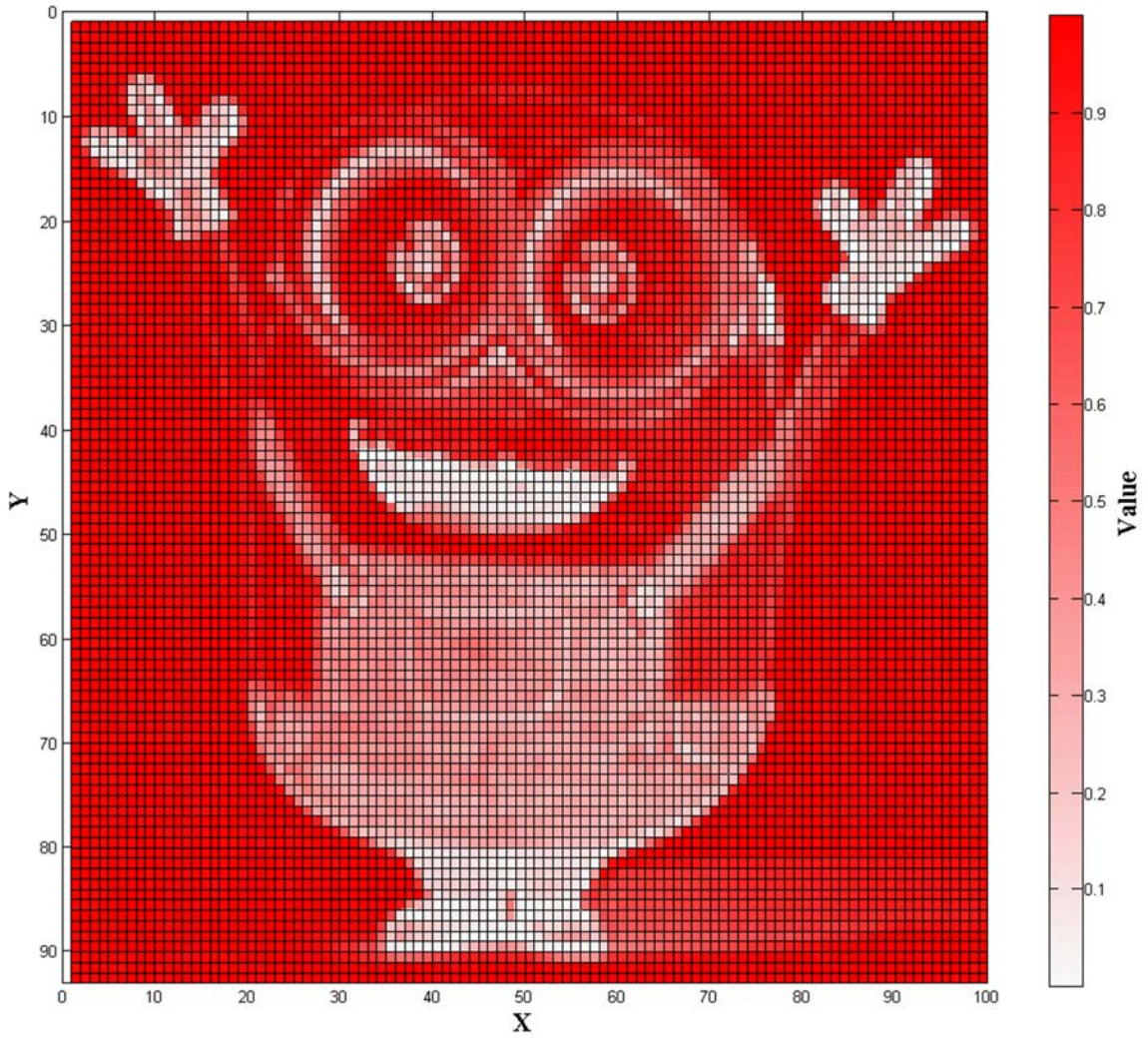
Visualization as Data Exploration



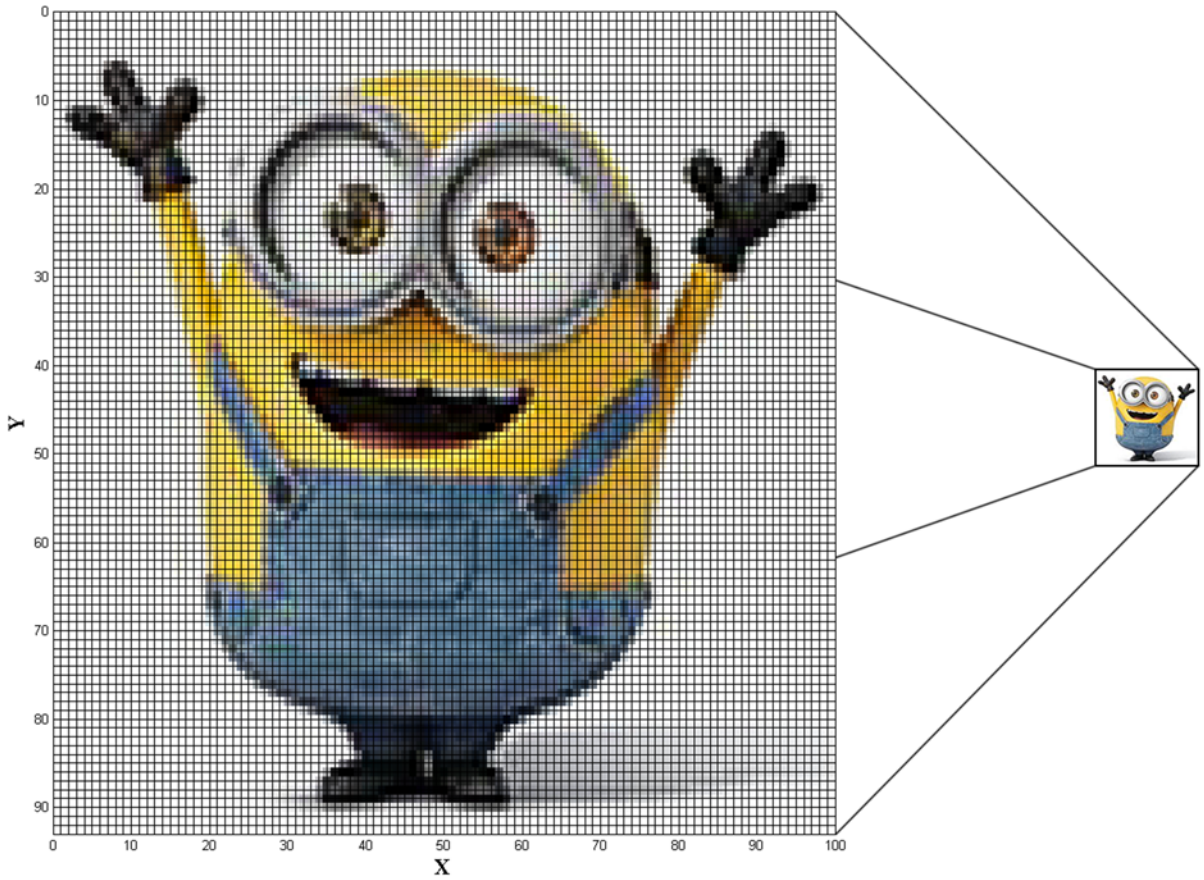
Visualization as Data Exploration



Visualization as Data Exploration



Visualization as Data Exploration

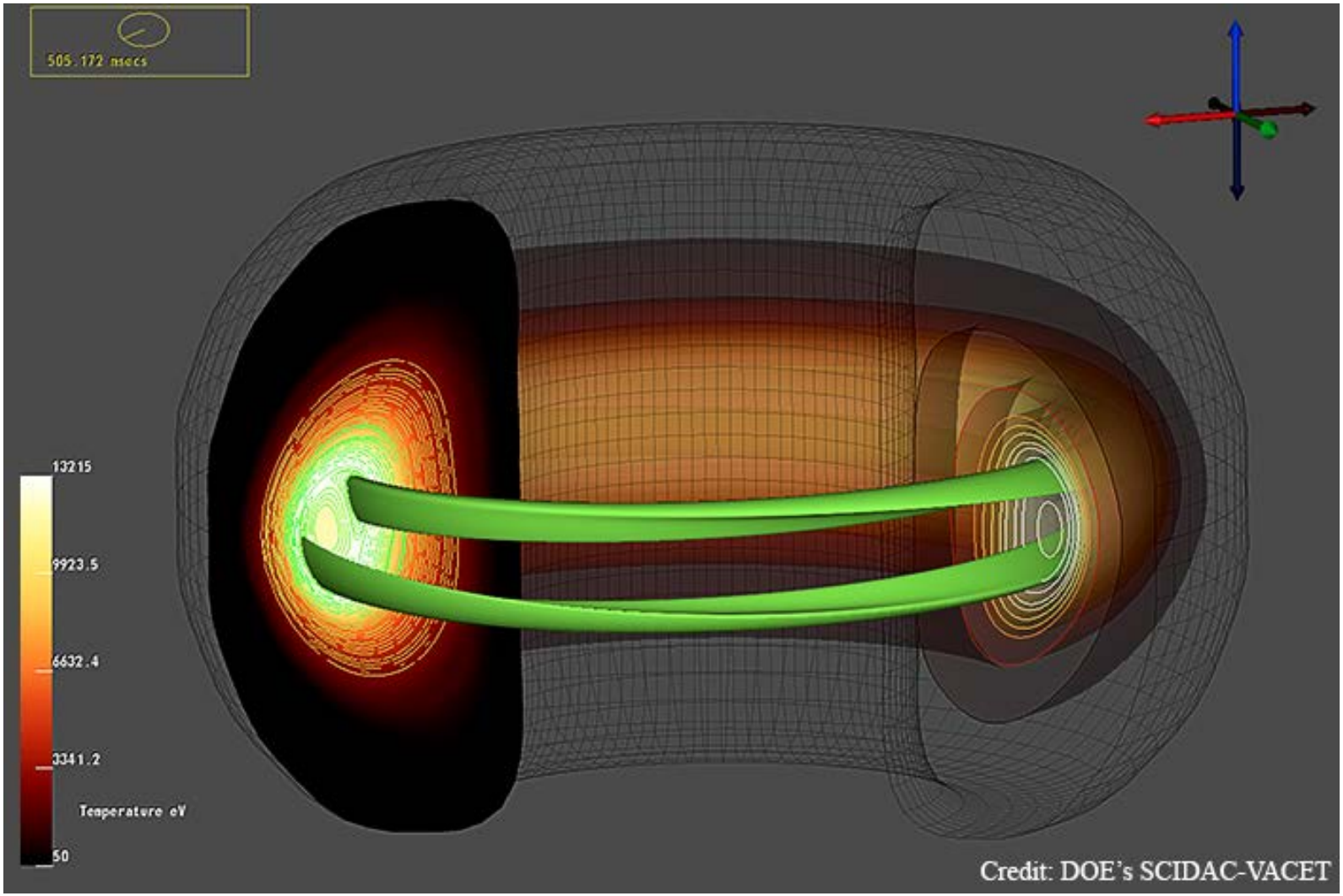


Minion Credit: Illumination Entertainment

Scientific Visualization For Data Validation

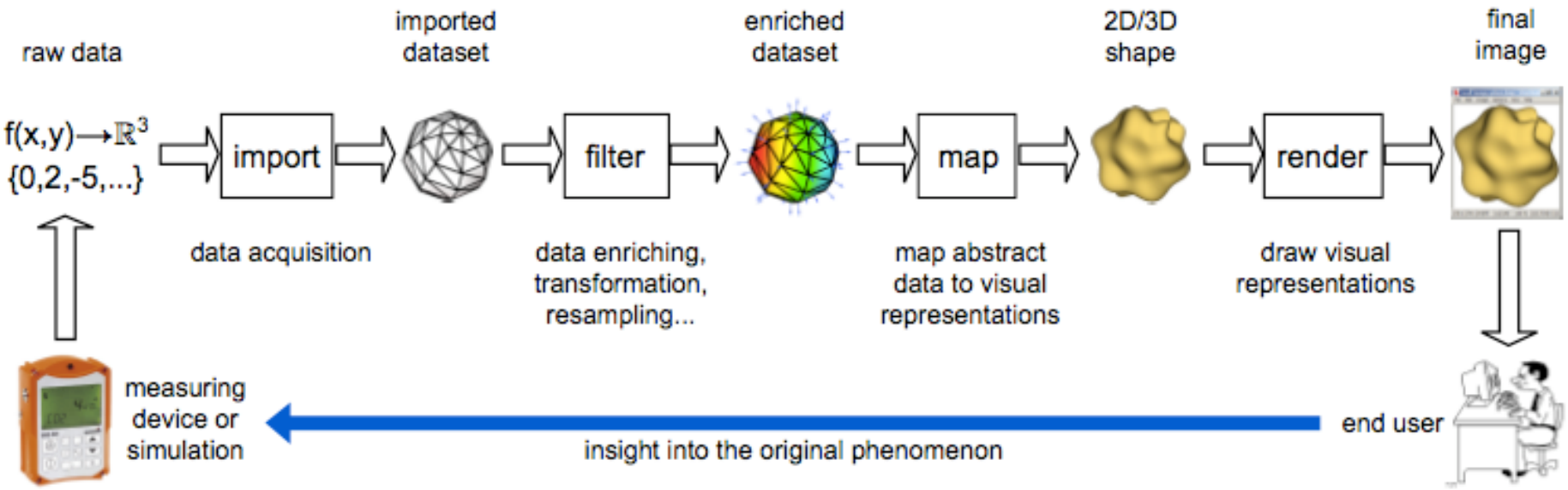
Visualization as Data Validation

Magnetic field containment for Tokamak fusion plasma experiments



The Modern Visualization Pipeline

Visualization Pipeline

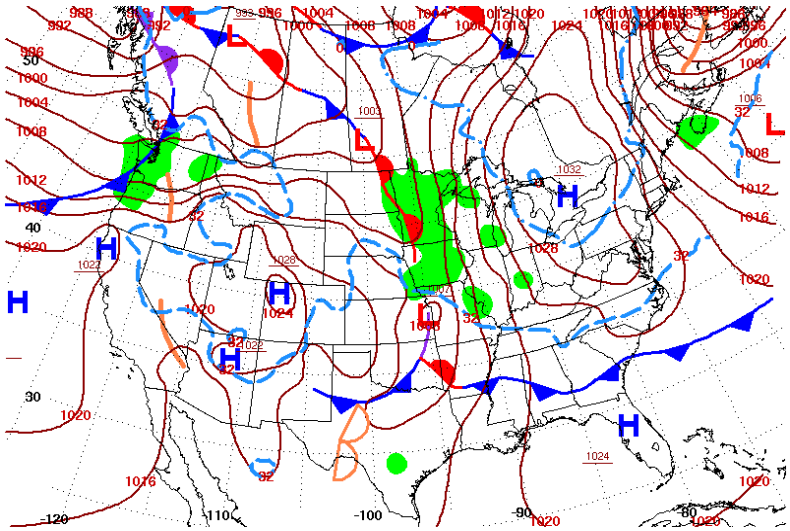


- Transform raw data into insightful answers
- Sequence of **steps**
  - data acquisition (conversion, formatting, cleaning)
  - data enrichment (transformation, resampling, filtering)
  - data mapping (produce visible shapes from data)
  - rendering (draw and interact with the shapes)

