

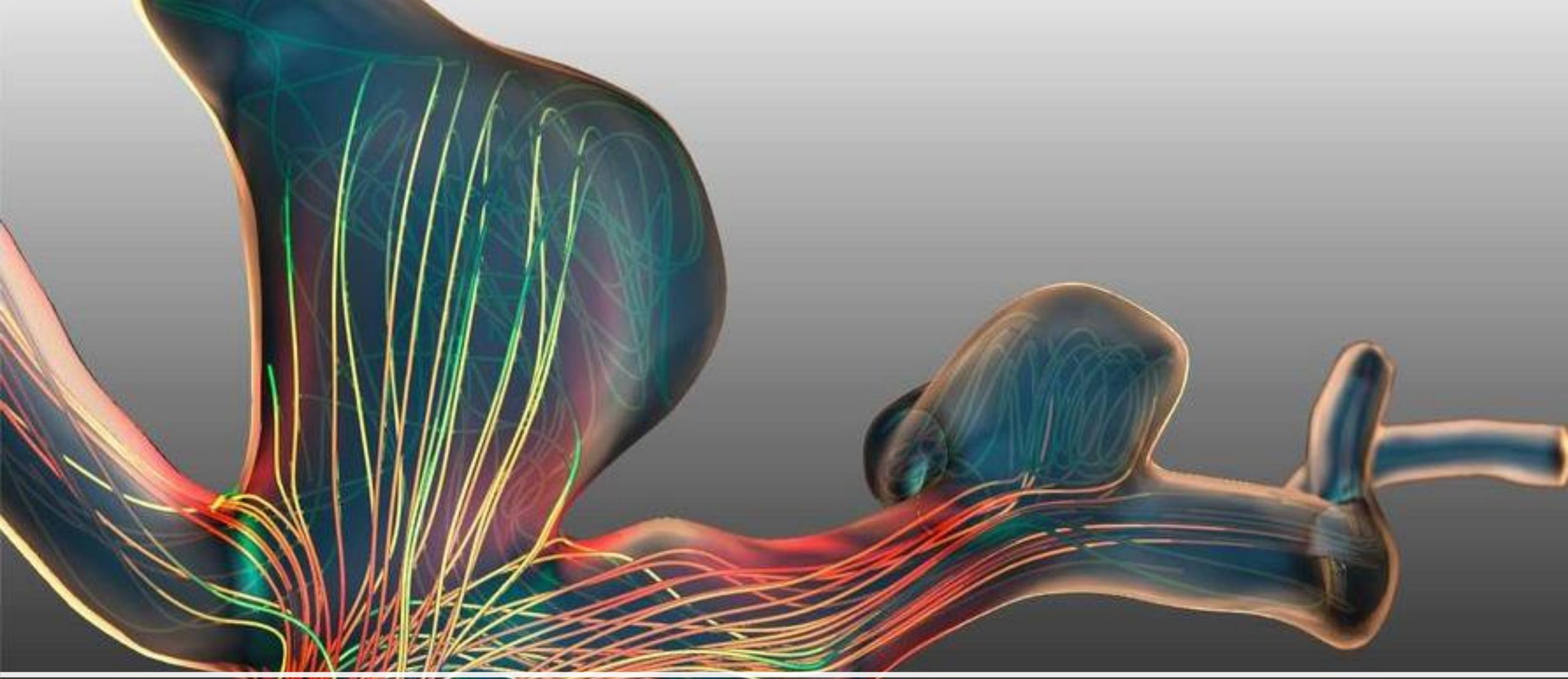
Visualization

- Introduction

J.-Prof. Dr. habil. Kai Lawonn

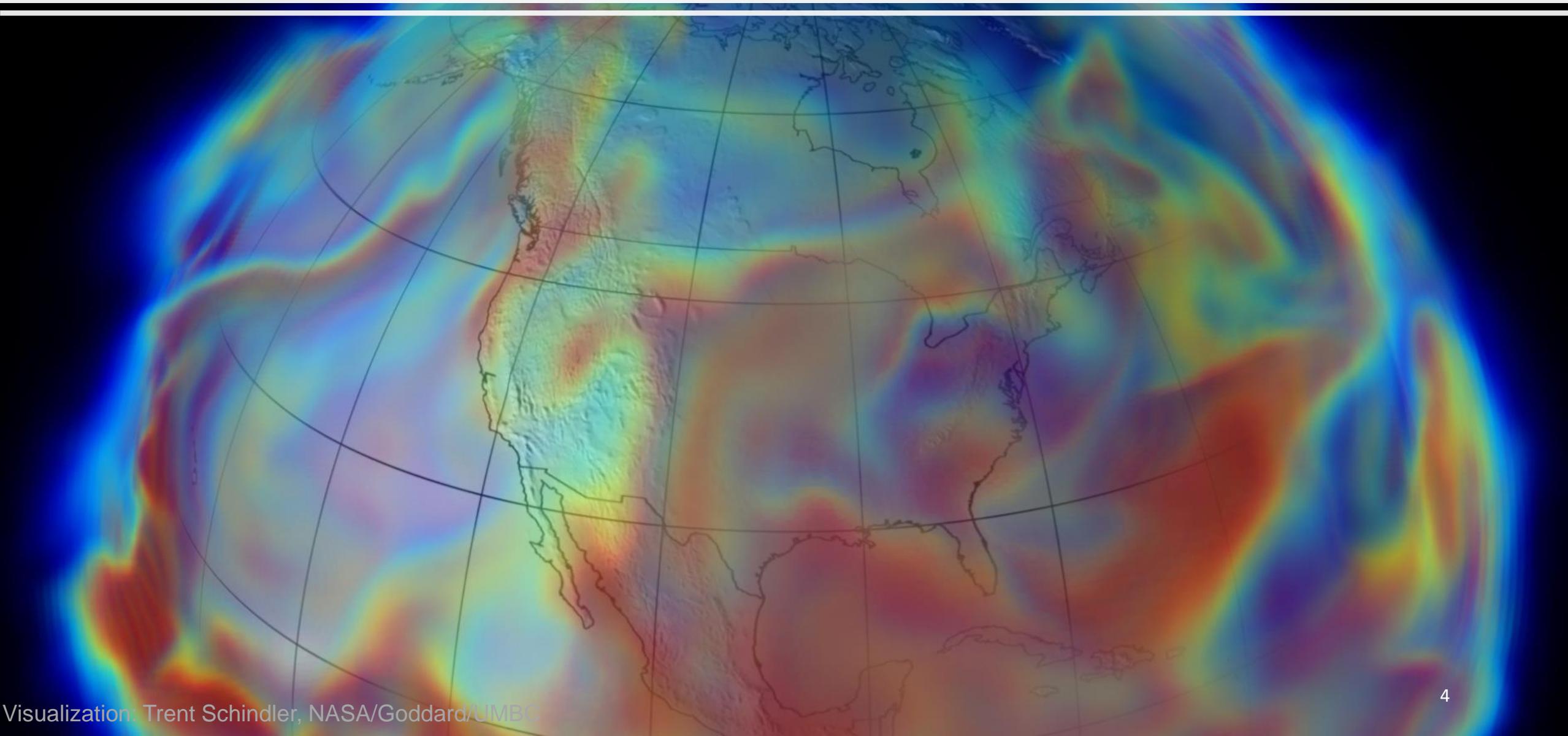
Data are everywhere...