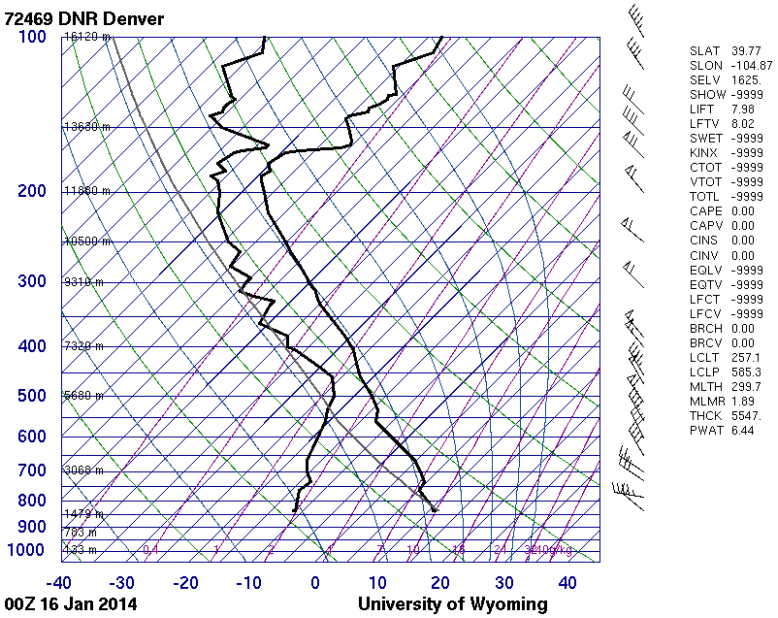
Credit: ***Data Visualization: Principles and Practice***, Second Edition, CRC Press, by Alexandru C. Telea (2014)

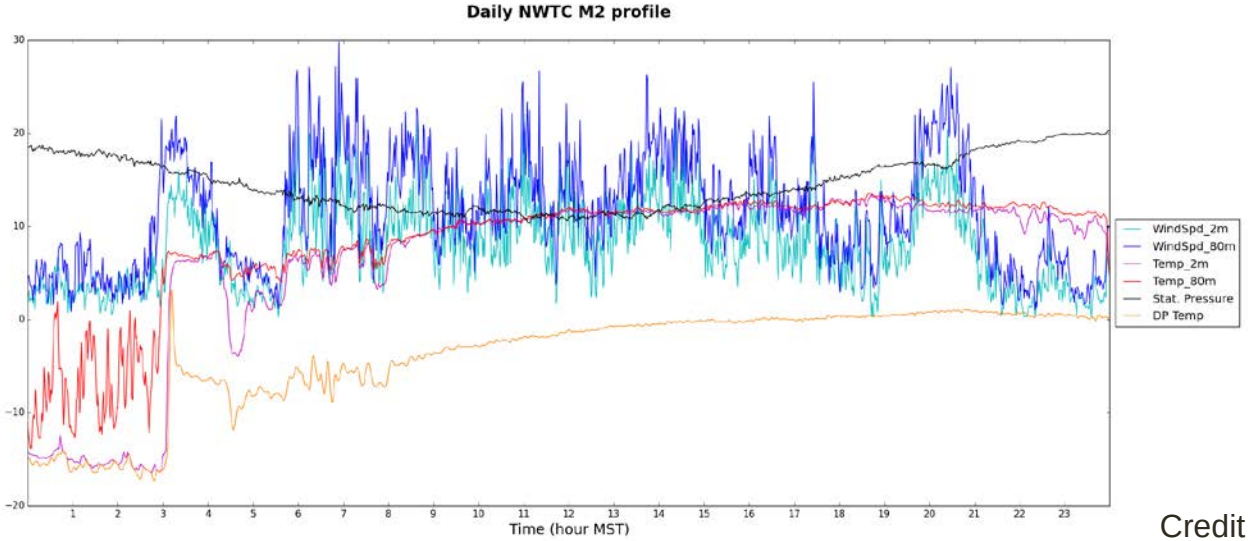
Scientific Visualization Methods

Standard Plotting Methods



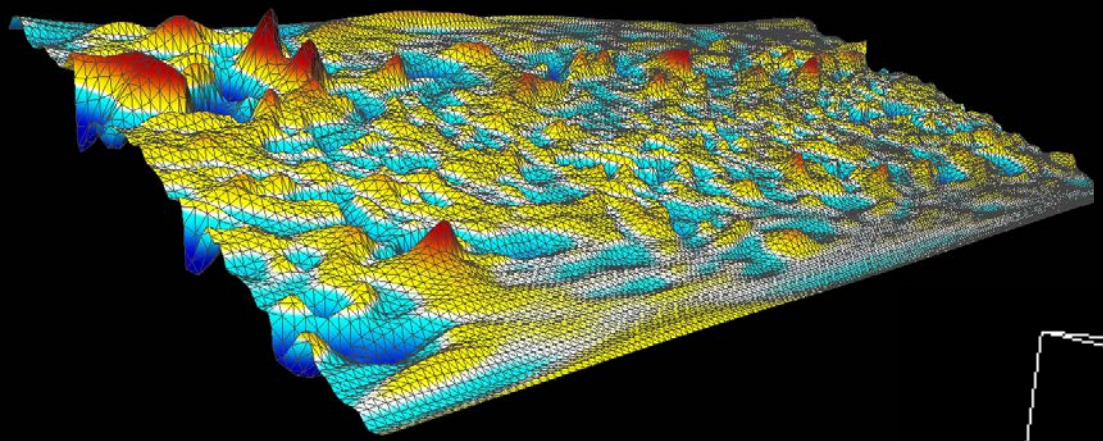
Surface Weather Map at 7:00 A.M. E.S.T.

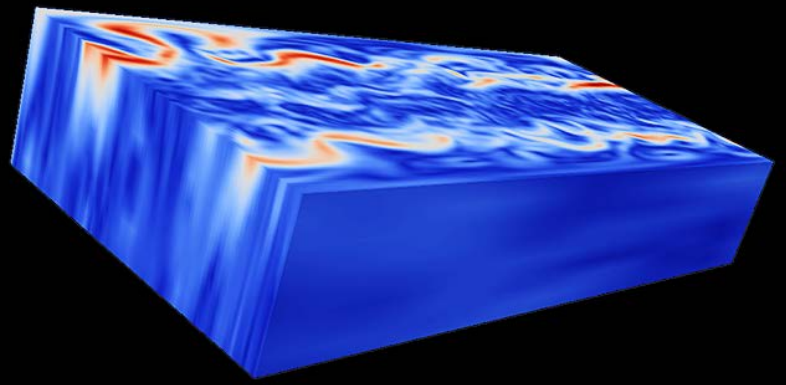


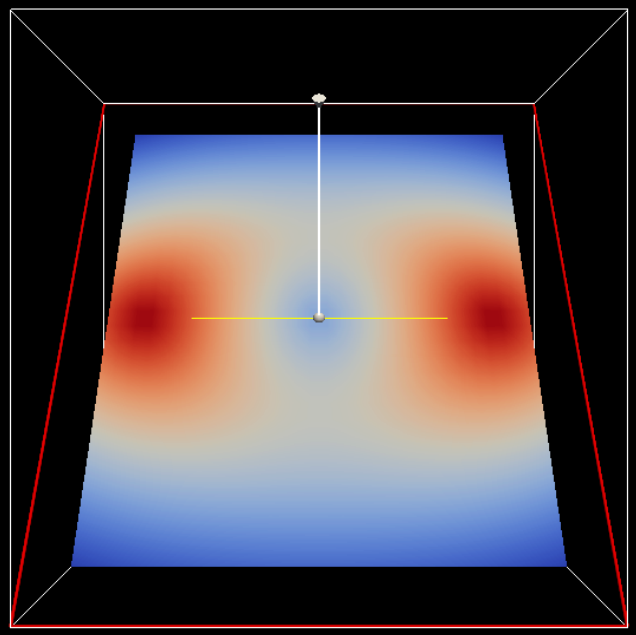


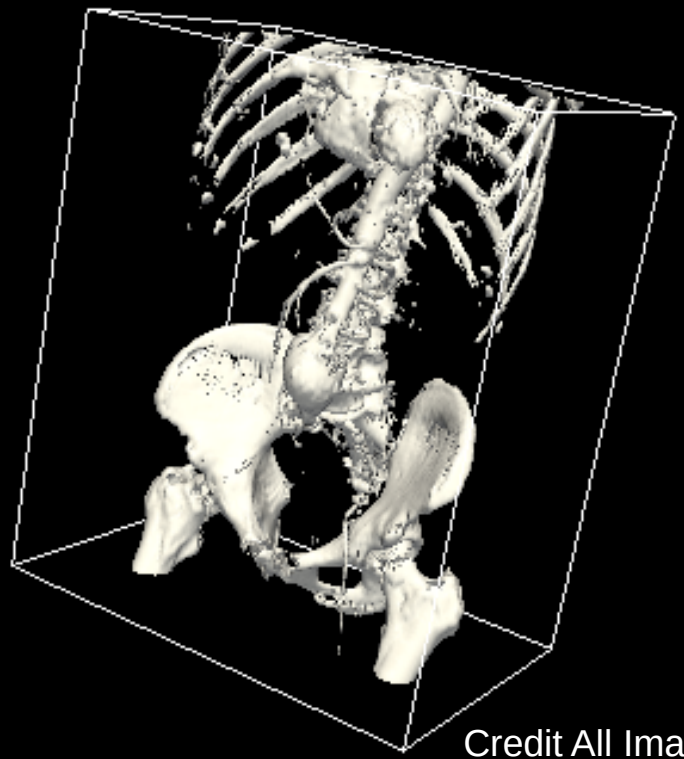
Credit All Images: Tim Dunn

Scalar Plotting Methods



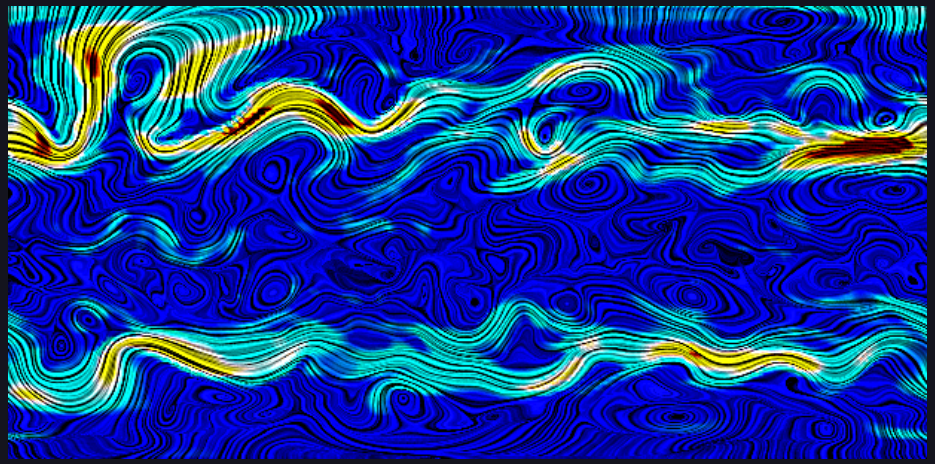


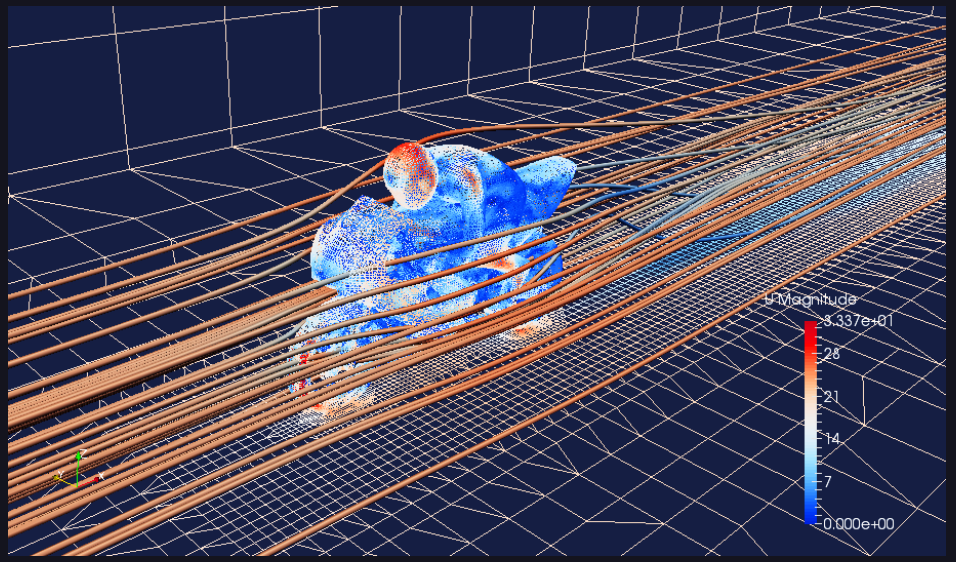


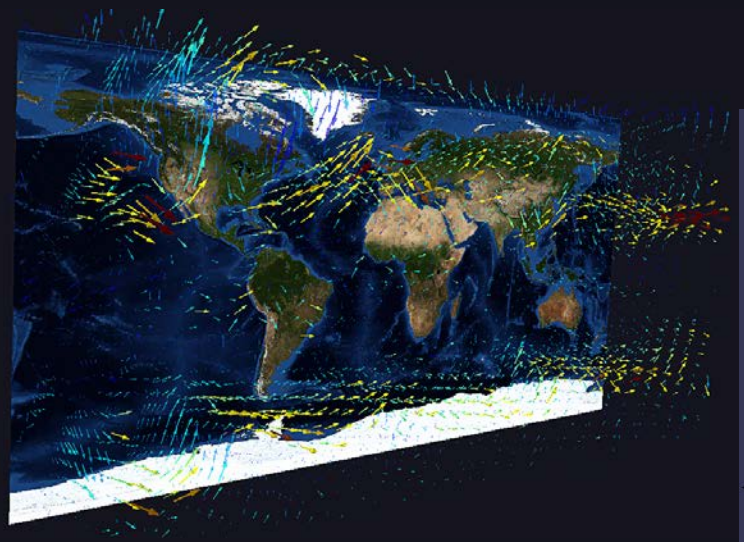


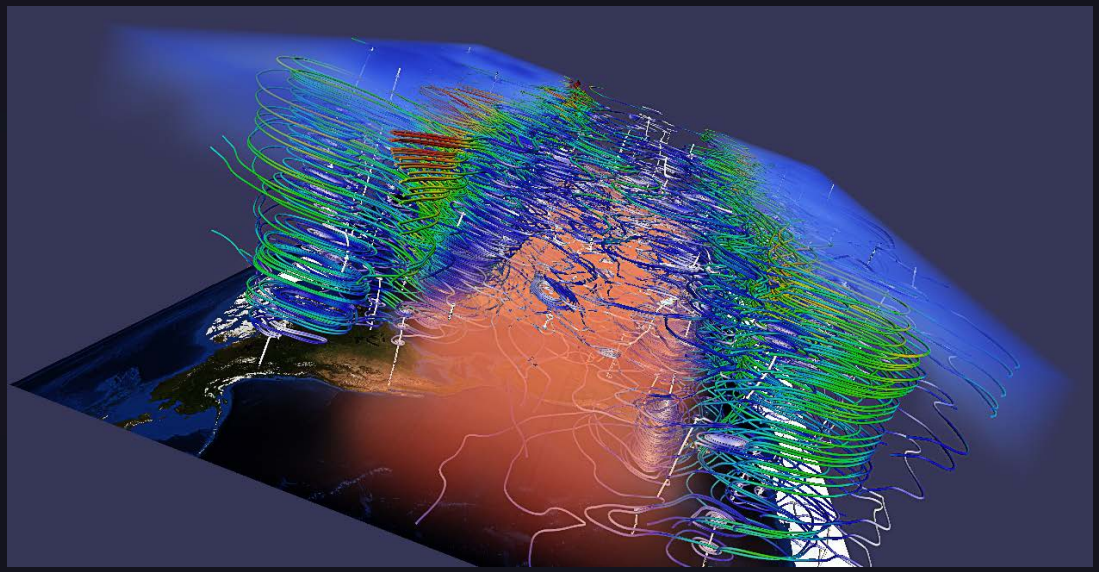
Credit All Images: Tim Dunn

Vector Plotting Methods



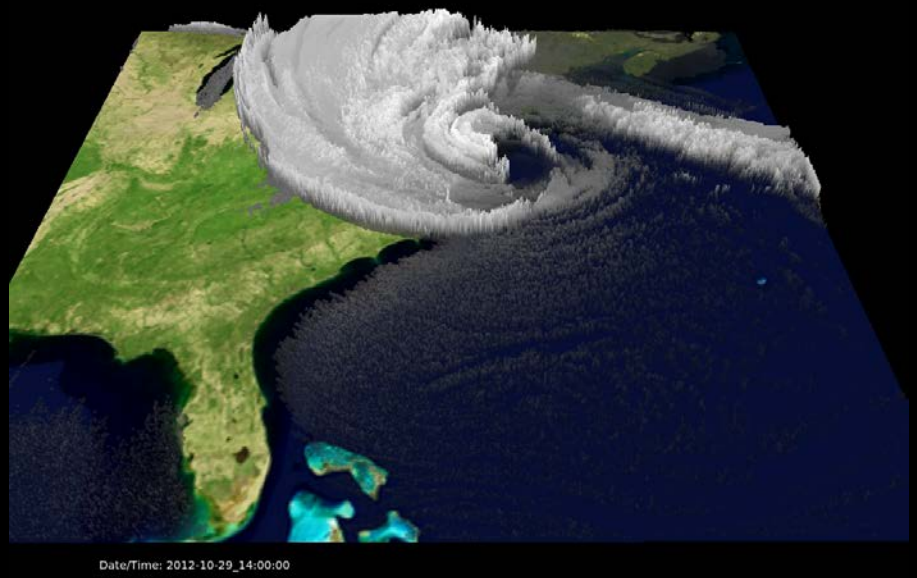


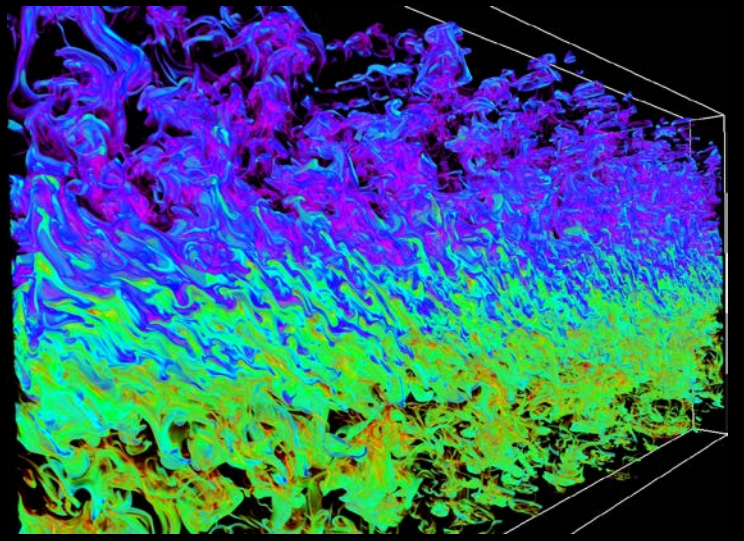


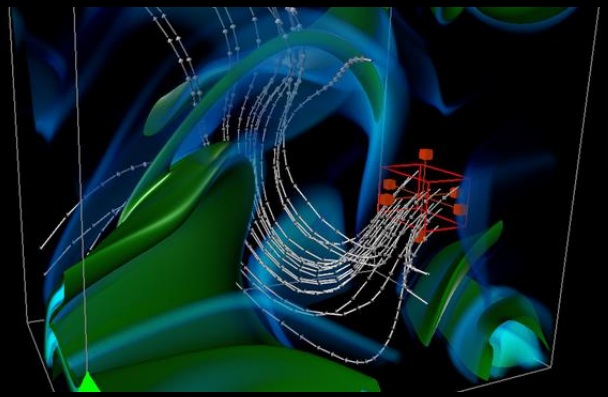


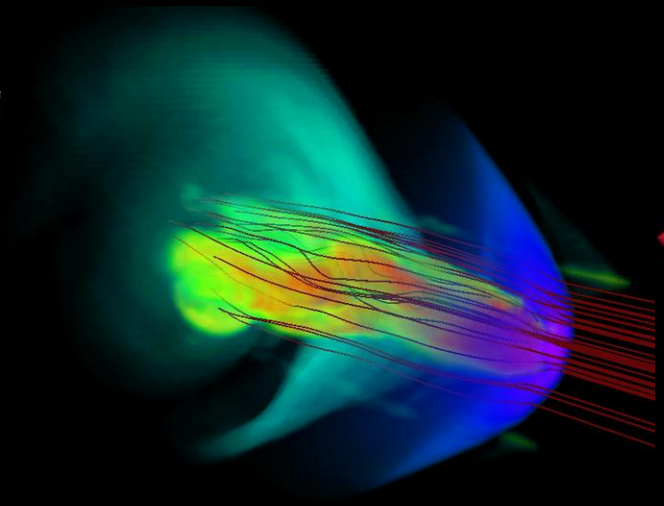
Credit All Images: Tim Dunn

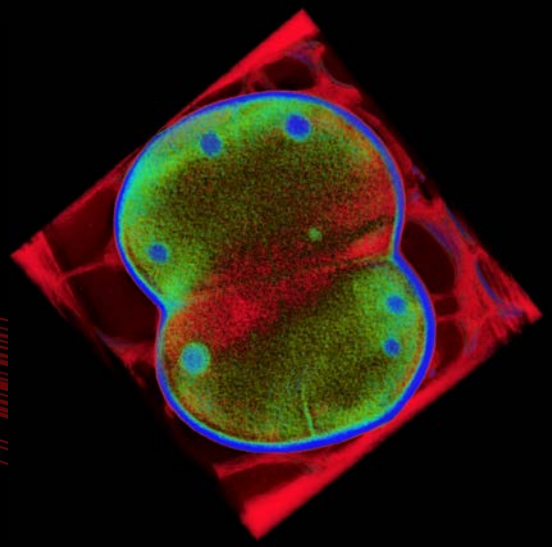
Volume Plotting Methods





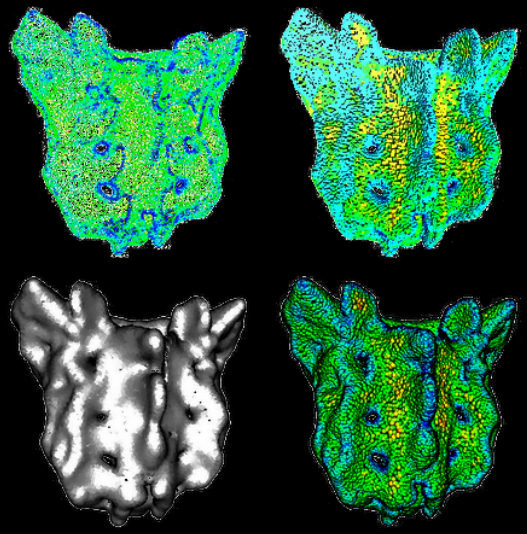




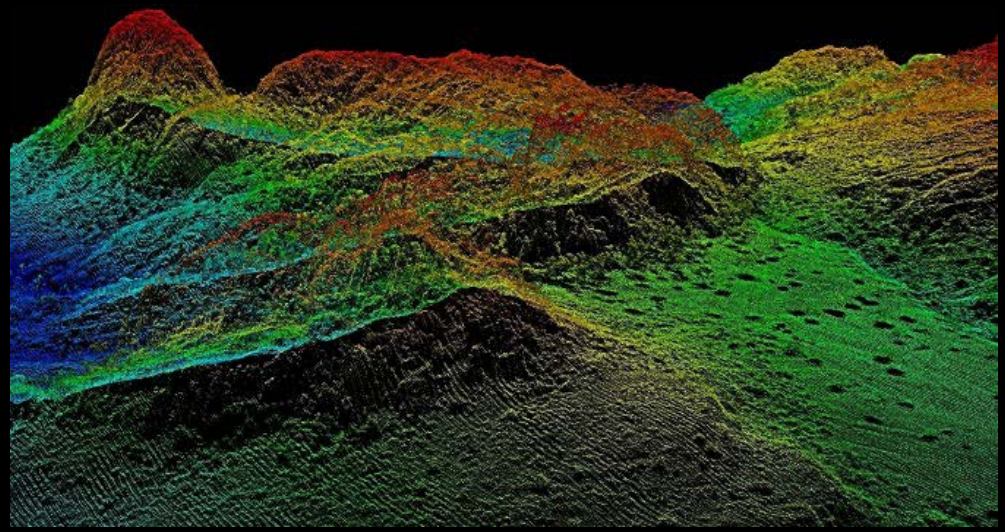


Credit All Images: https://www.vapor.ucar.edu/gallery

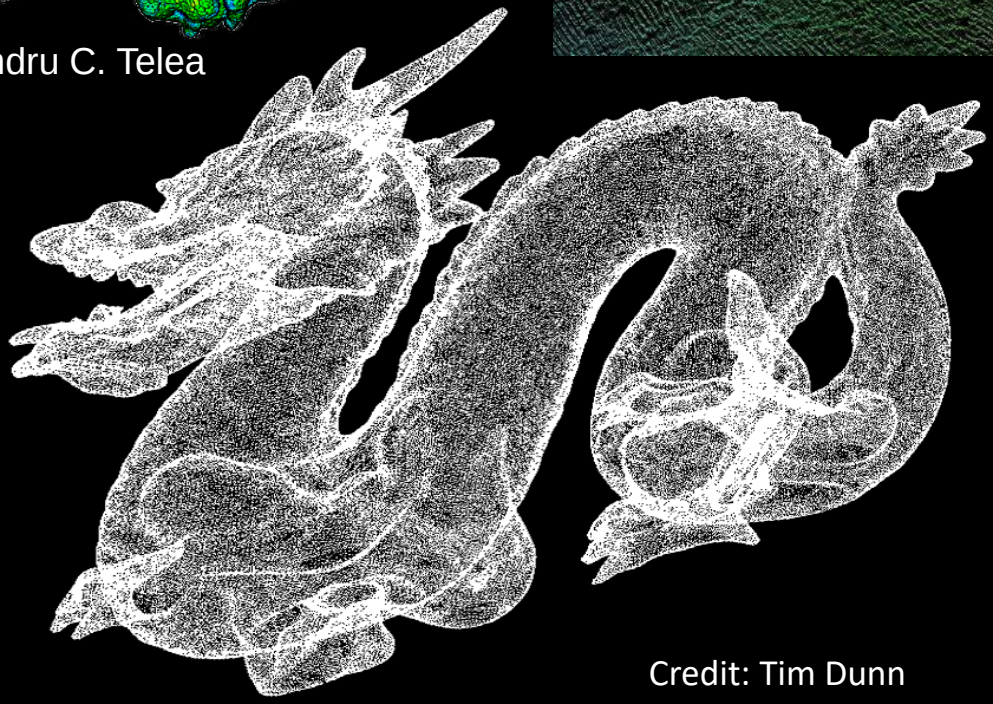
Point Cloud Methods



Credit Alexandru C. Telea

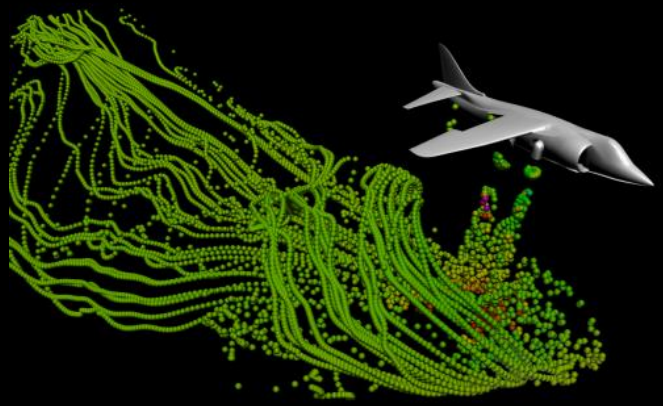


Credit: OpenTopography.com



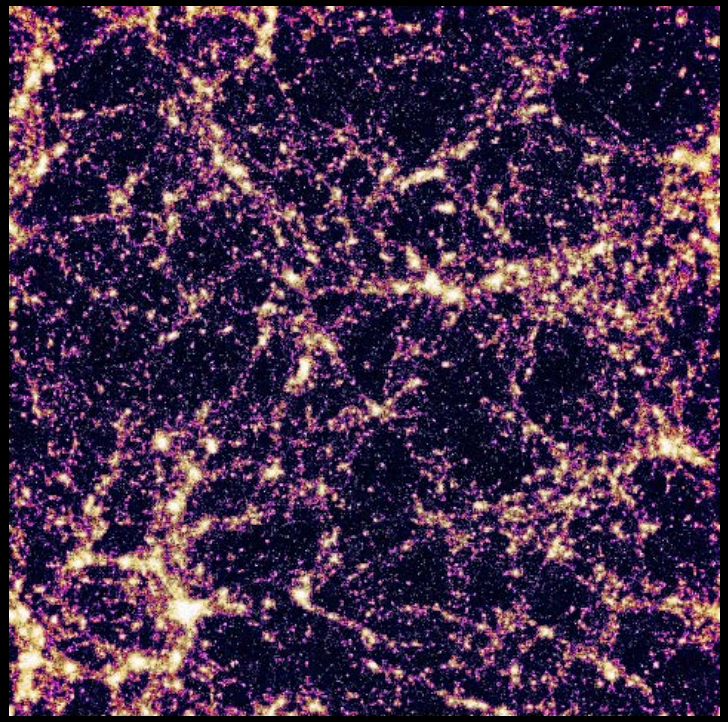
Credit: Tim Dunn

Particle Plotting Methods