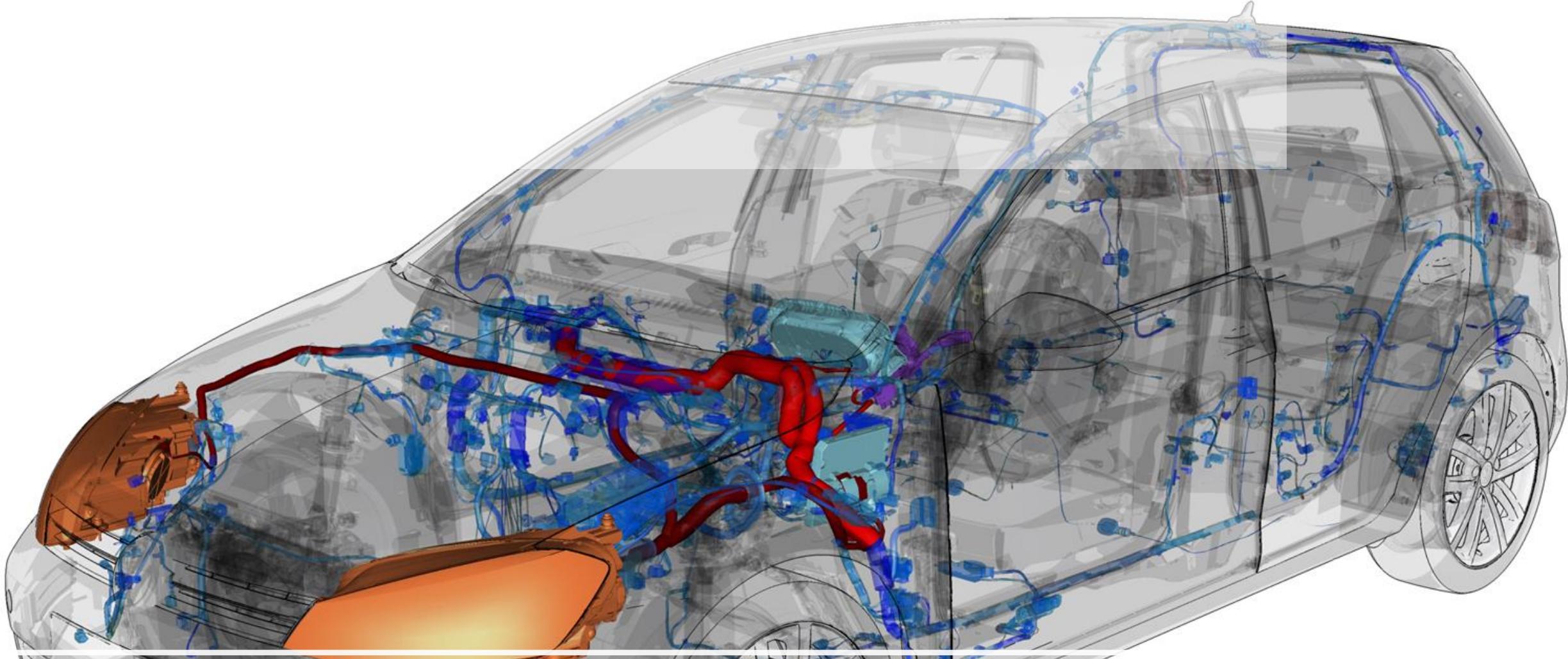
- ... and they are large



Medicine

Climate Simulations





Automotive Engineering

Cohrs et al.: A Methodology for Interactive Spatial Visualization of
Automotive Function Architectures for Development and Maintenance

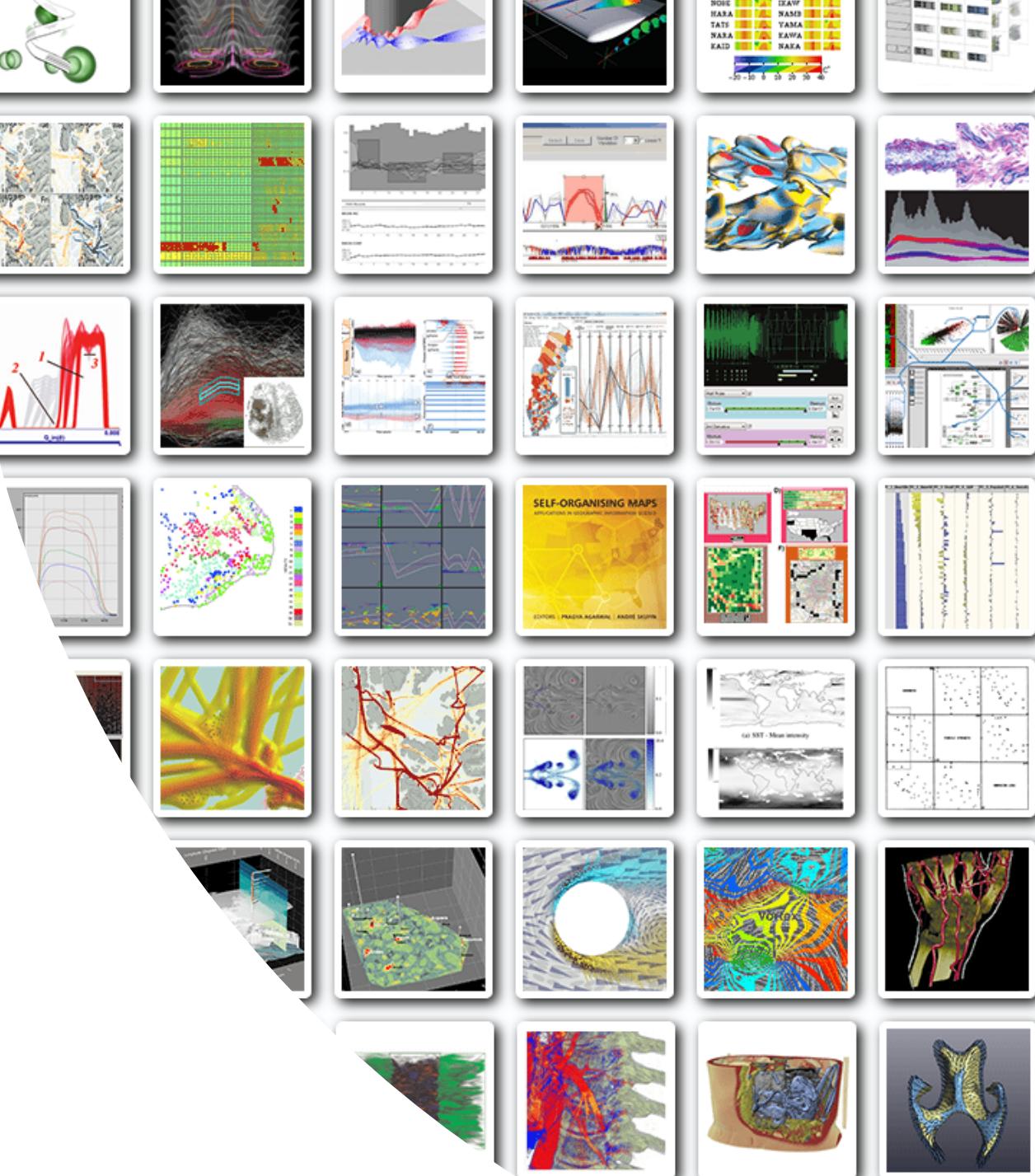
Social Data



Visualization

- **to vis·u·al·ize:**
to form a **mental vision, image, or picture** of (something not visible or present to sight, or of an abstraction);

to make **visible to the mind or imagination**.



[Oxford English Dictionary]



Visualization – Examples

Virtual fetoscopy (4D Ultrasound)

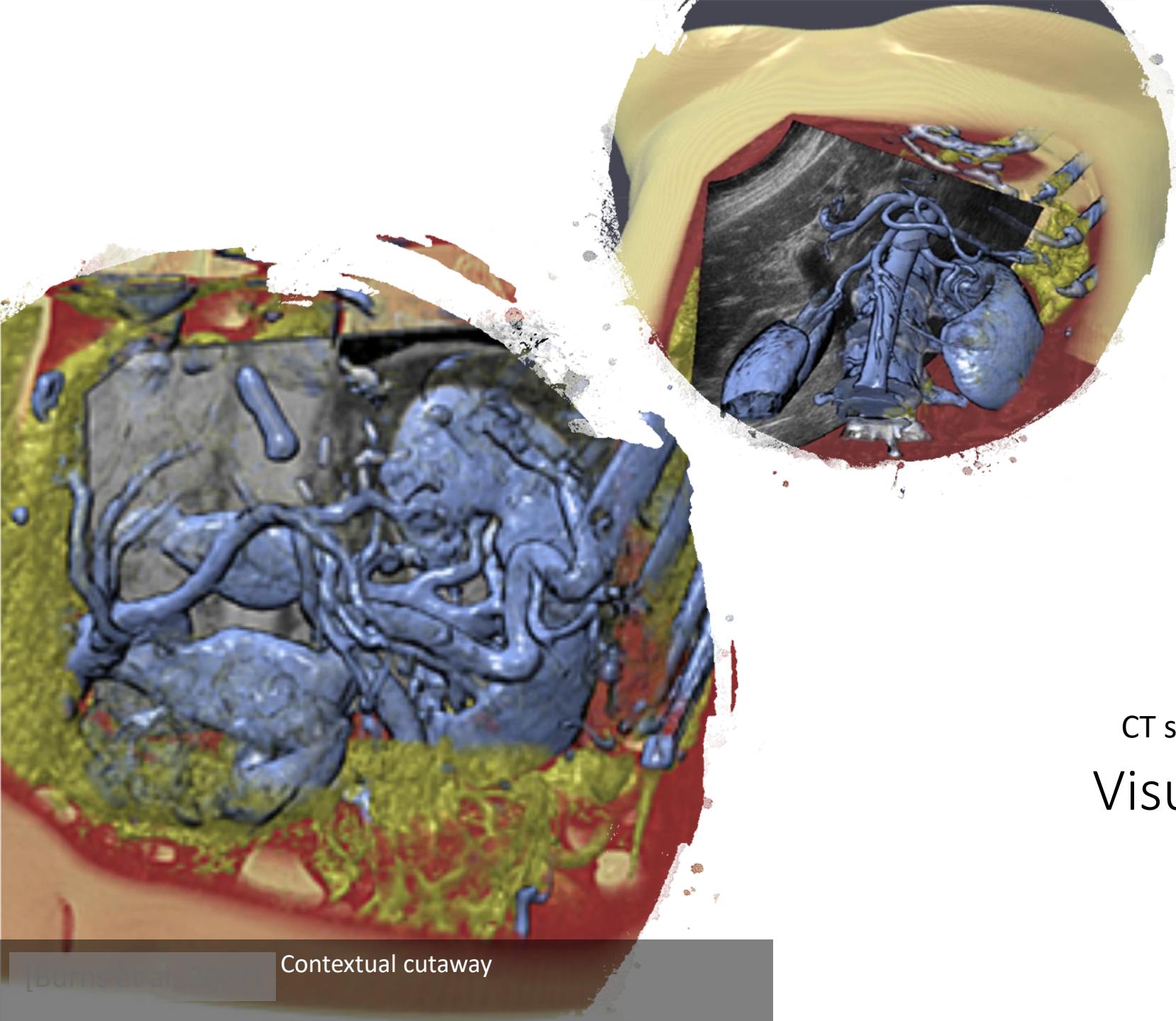
Visualization – Examples

- Virtual fetoscopy (4D Ultrasound)
 - Enhance clinical confidence
 - User interest & involvement



Visualization – Examples

- Preoperative planning of a tumor resection
 - Black/white: brain – Magnetic Resonance Imaging (MRI)
 - Green: tumor – MRI
 - Red: vessels – Magnetic Resonance Angiogram (MRA)
 - Brown: skull – Computer Tomography (CT)