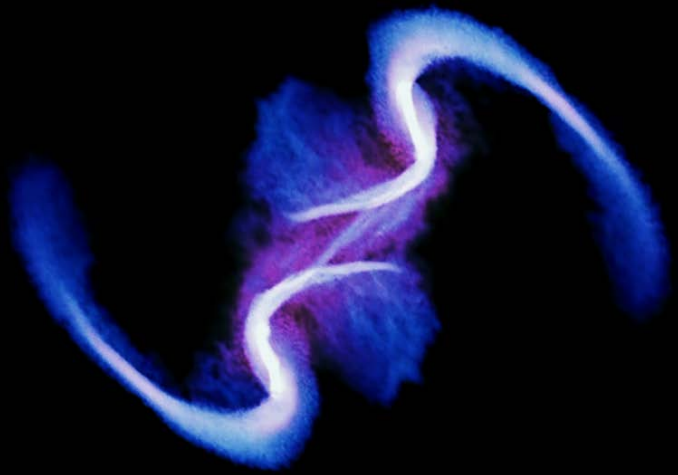


Credit: David Ellsworth NASA Ames

Time = 510 Myr



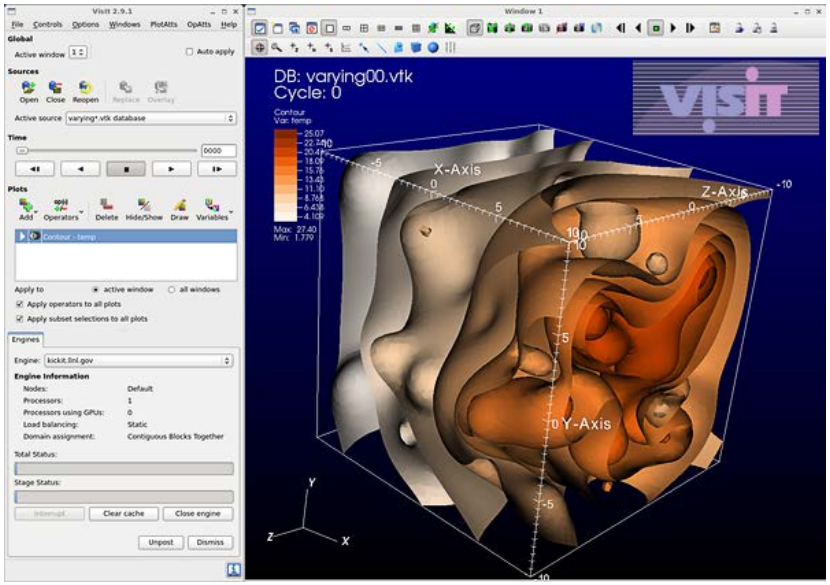
Credit: Tim Dunn

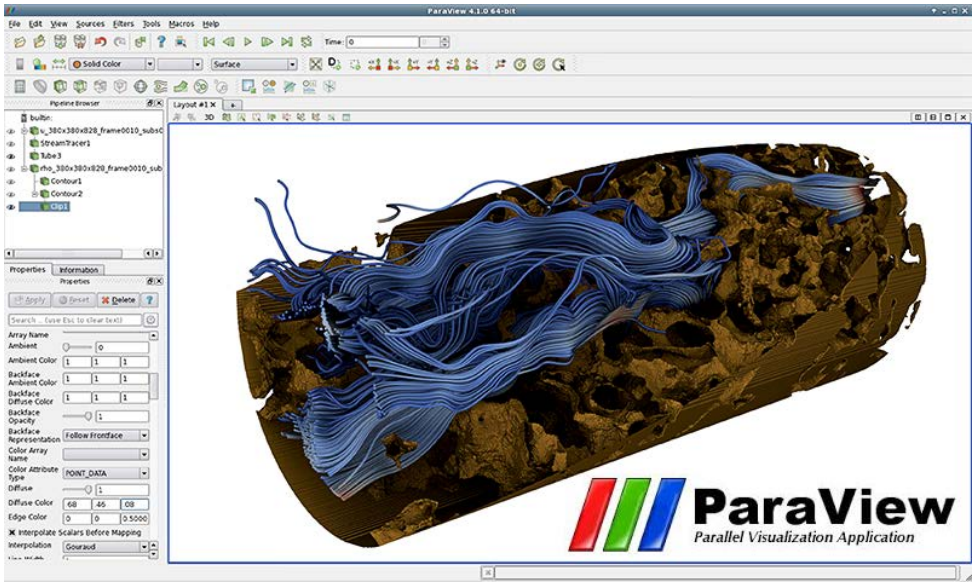


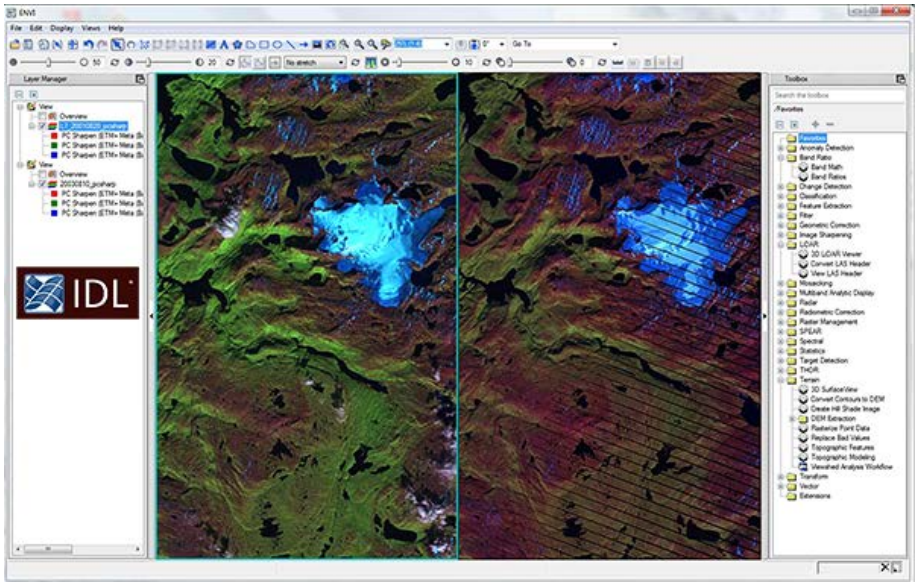
Credit: Tim Dunn

Scientific Visualization Software

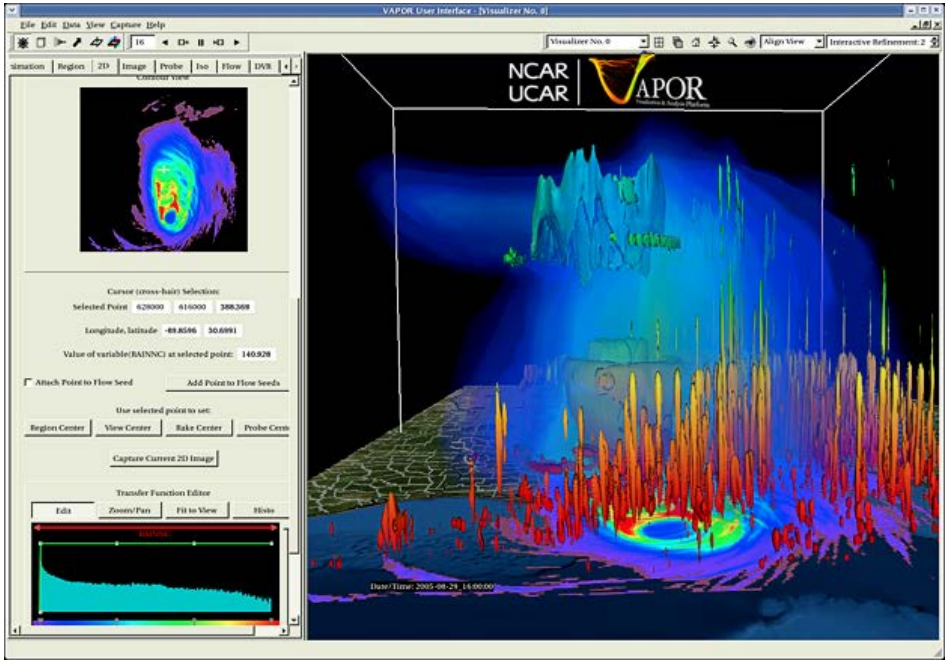
All Purpose Visualization Applications

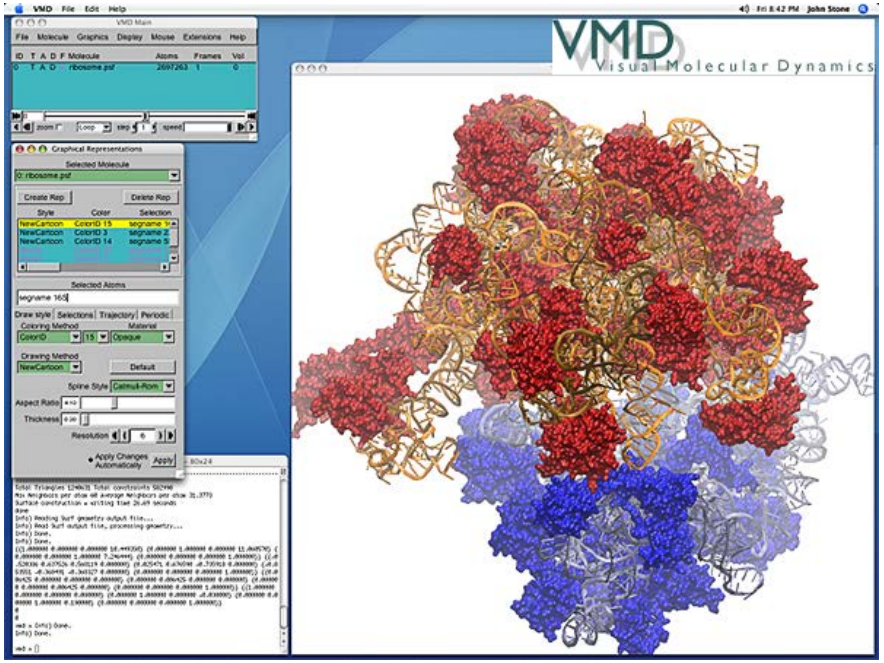


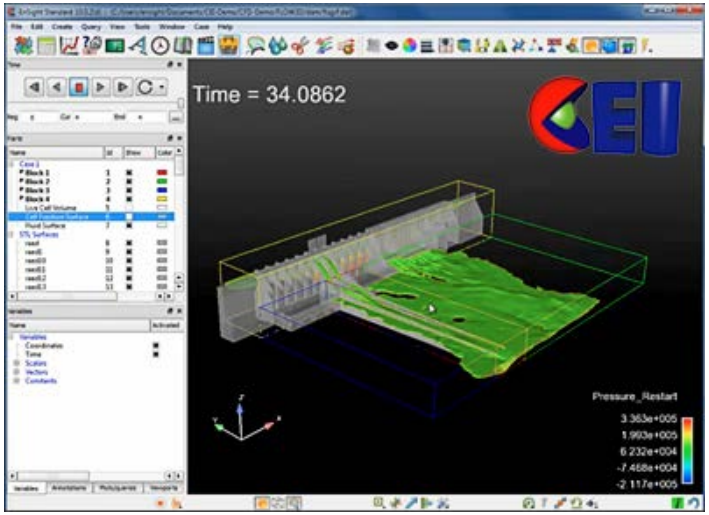




Specialized Visualization Applications







Data Preparation

A Piece of Cake

or Requires ‘Black Arts’ Magic

Credit: Brian LeBlanc

Data Formats the Big Four

- CSV
- HDF5
- NetCDF
- Application specific

The 2/3 Rule

- **2/3 of the time required to complete a scientific visualization project is devoted to data mangling.**

Perception, Color Theory, And Story Telling

Welcome to The Grand Illusion

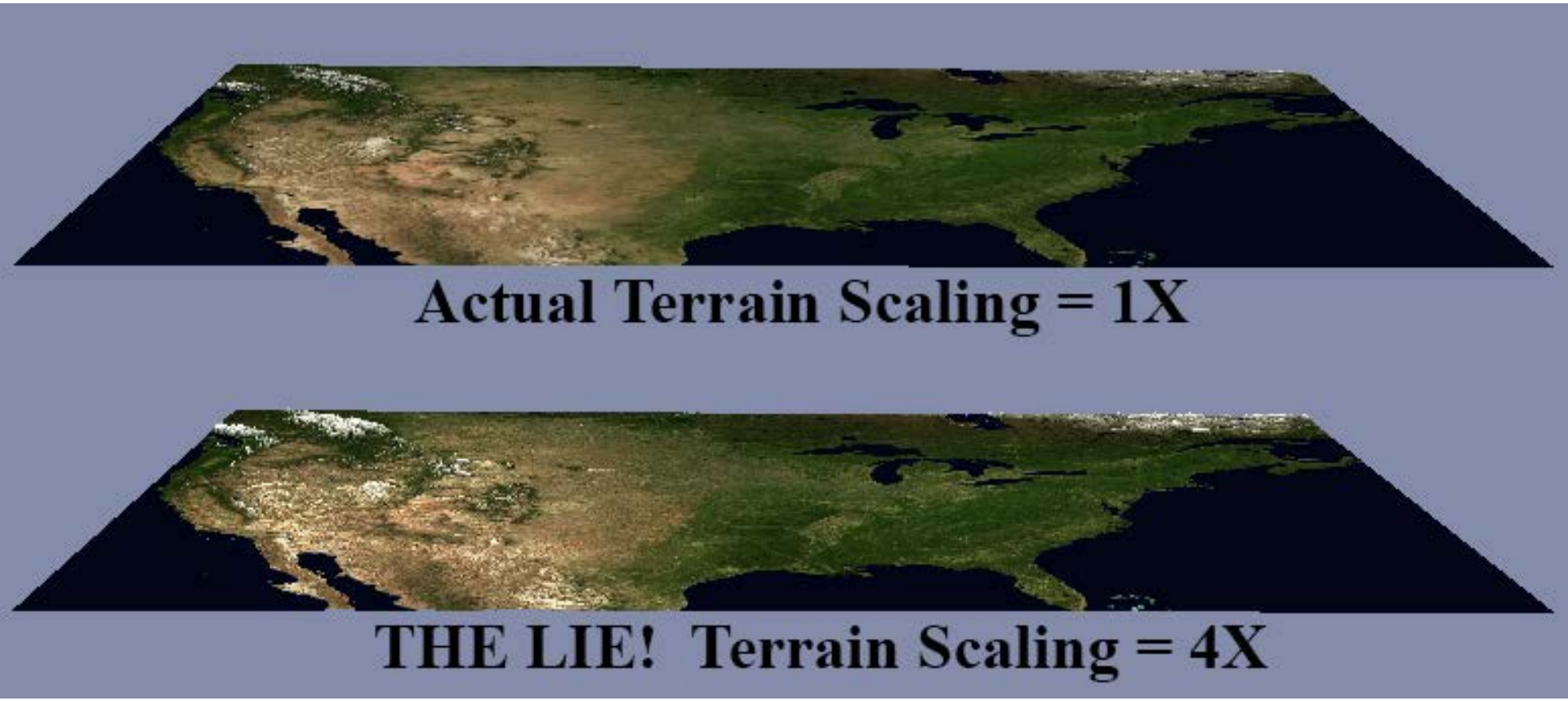
How Honest is Scientific Visualization?

“The purpose of computing is insight, not numbers”

Richard Hamming

“Art is the lie that tells the truth”

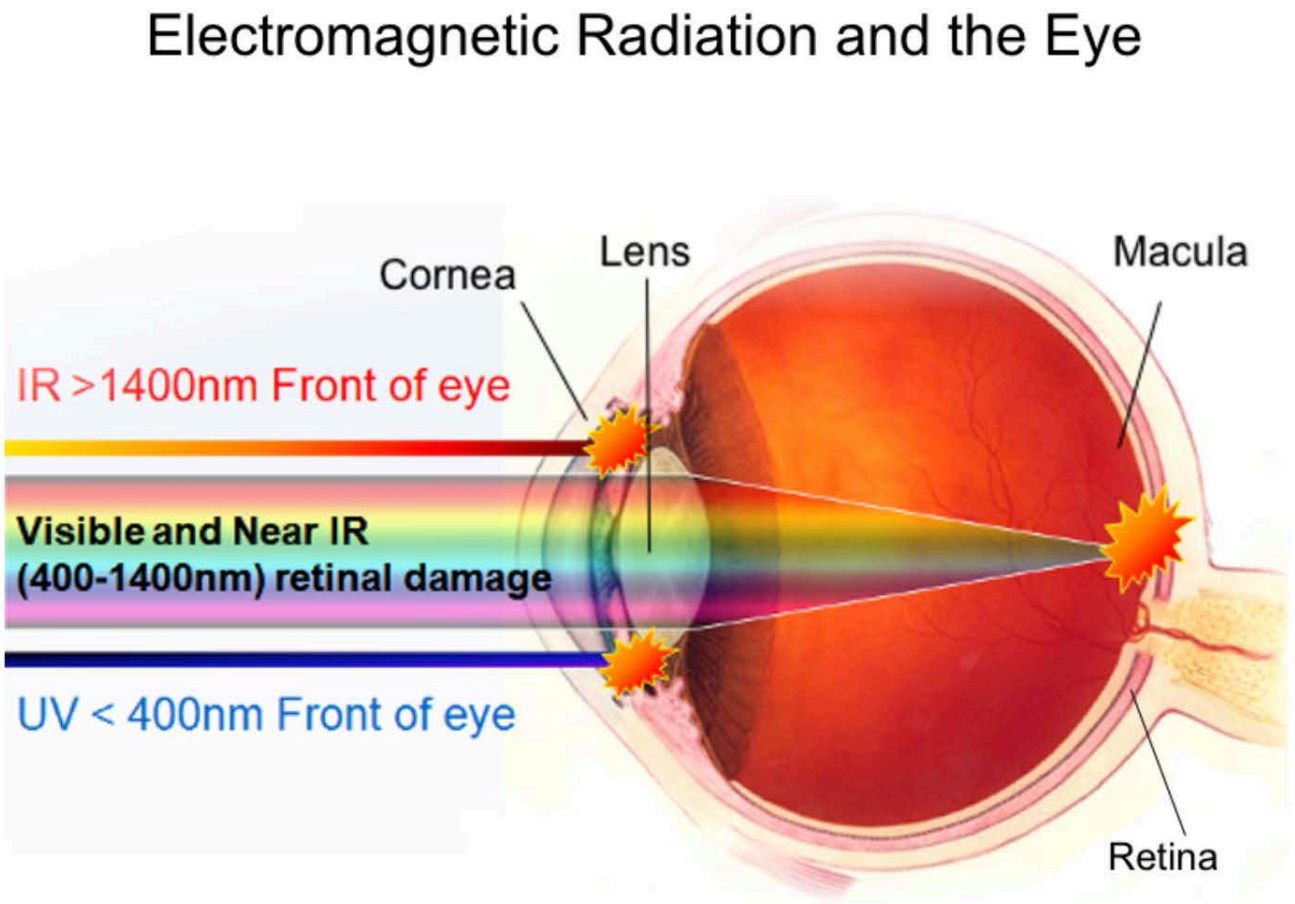
Pablo Picasso



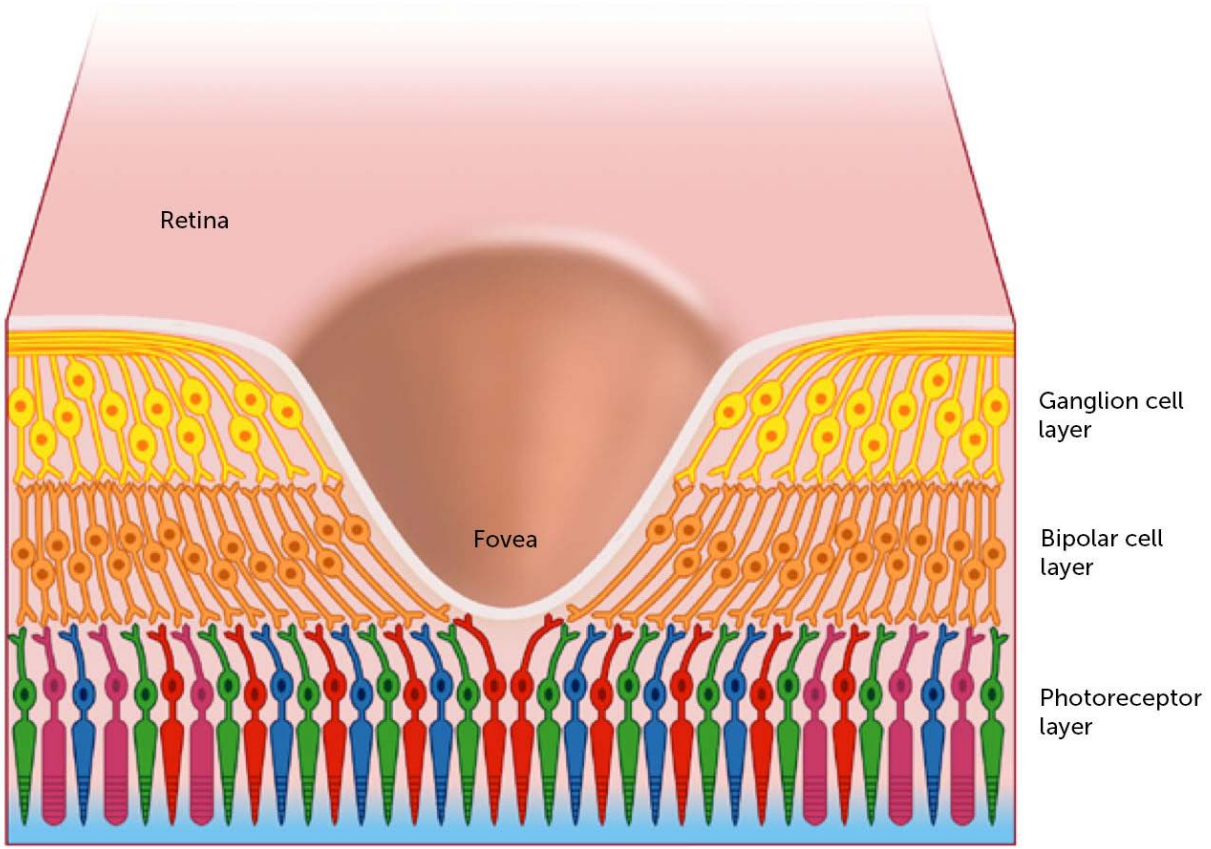
Credit: Tim Dunn

What’s the True major lie here?