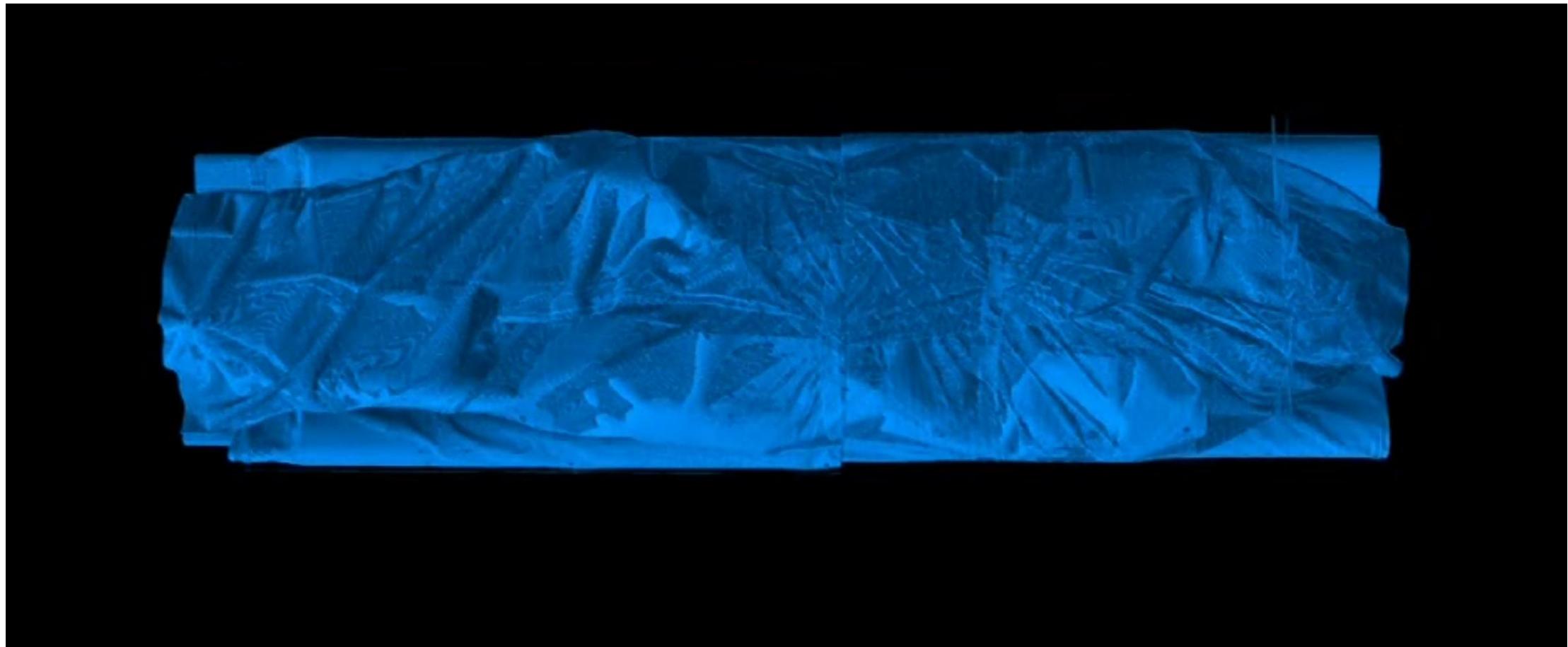
Contextual cutaway



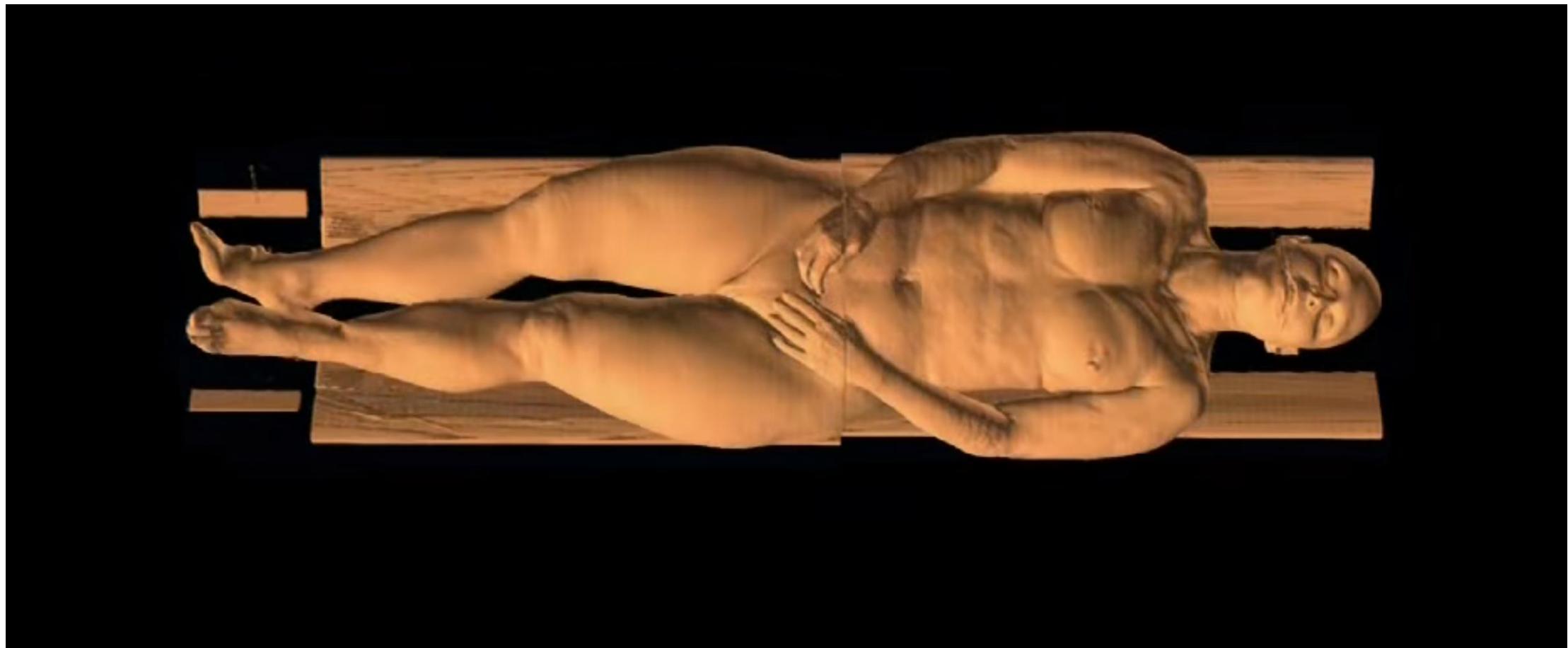
Traditional cutaway

CT scan with embedded Ultrasound data
Visualization – Examples

Visualization – Examples



Visualization – Examples



Visualization – Examples



Visualization – Examples

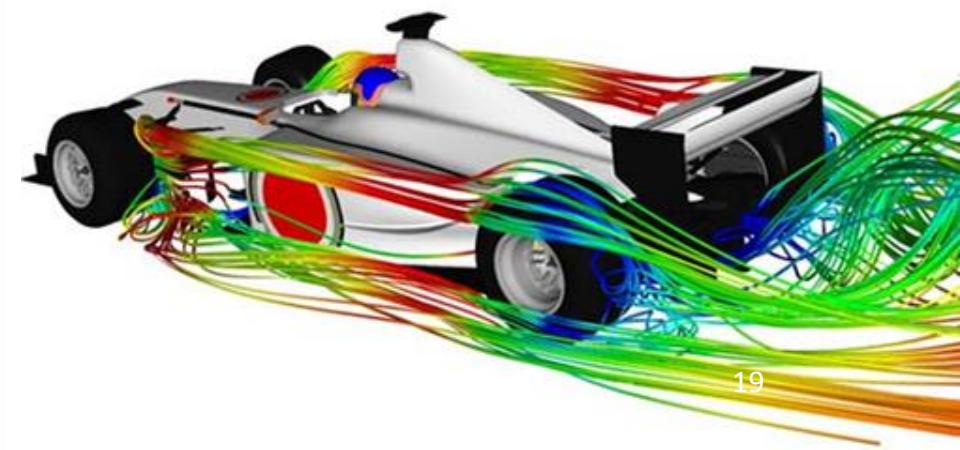
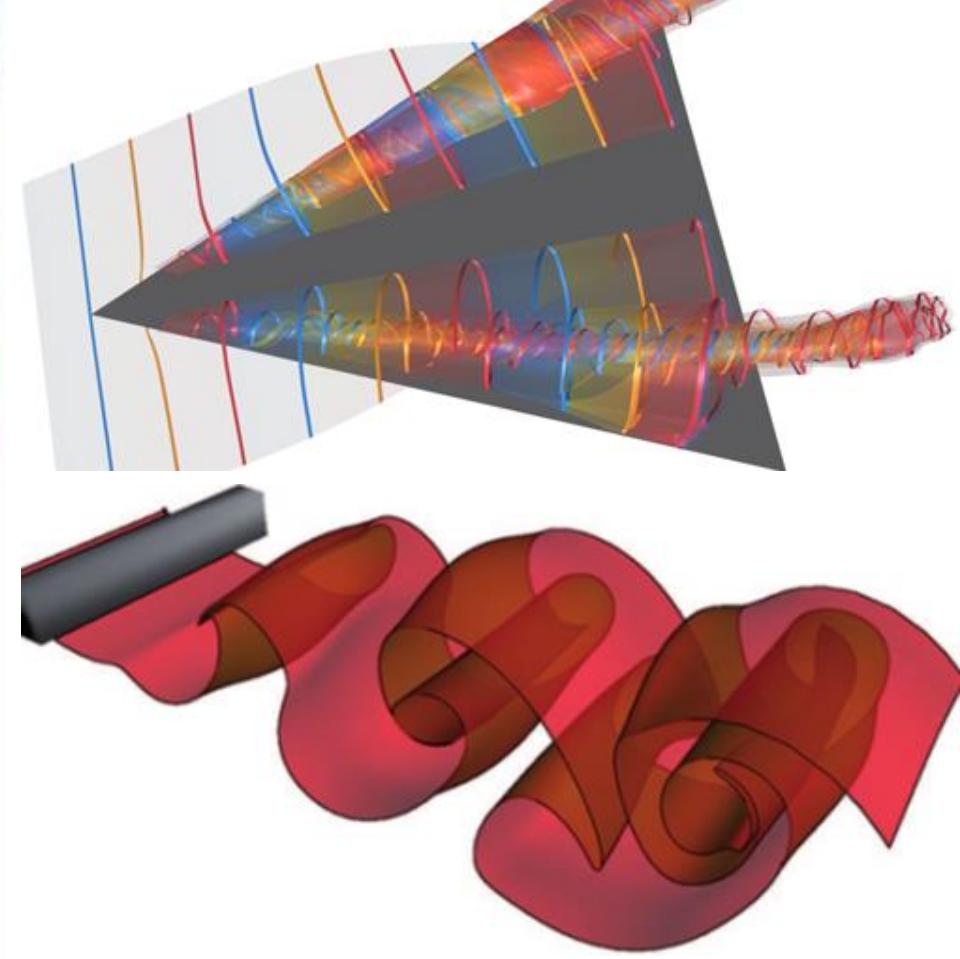
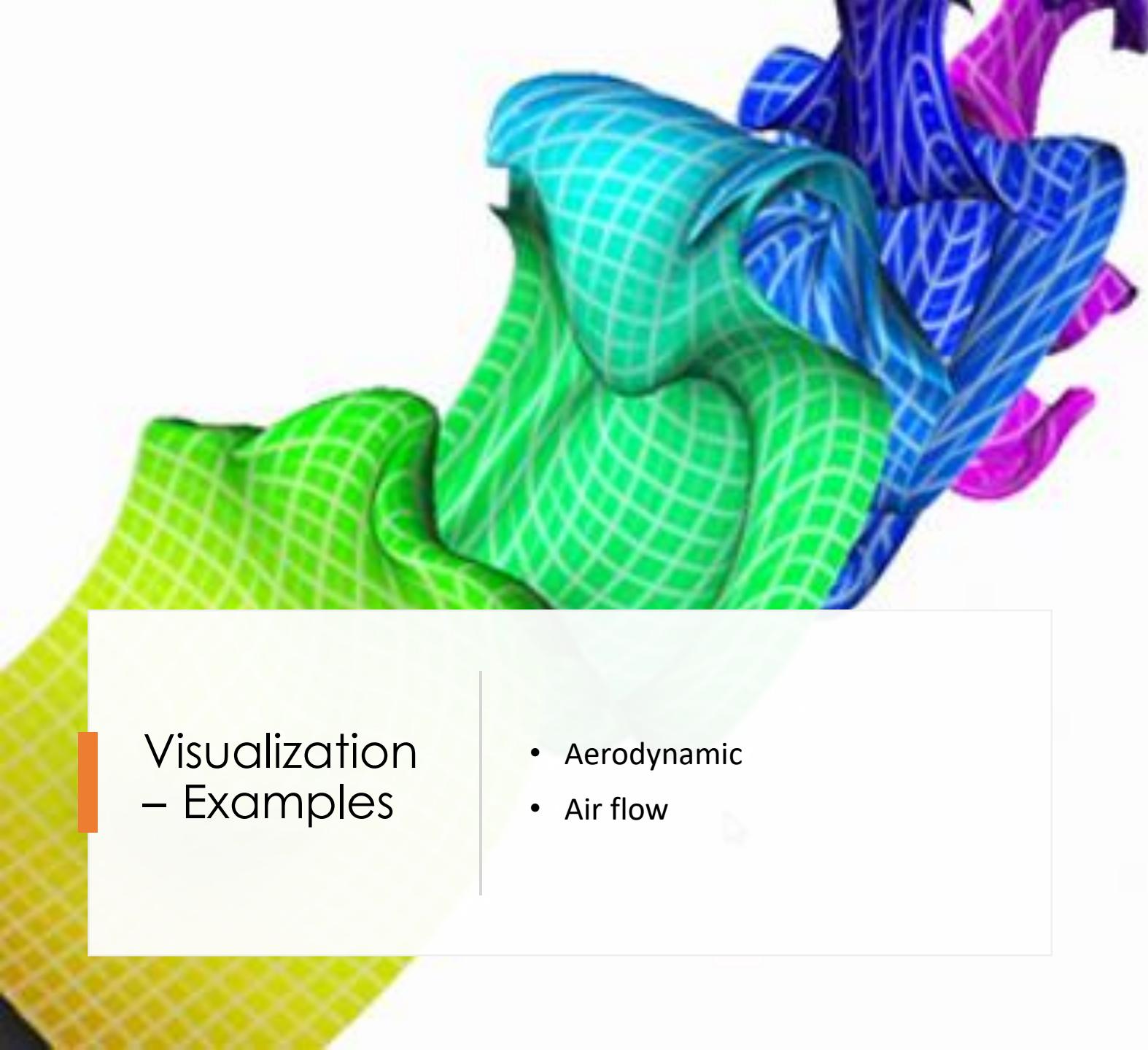


Visualization – Examples

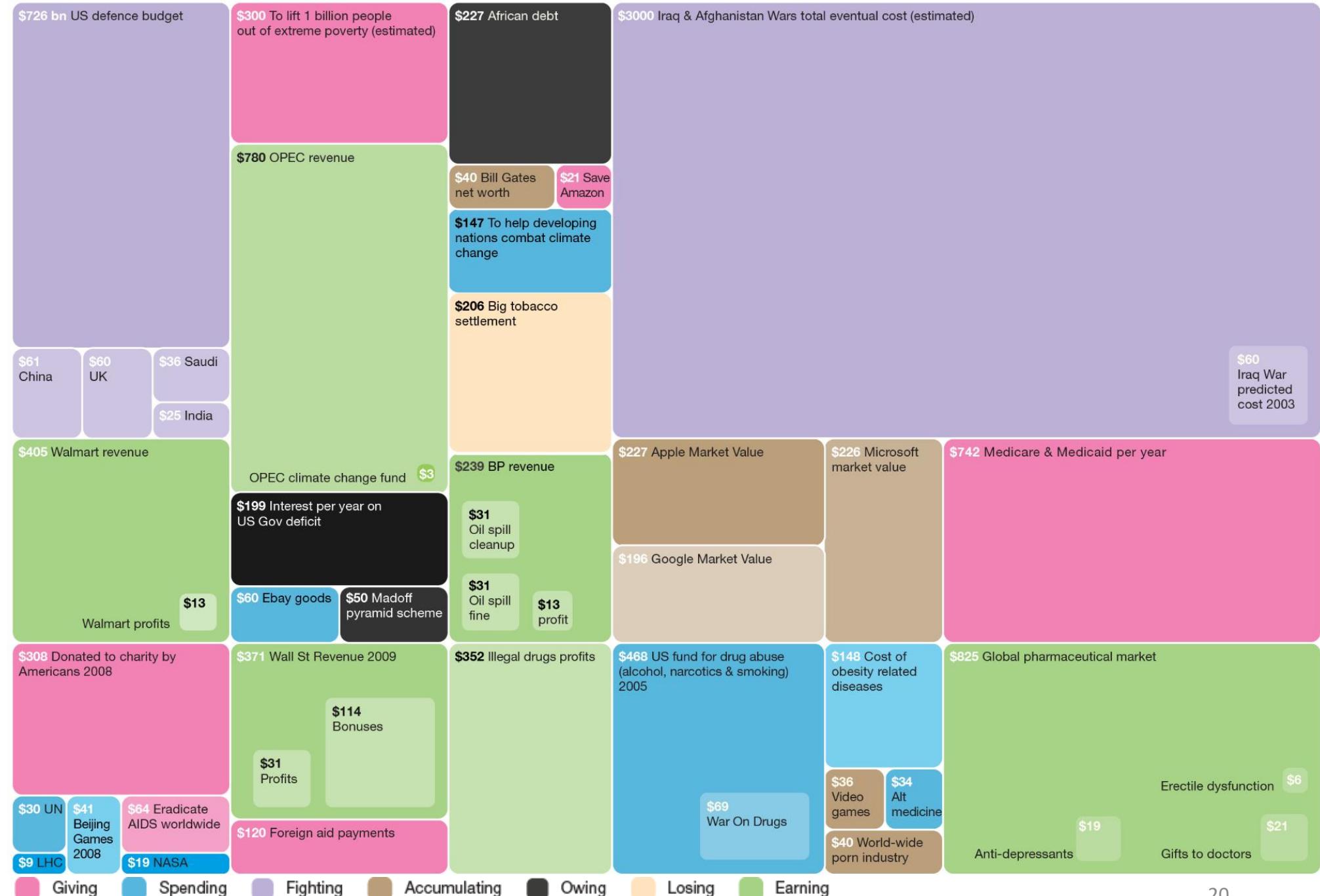


Visualization – Examples

- Aerodynamic
- Air flow



The Billion Dollar-o-Gram (2009)