The Human Eye

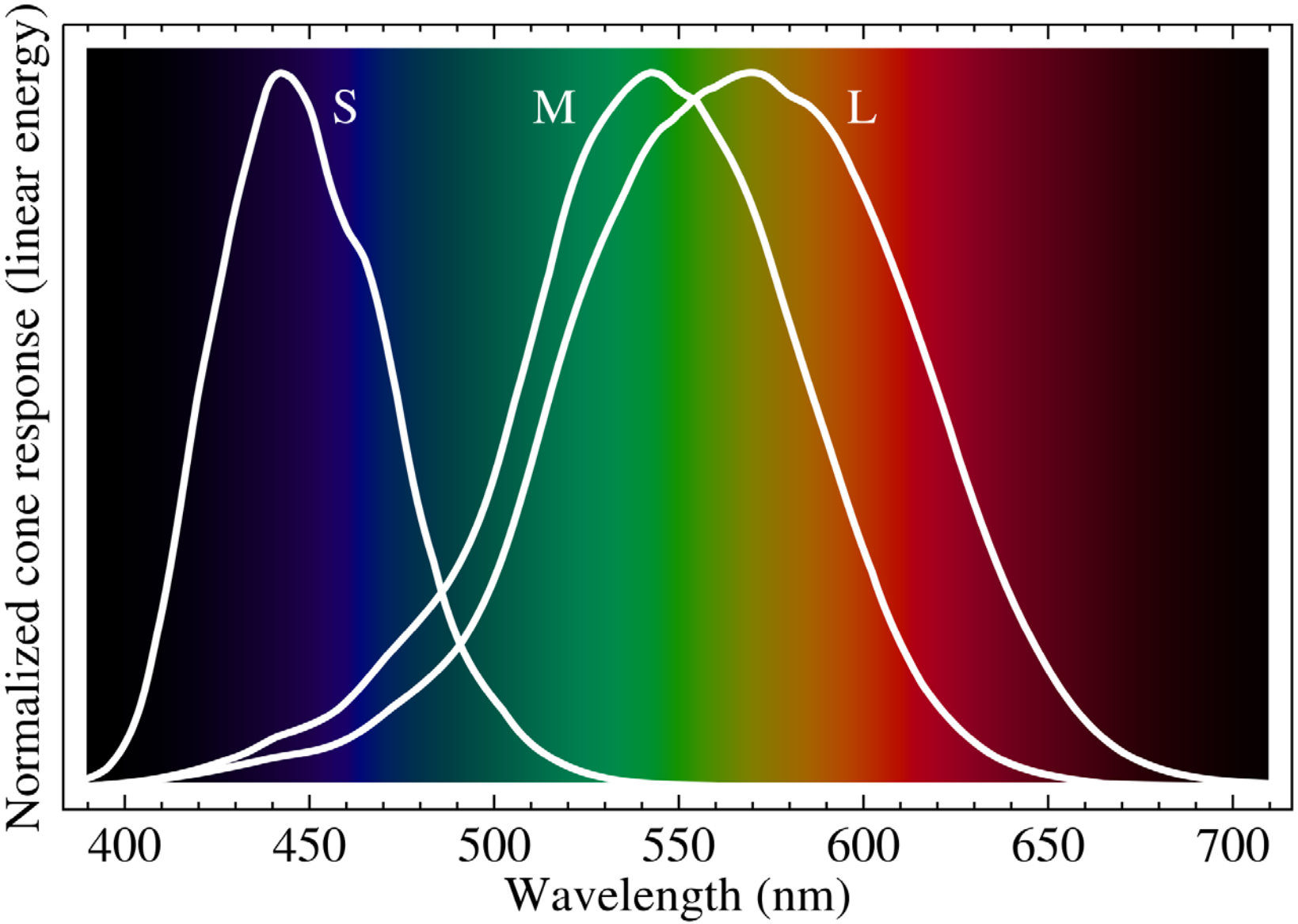


Human Pigment Neurons

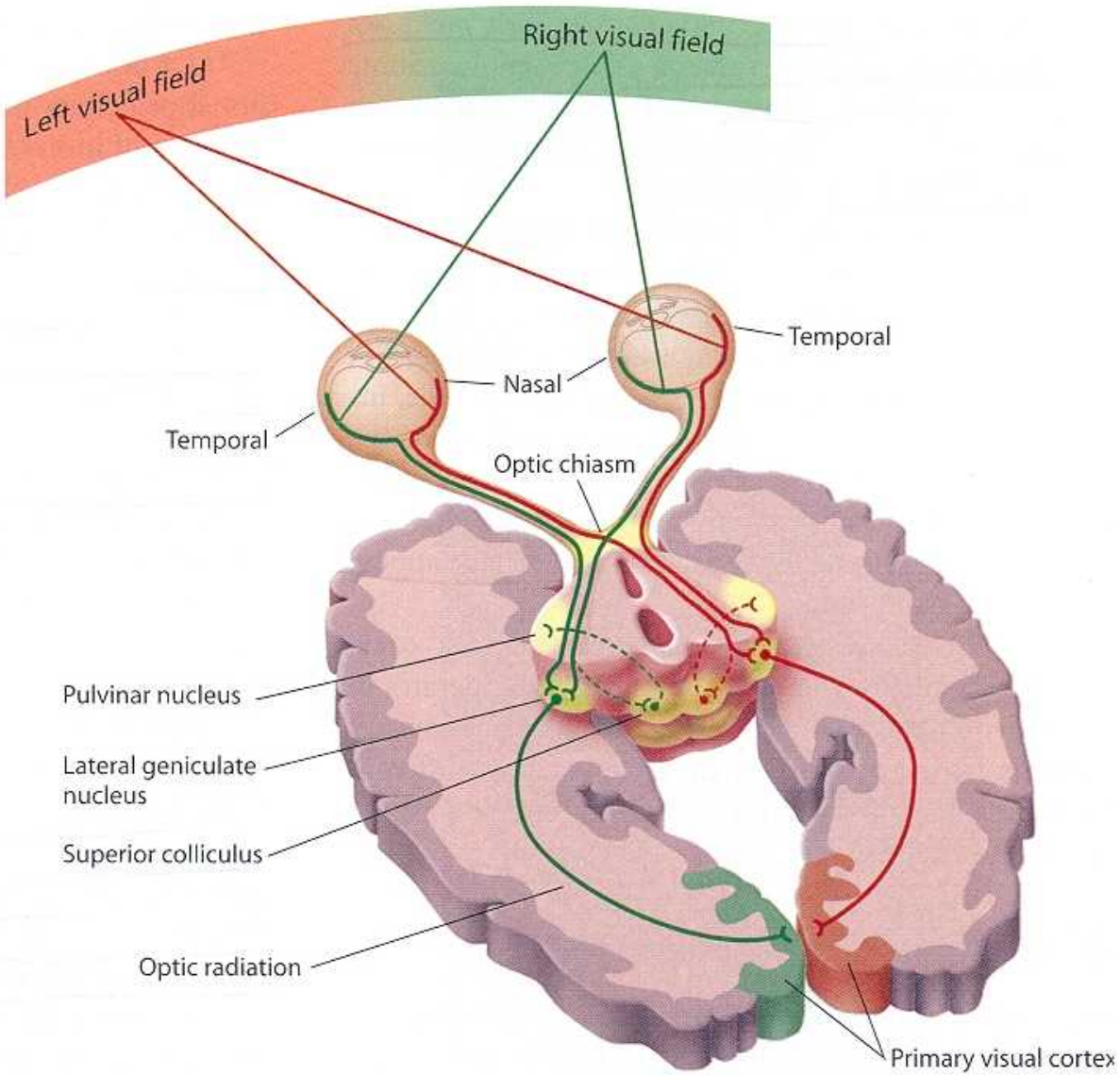


brainHQ from Posit Science

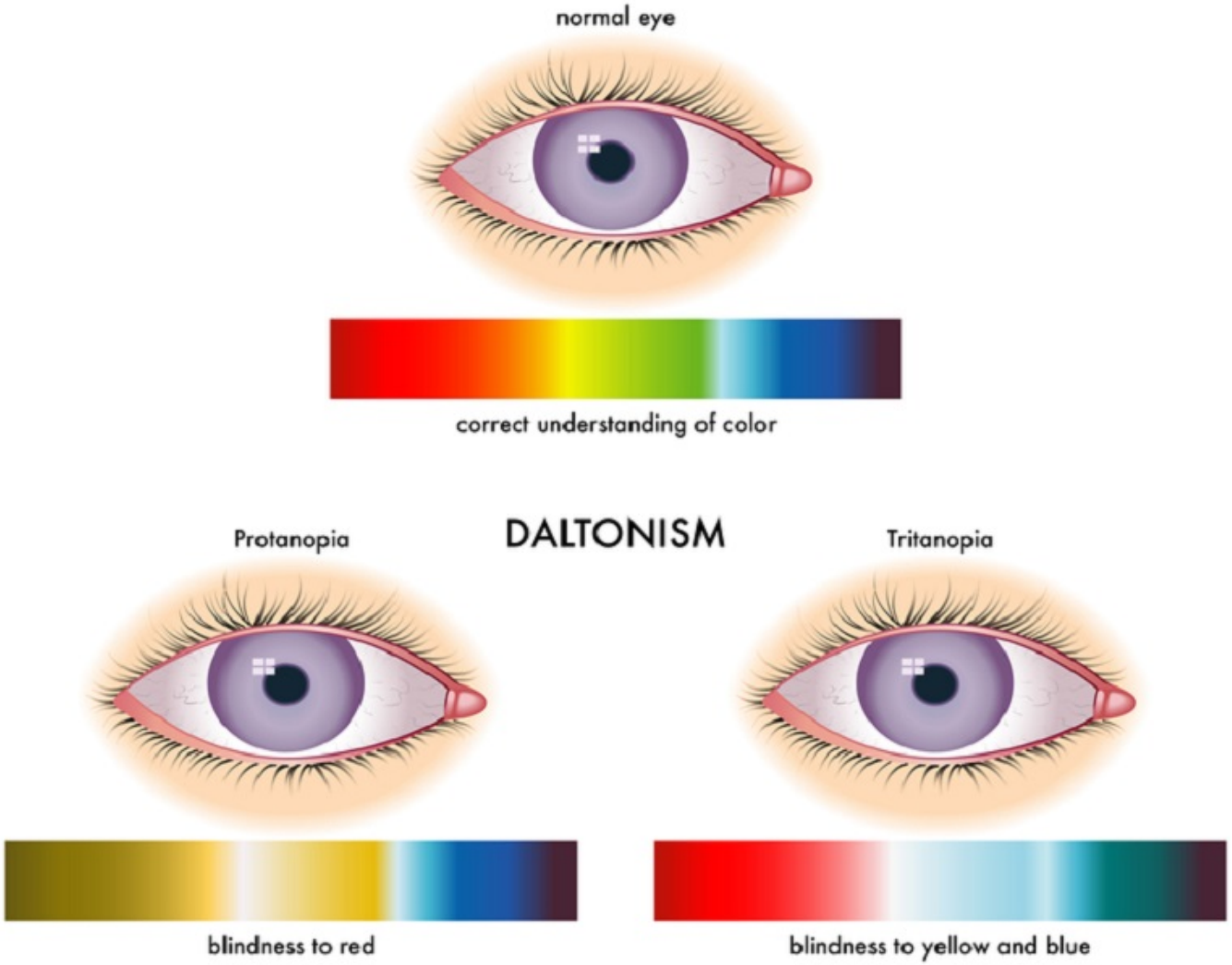
The Spectrum the Human Eye Sees



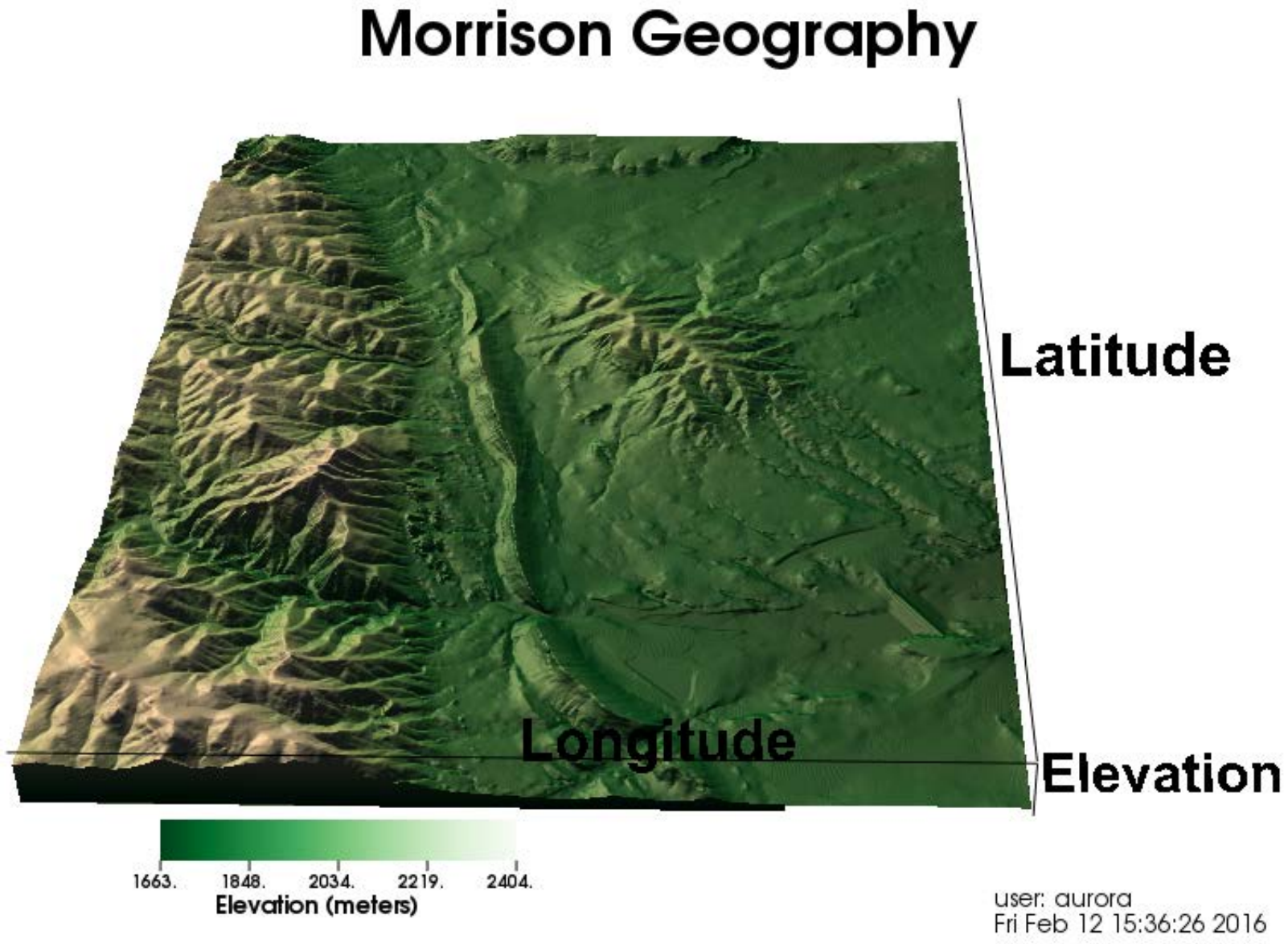
The Human Visual Neural Network



Illusion Proof 1 – Color Blindness

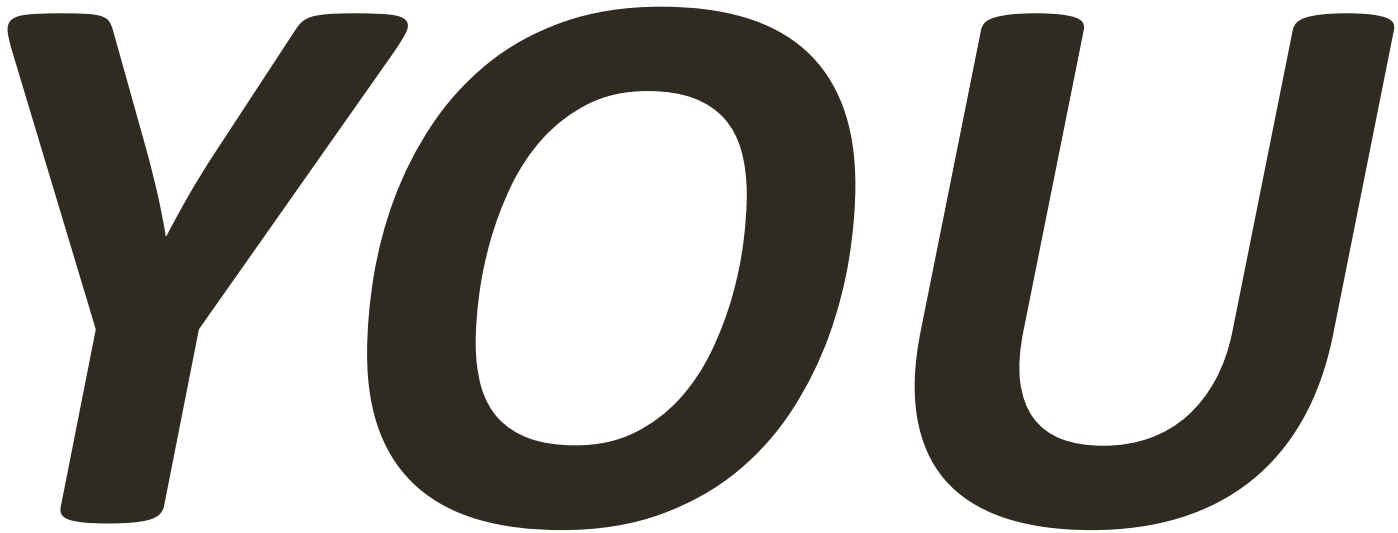


Illusion Proof 2 – The Massive Lie



Illusion Proof 3 – *THE* Dress

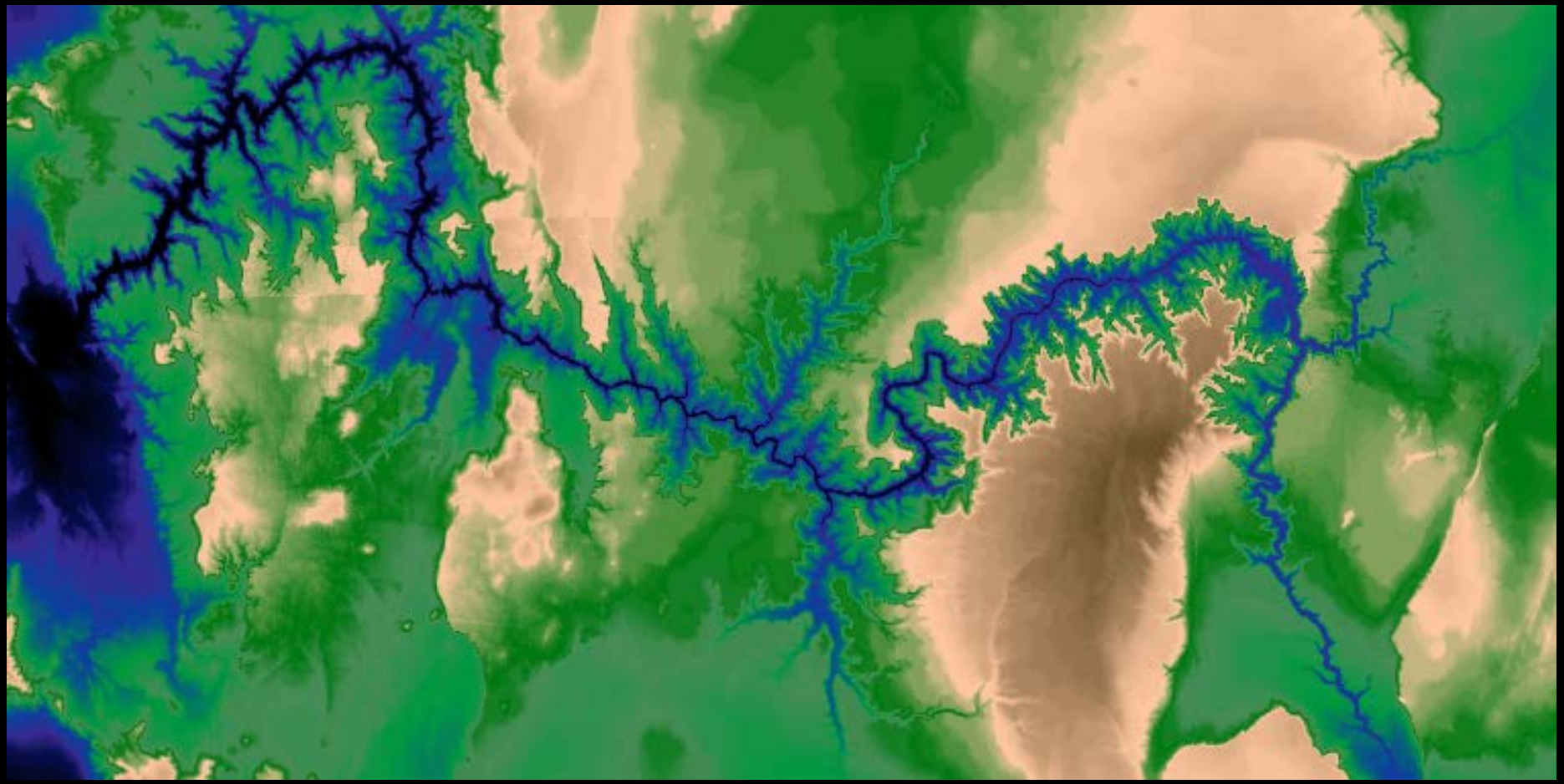
Illusion Proof 4 –

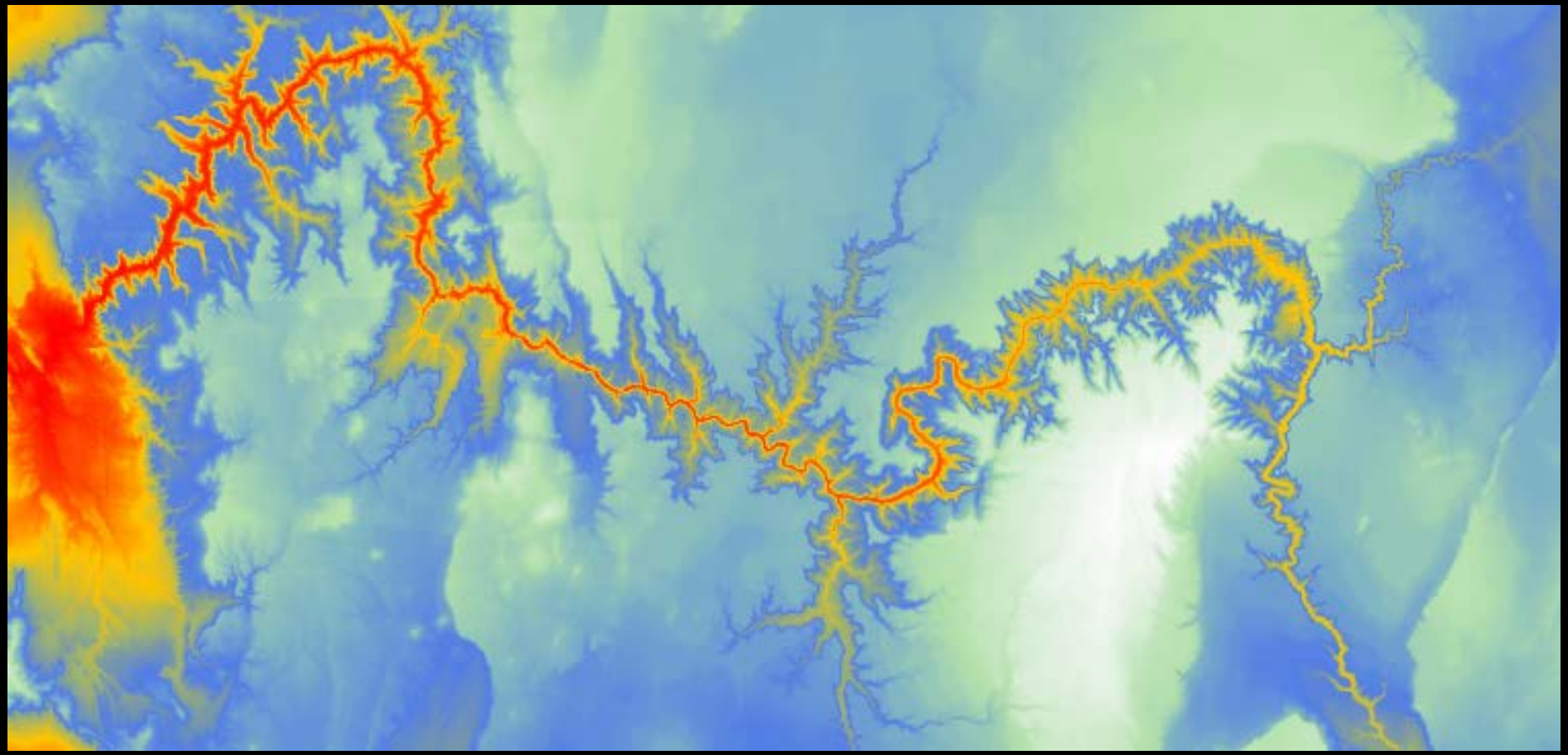


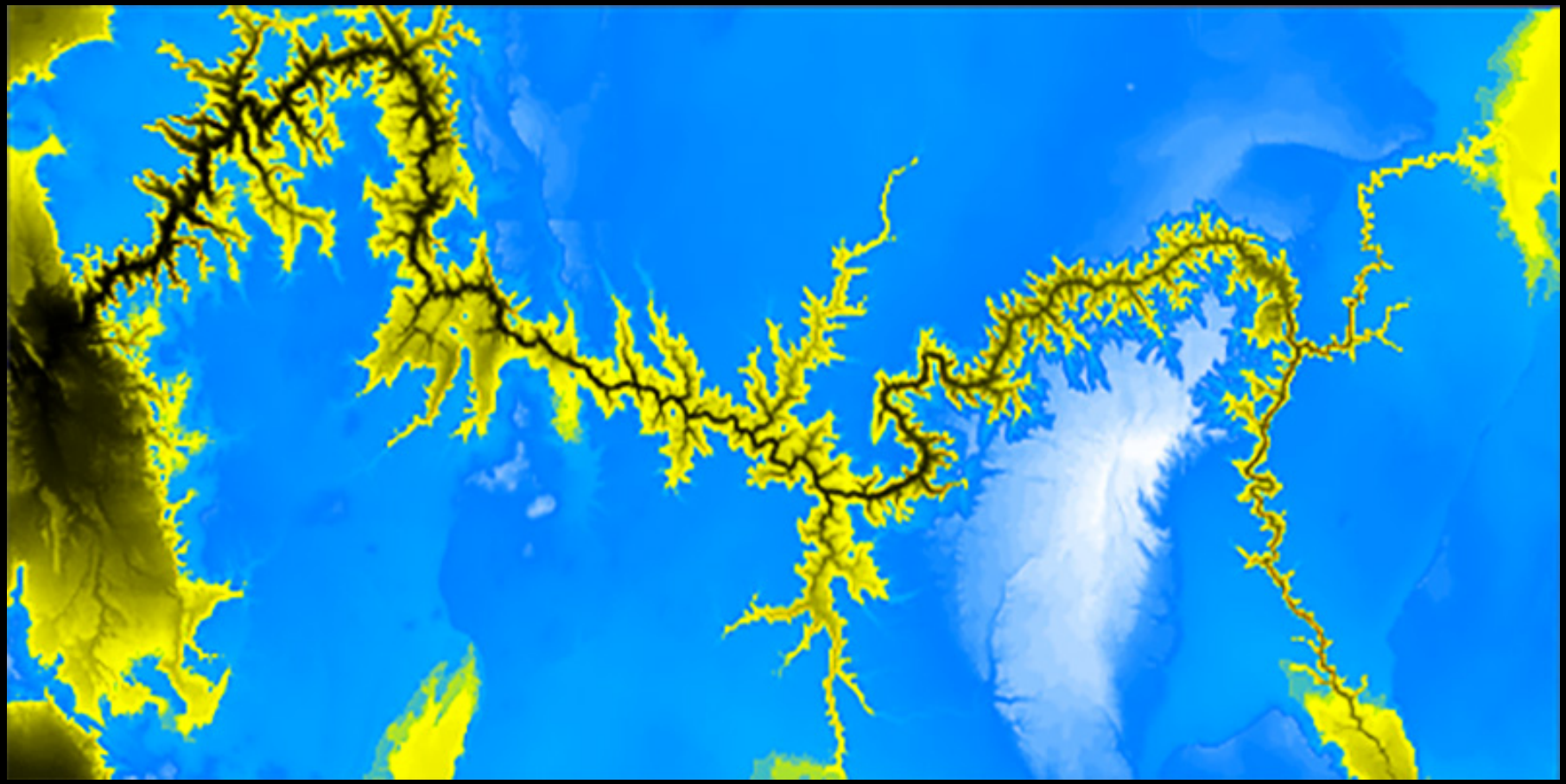
Transfer Functions

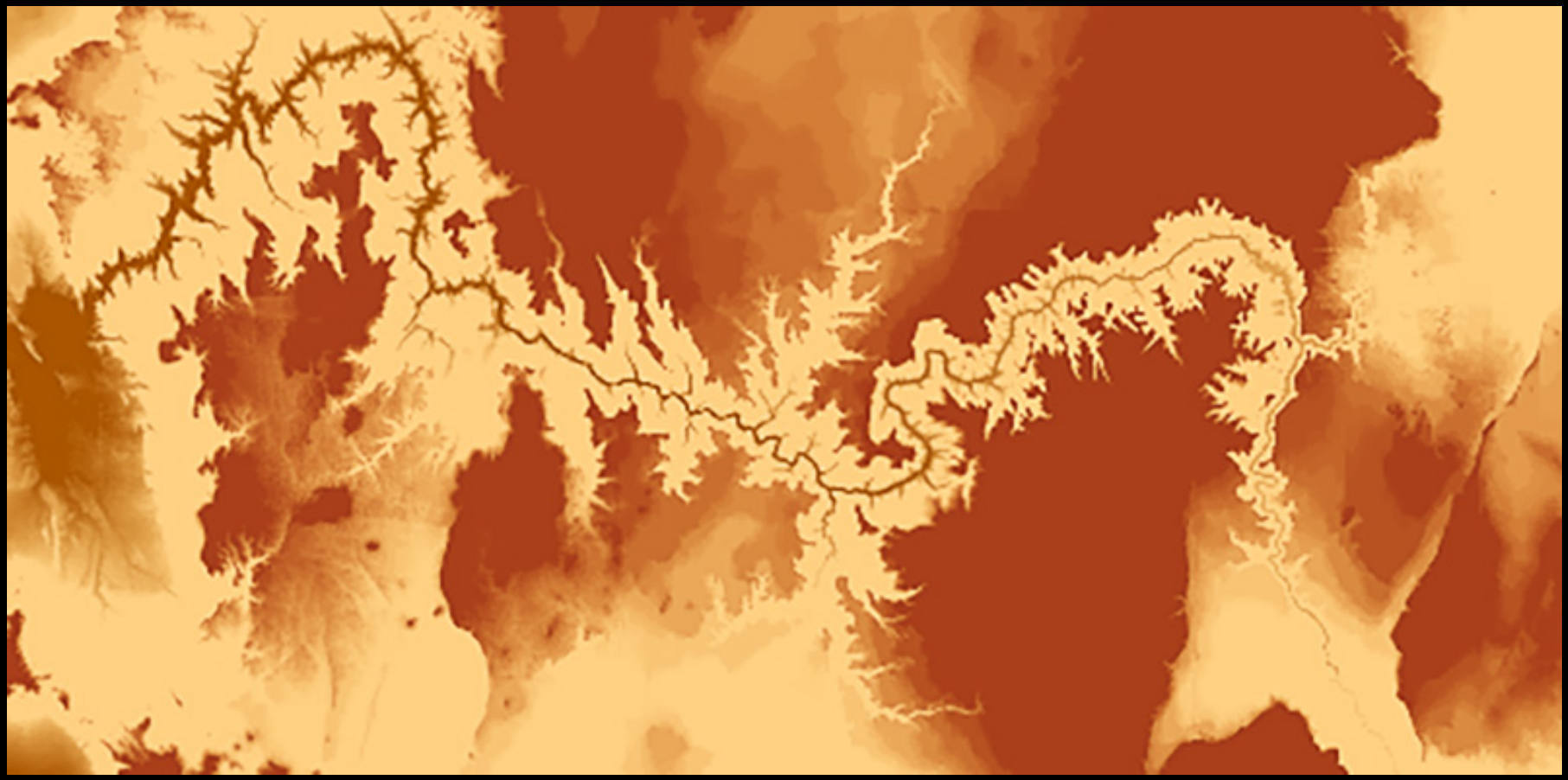
Paraview Demonstration

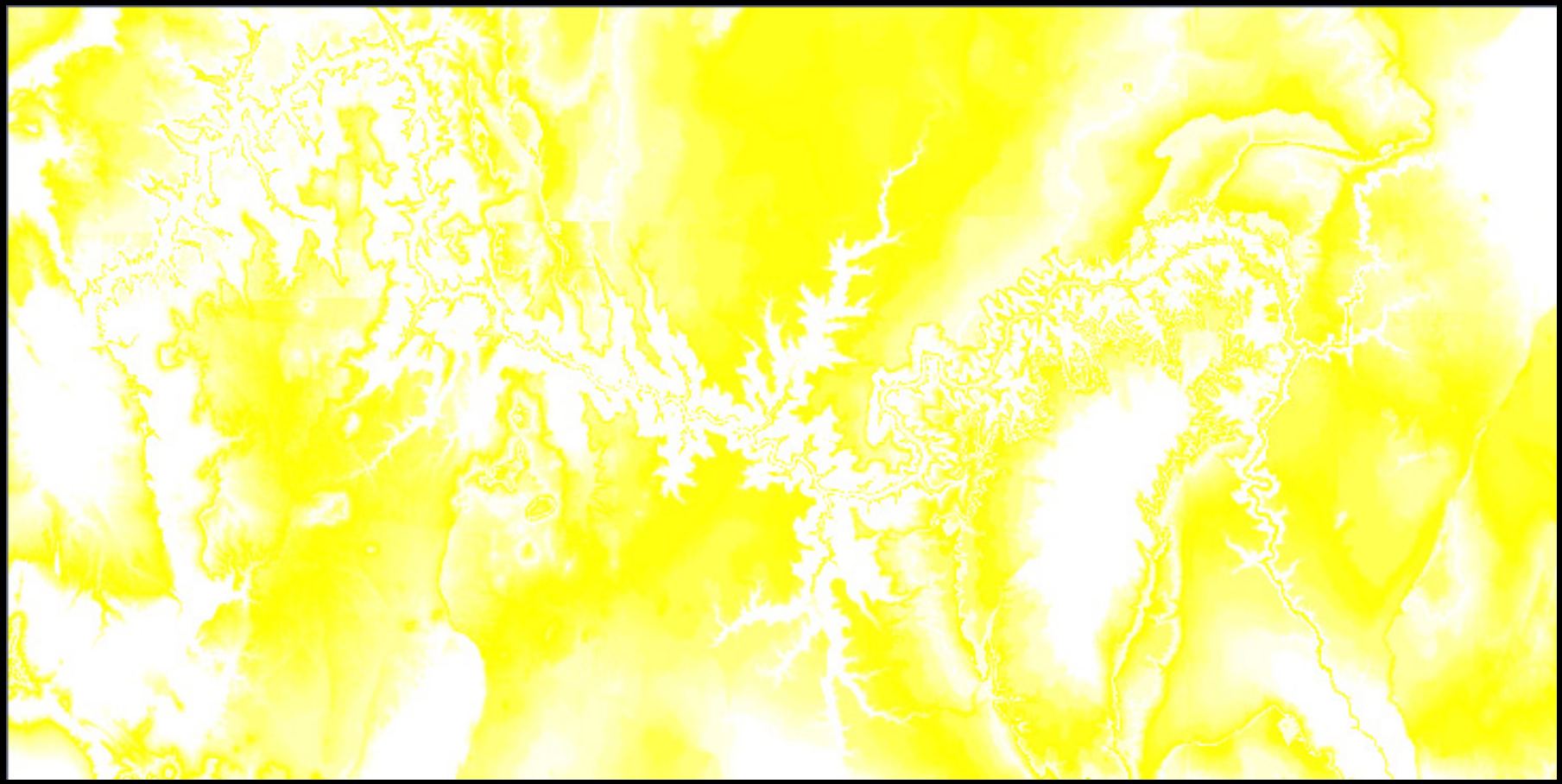
Credit for following images to previous SciViz class and workshop students