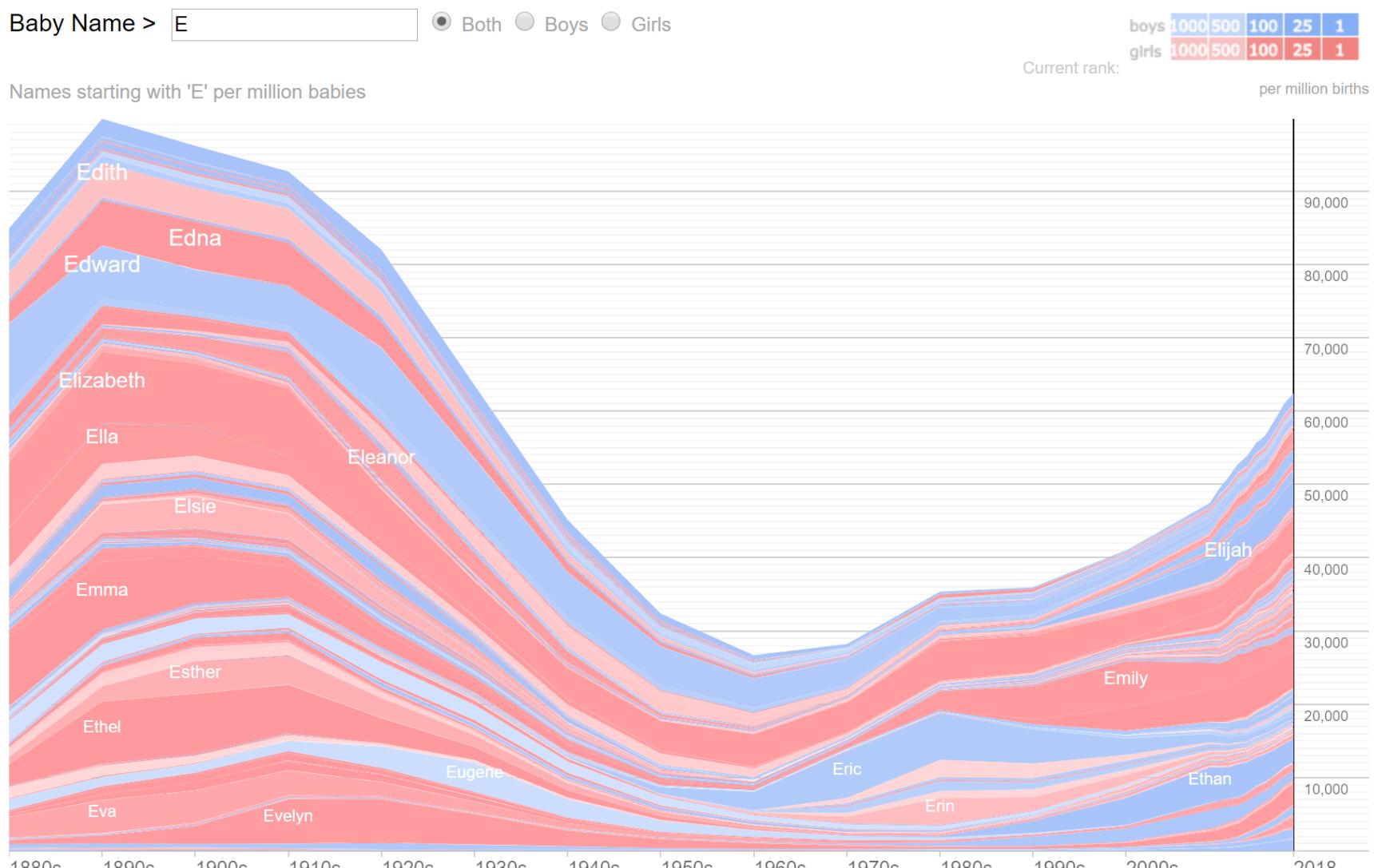


Visualization – Examples

2018

1. Olivia
 2. Ava
 3. Isabella

1. Liam
2. Noah
3. William



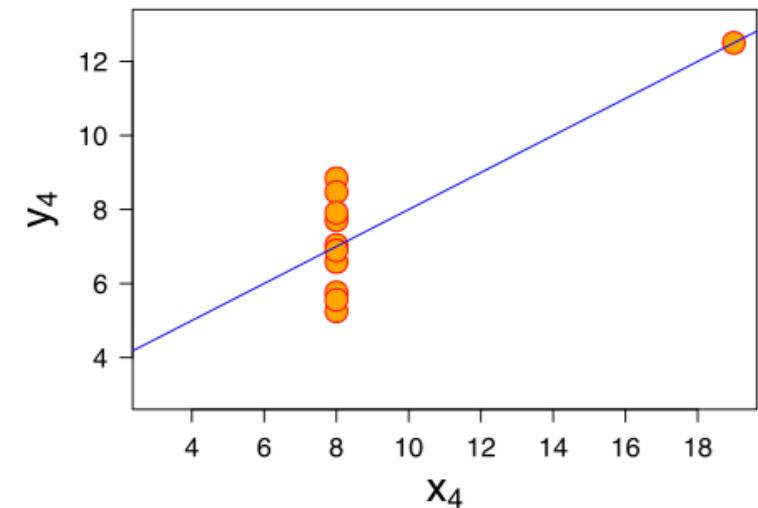
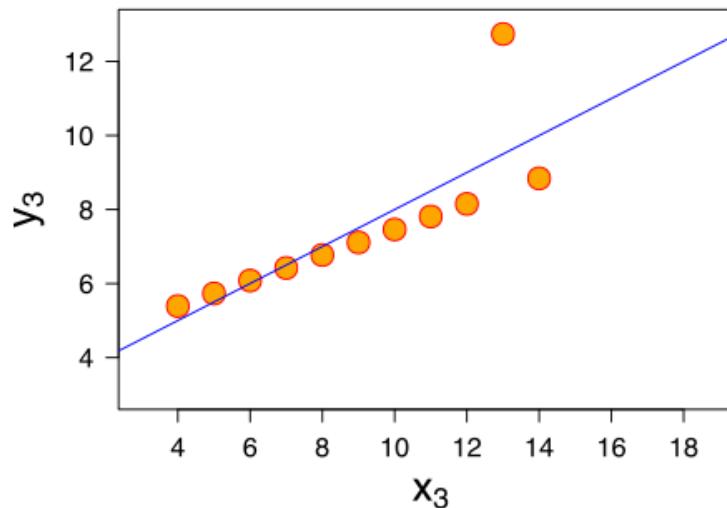
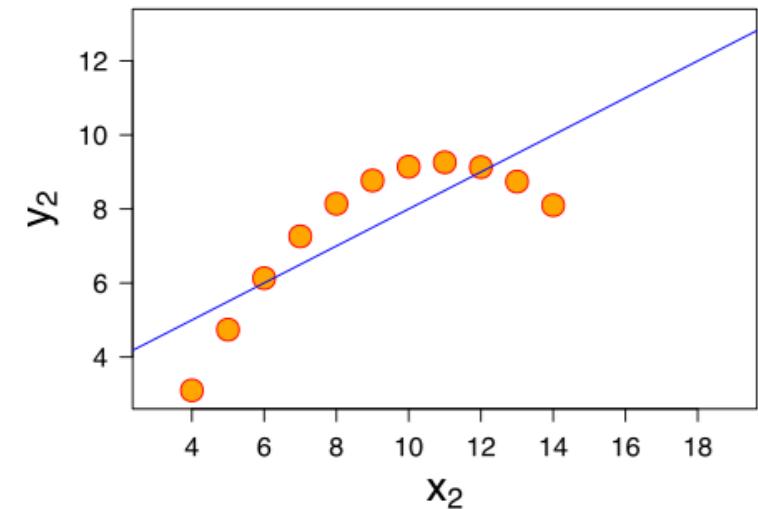
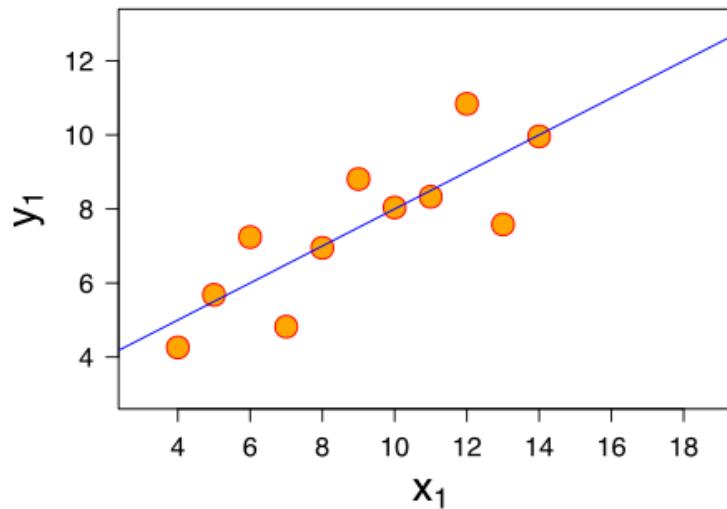
Why Visualization?

- Same mean, std dev, Pearson correlation, linear regression !

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

Why Visualization?

- Same mean, std dev, Pearson correlation, linear regression !



Why Visualization?

“A picture is worth a thousand words”

“The purpose of visualization is **insight**, not pictures.”

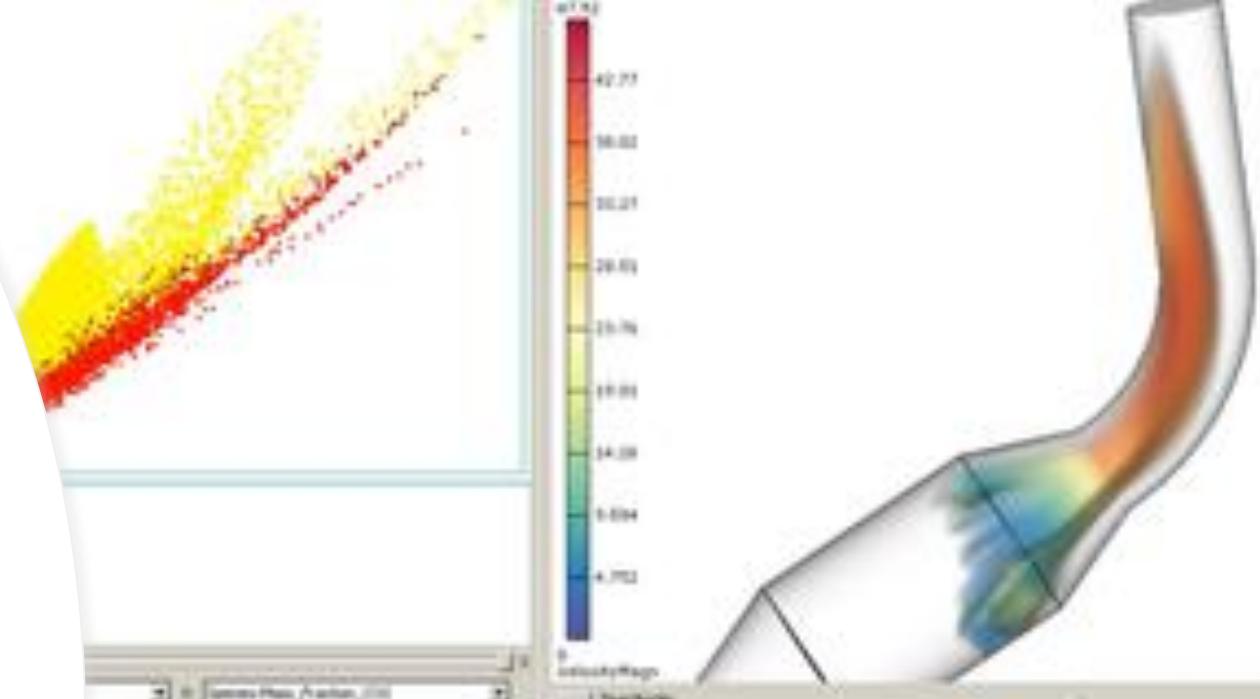
[B. Shneiderman]

- Vision is the dominant sense for acquiring information from our world
- Nearly 1/3 of our brain is devoted to processing visual information
(8% for touch, 3% for hearing)



Why Visualization Matters?