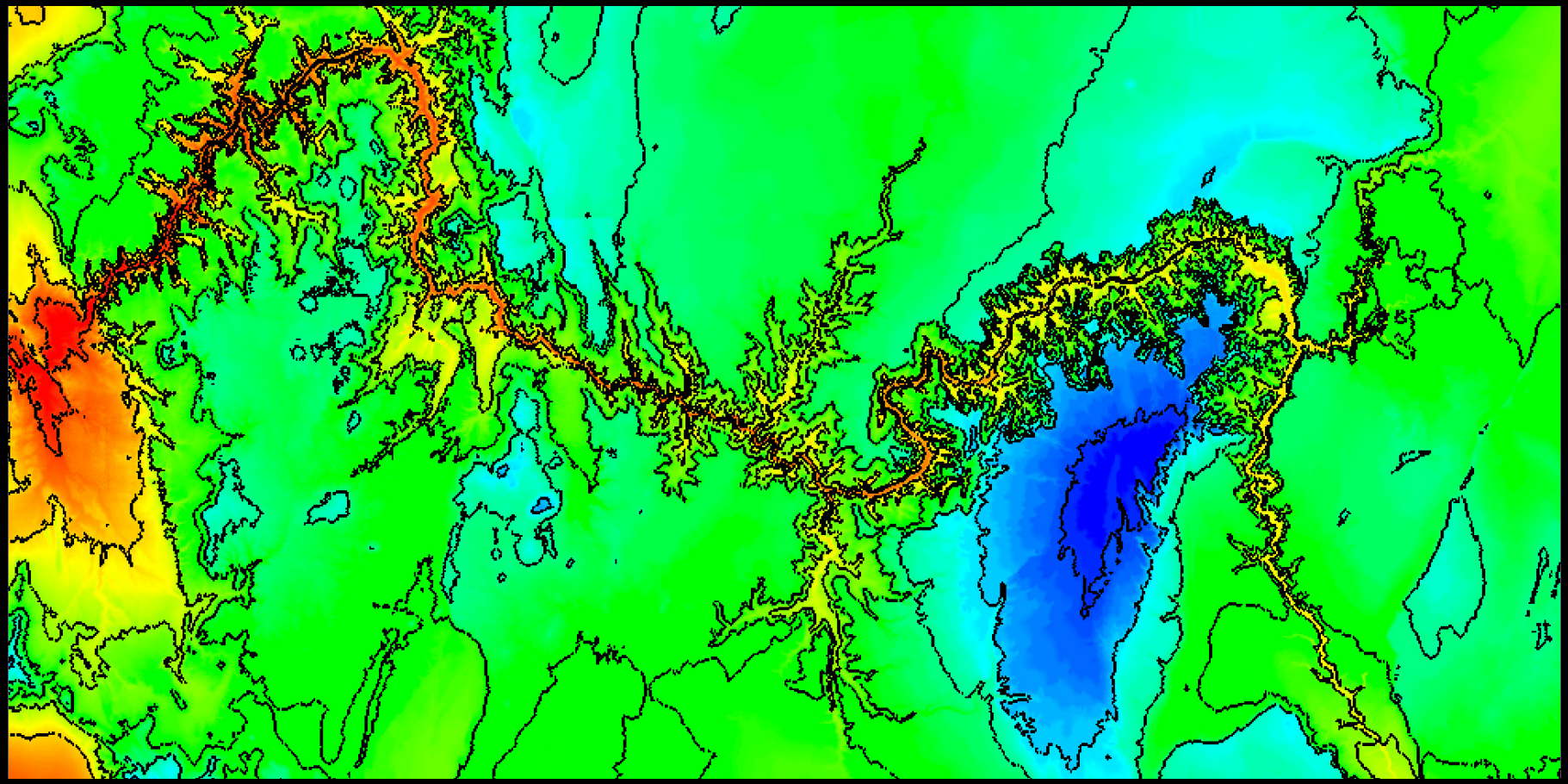




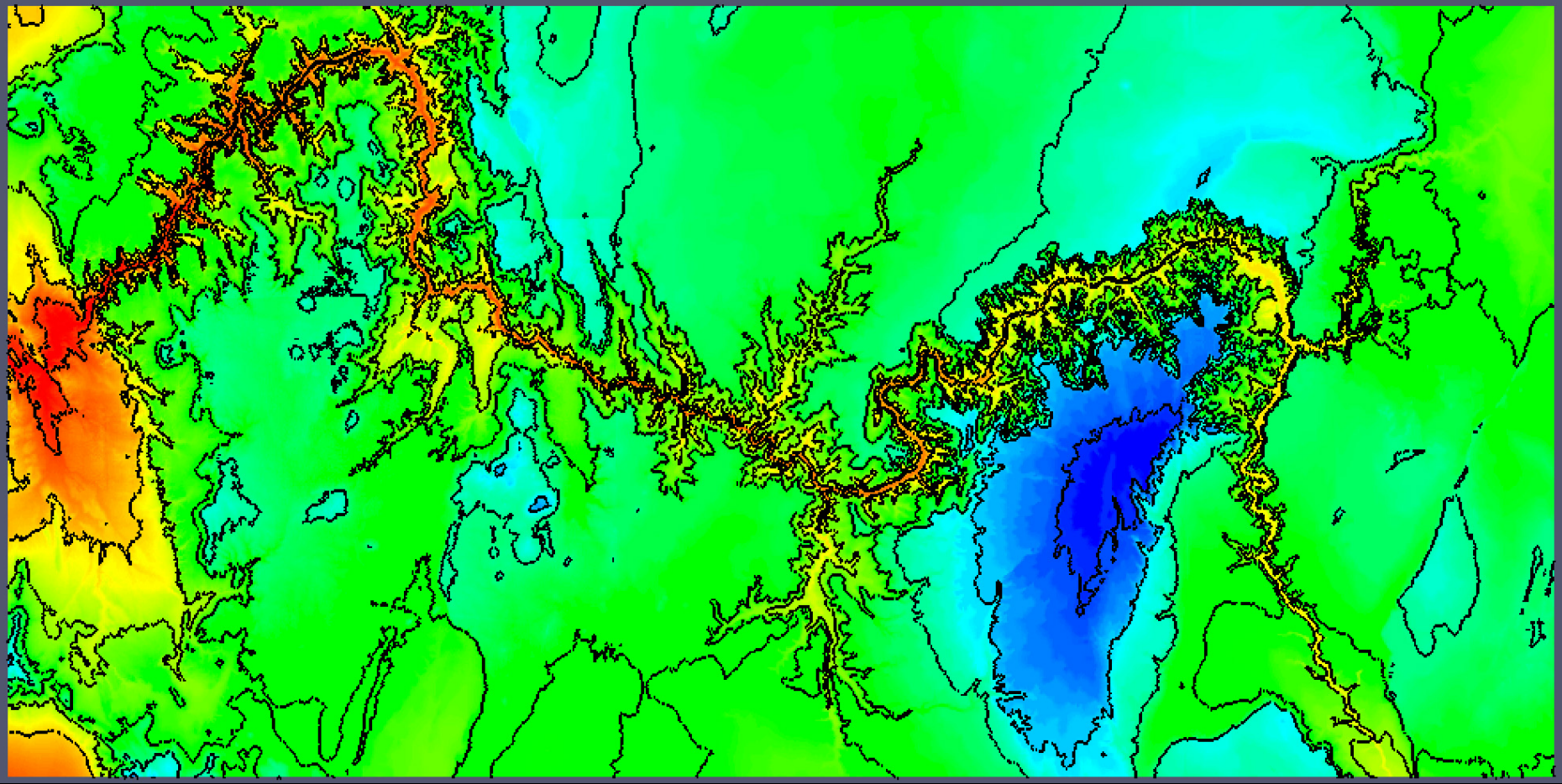




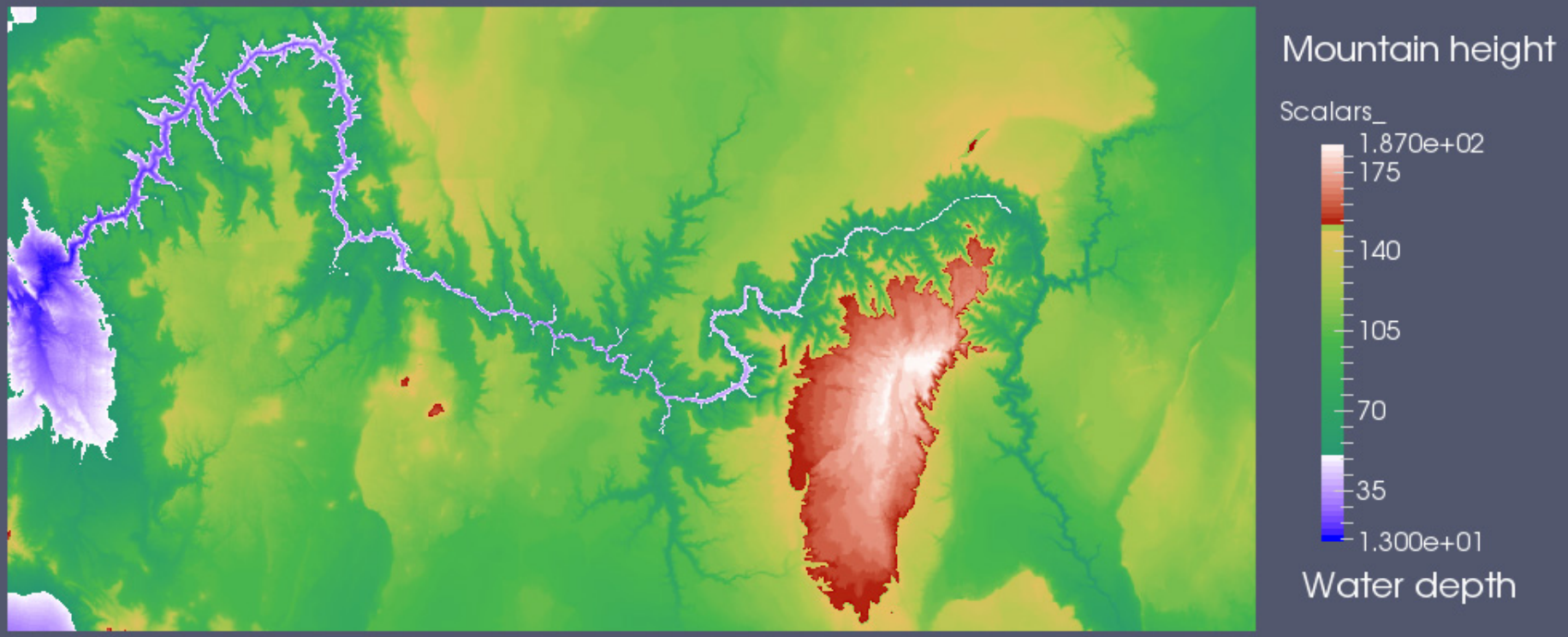


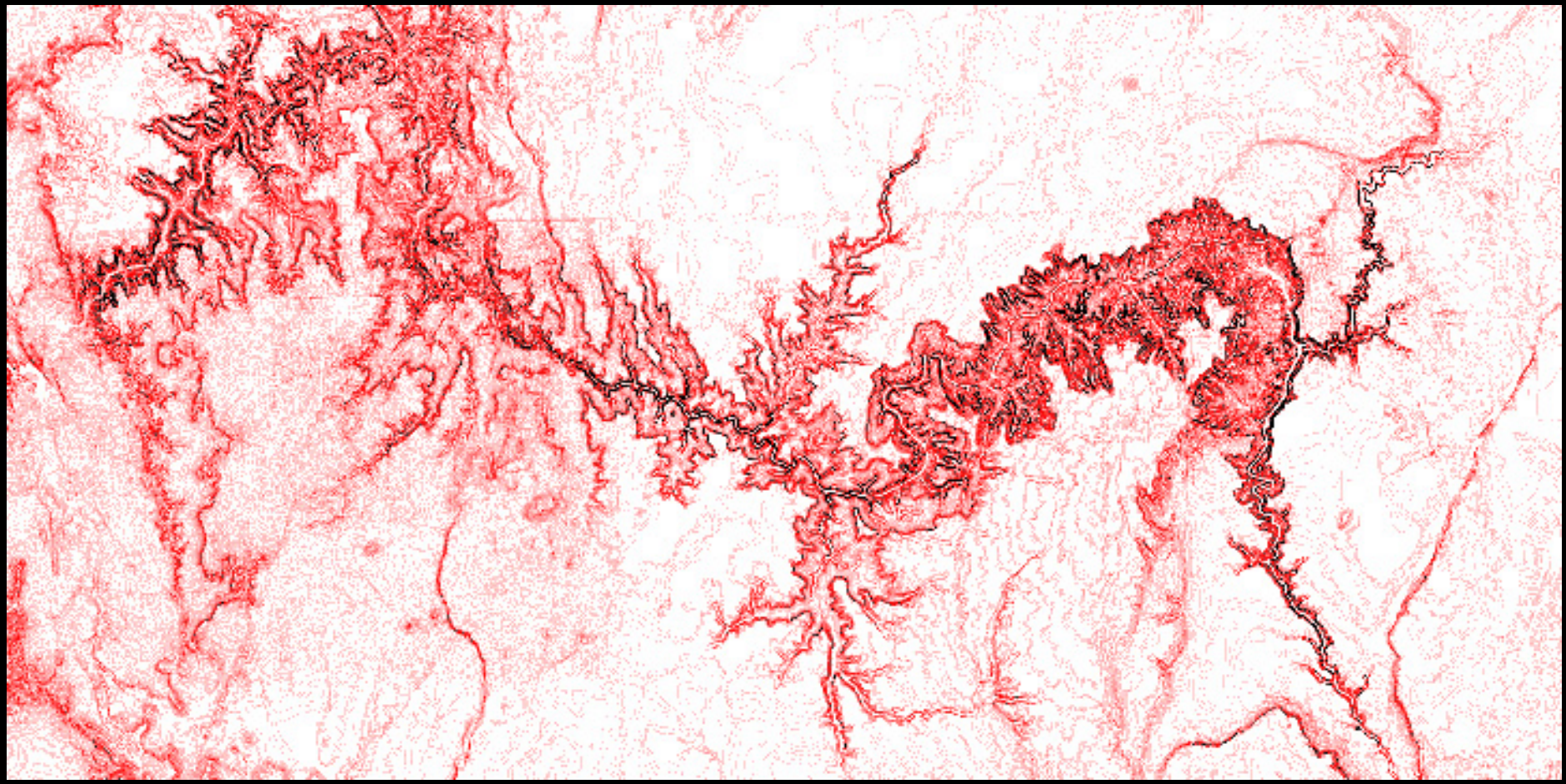


Mucho Mucho Grande Can Yone - Temperature Heat Hiking Guide Map

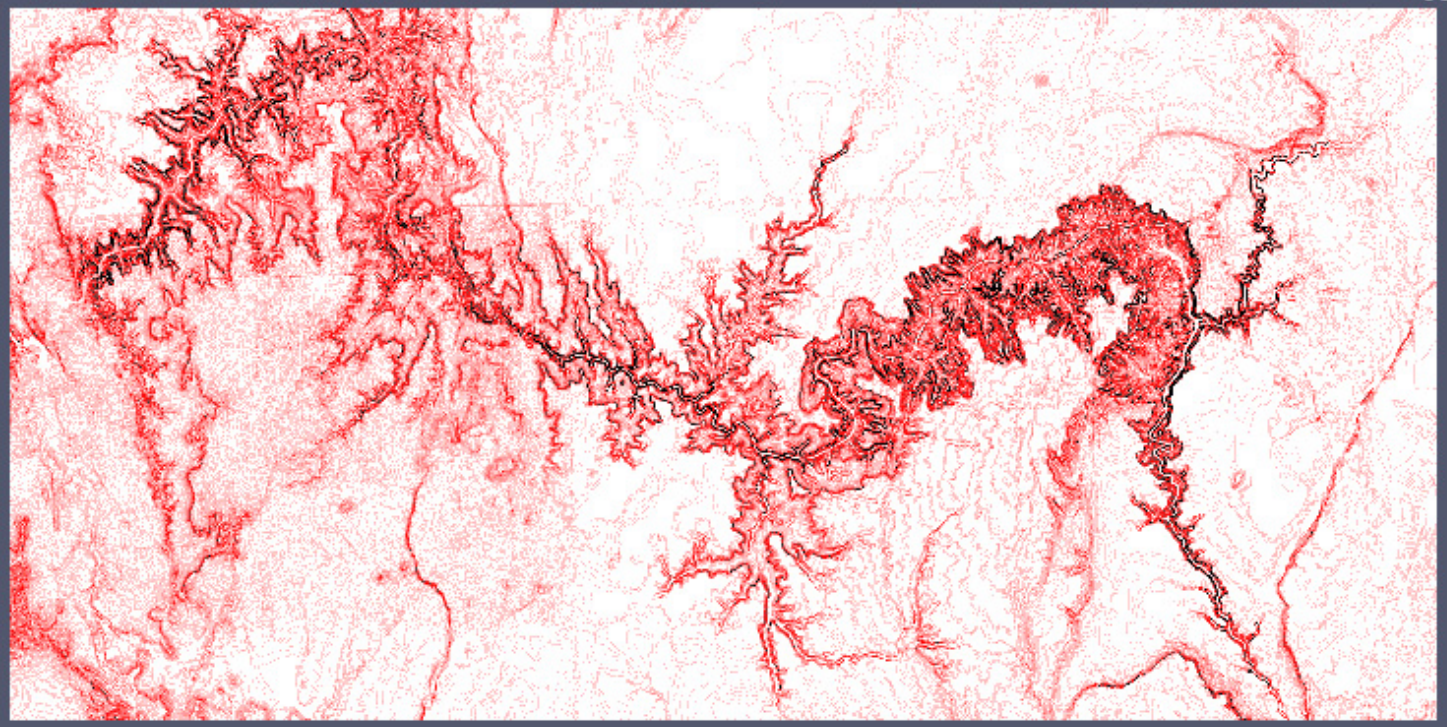


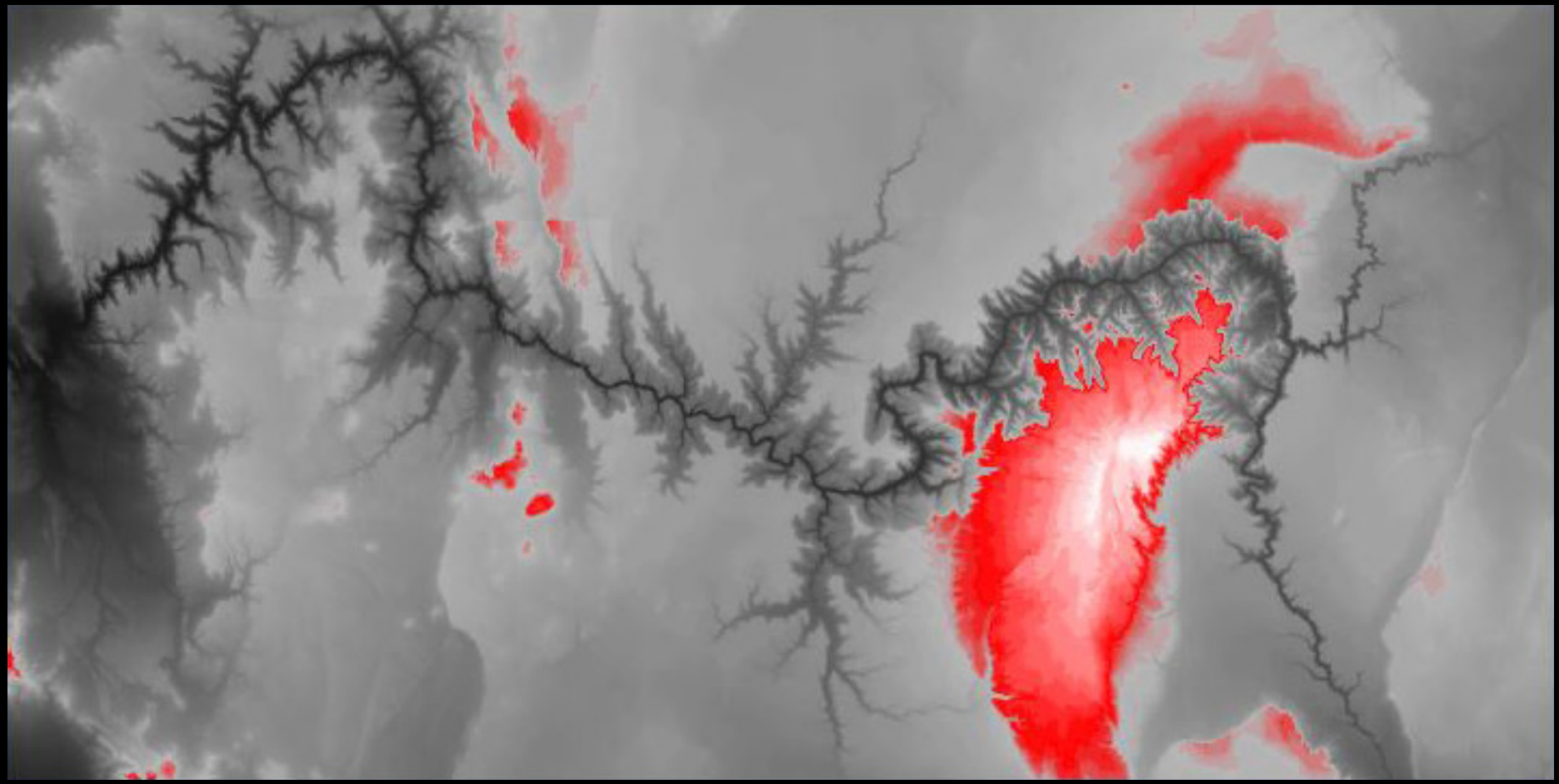
This is a canyon

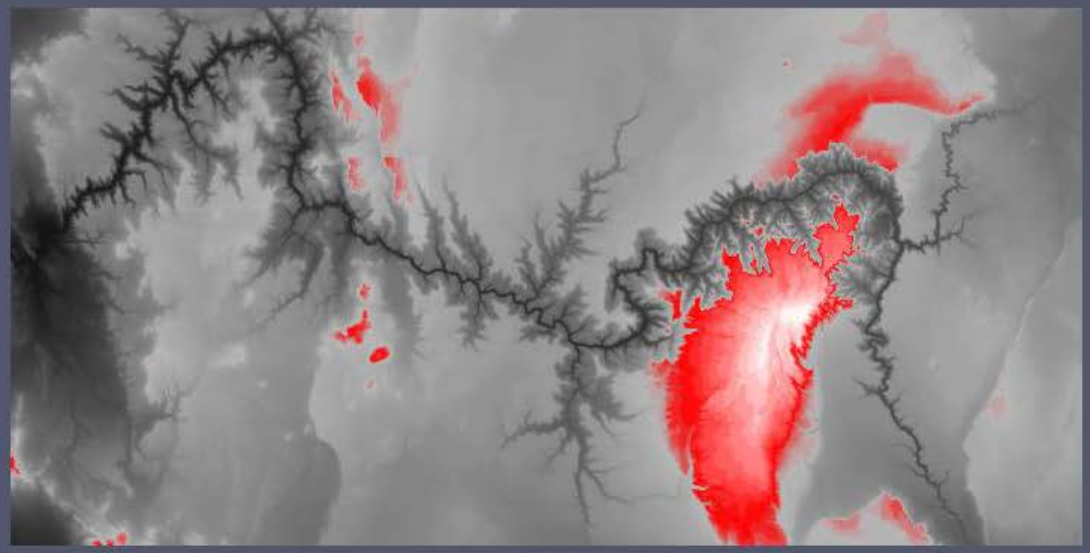




Magnitude of the Slope Vector







Save the American Pika! These areas highlighted in red represent the natural high-mountain habitat of the American Pika. It's adapted to temperatures well below freezing and can even die in temperatures as mild as 78 degrees Fahrenheit.

Questions?