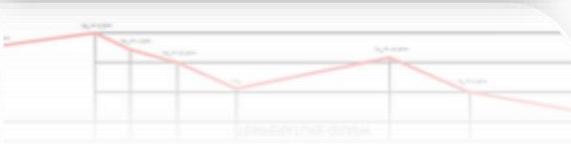
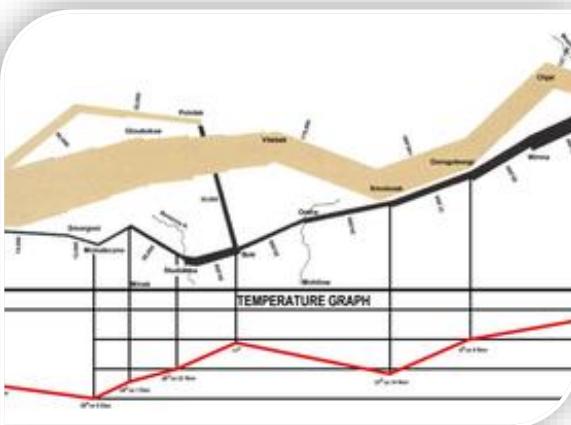
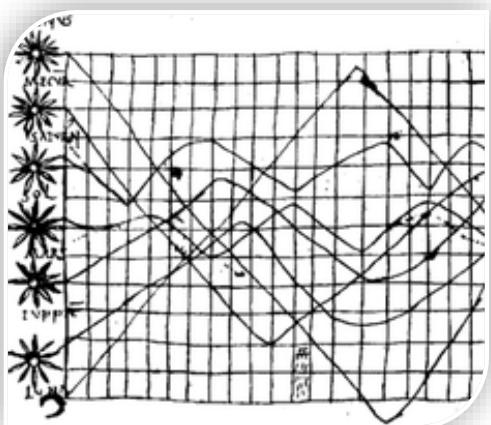
- Visualization ...
 - lets you see things that would rather go unnoticed (data trends, outliers, dependencies, etc.)
 - gives answers faster
 - lets you interact with your data, study causes and effects, etc.
 - helps to deal with increasing size and diversity of data
 - produces pretty, informative, & interactive pictures



History

History

- Techniques for finding visual representations of (abstract) data are not new!



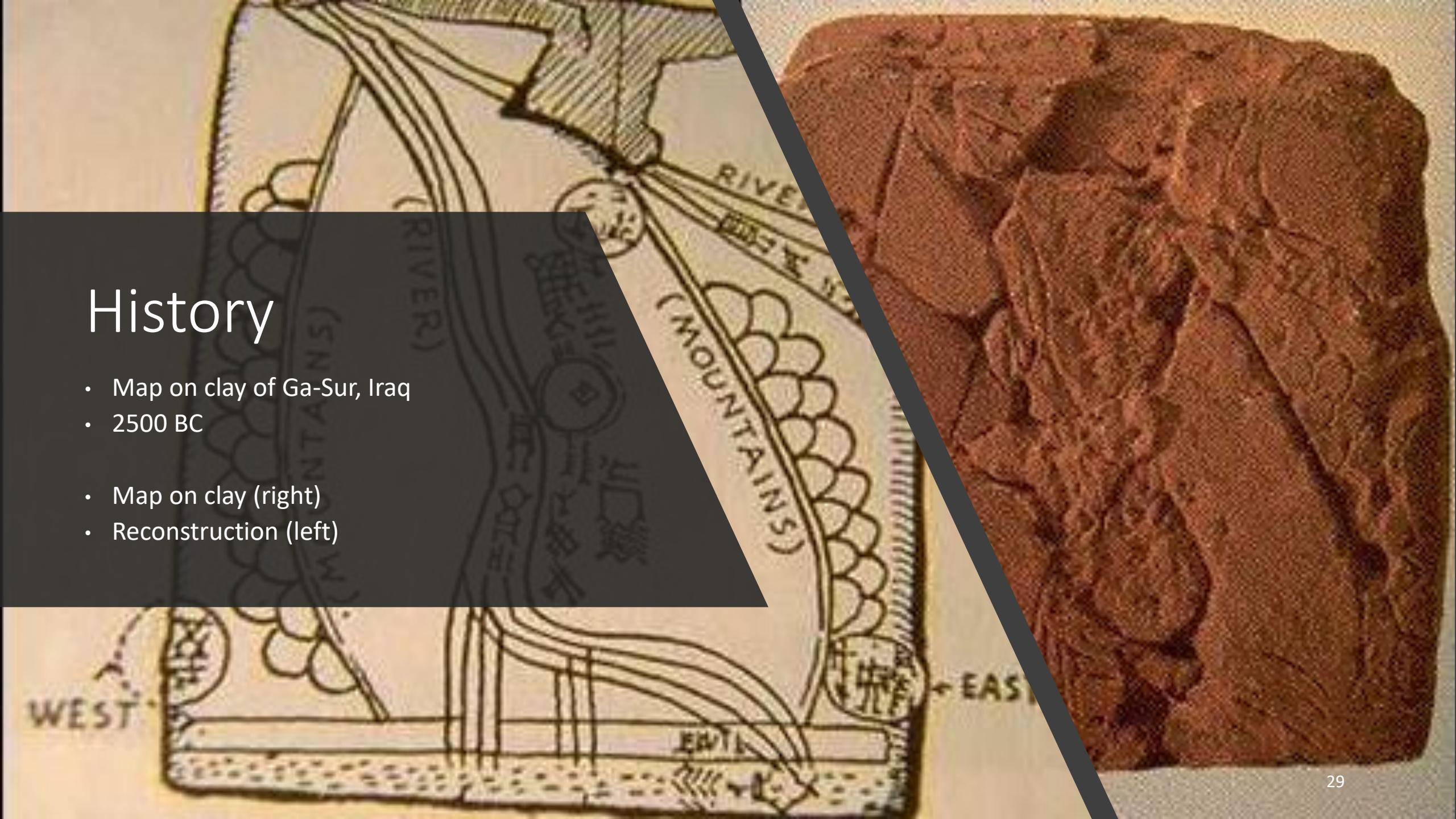
History

- (Oldest) Map of Catal Hyük,
- Turkey 6200 BC
- Excavation

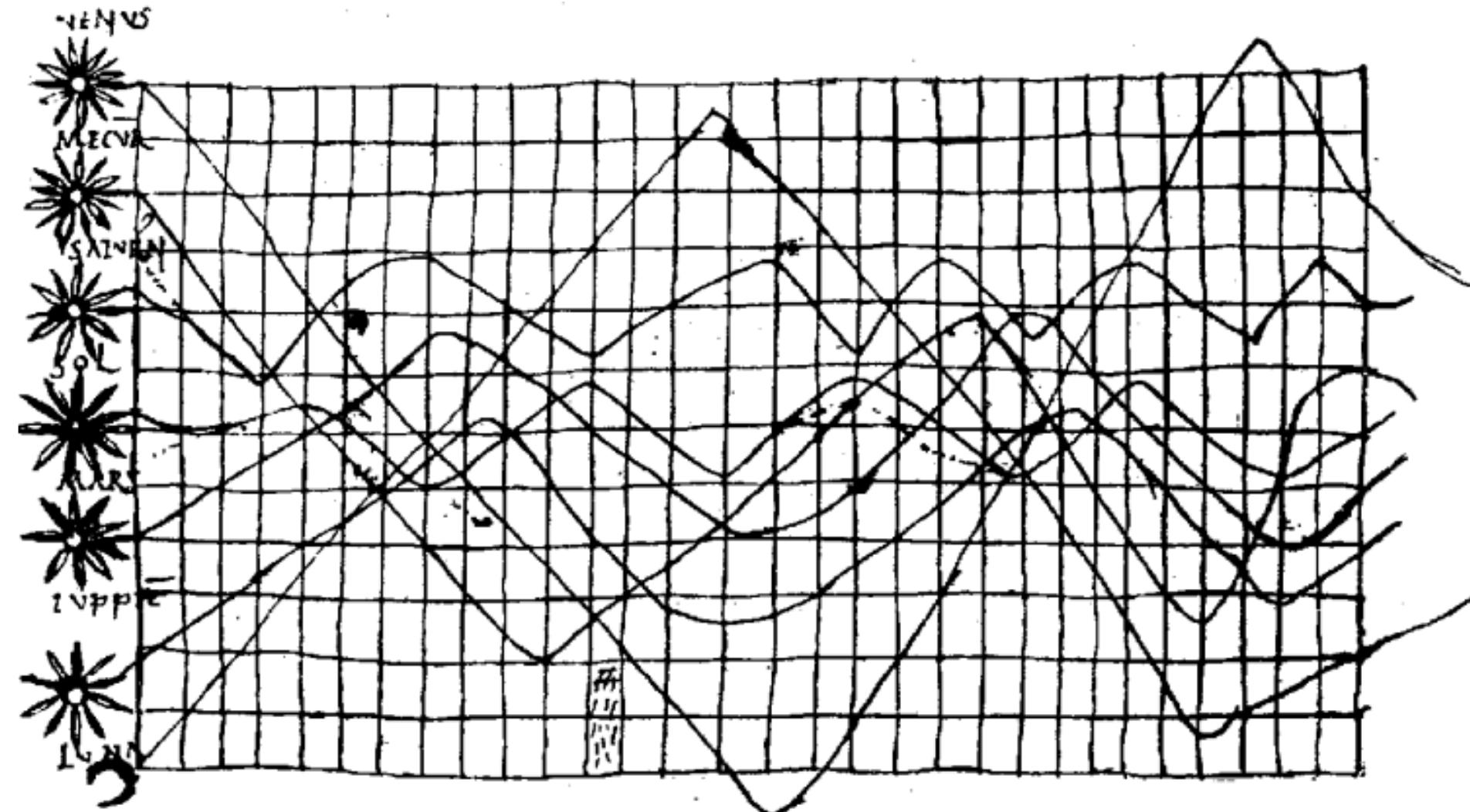


History

- Map on clay of Ga-Sur, Iraq
- 2500 BC
- Map on clay (right)
- Reconstruction (left)



History

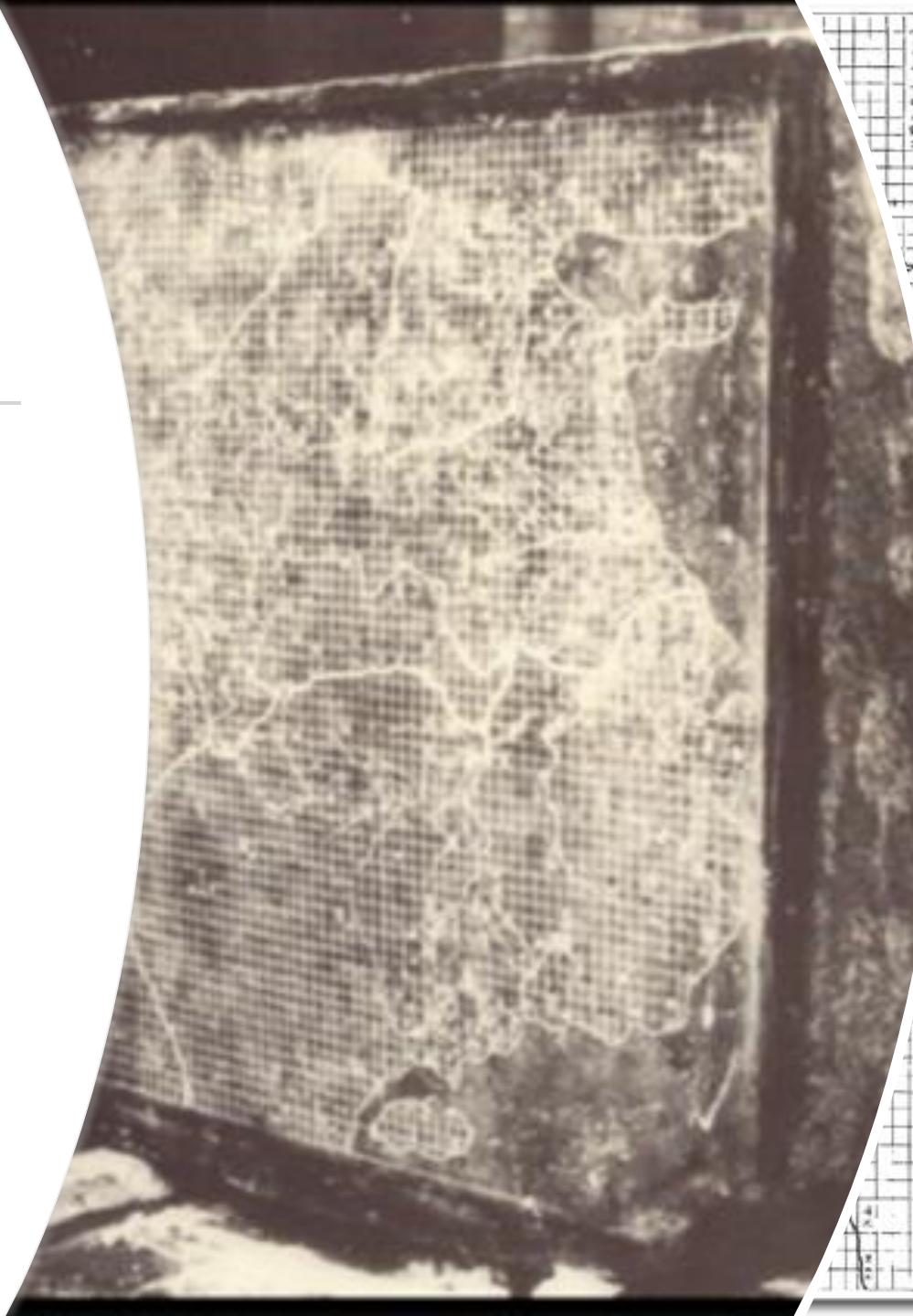


Inclinations of
planetary
orbits as
function of
time

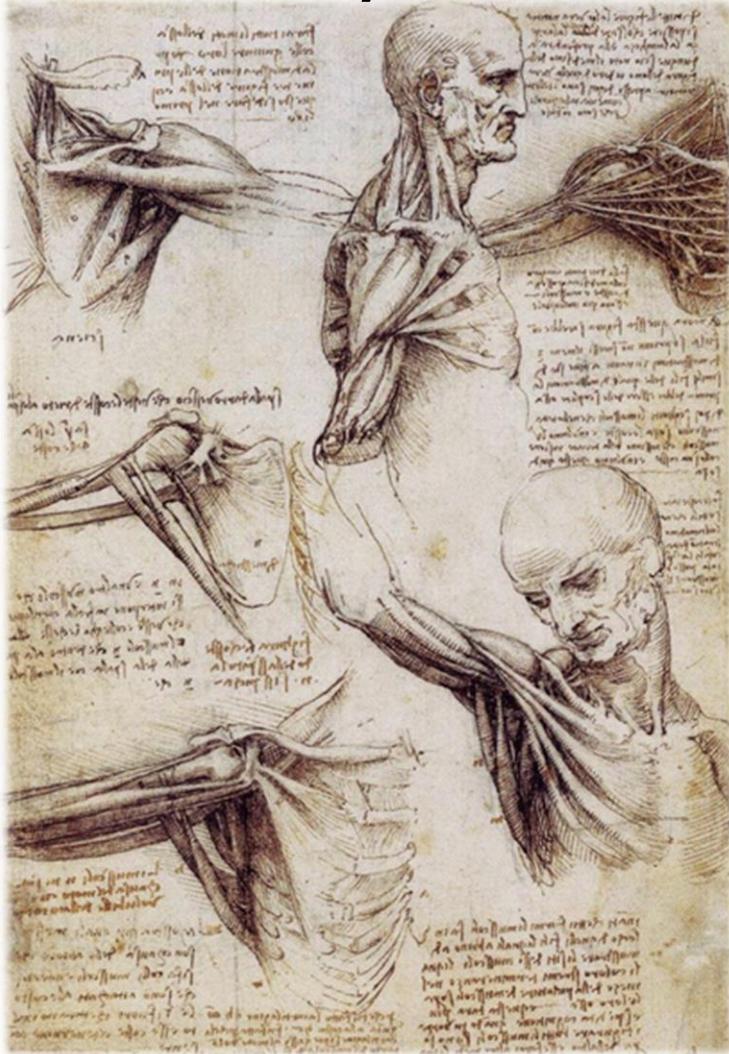
10th century

History

- Map of the Tracks of Yü the Great, China (11th century)



History

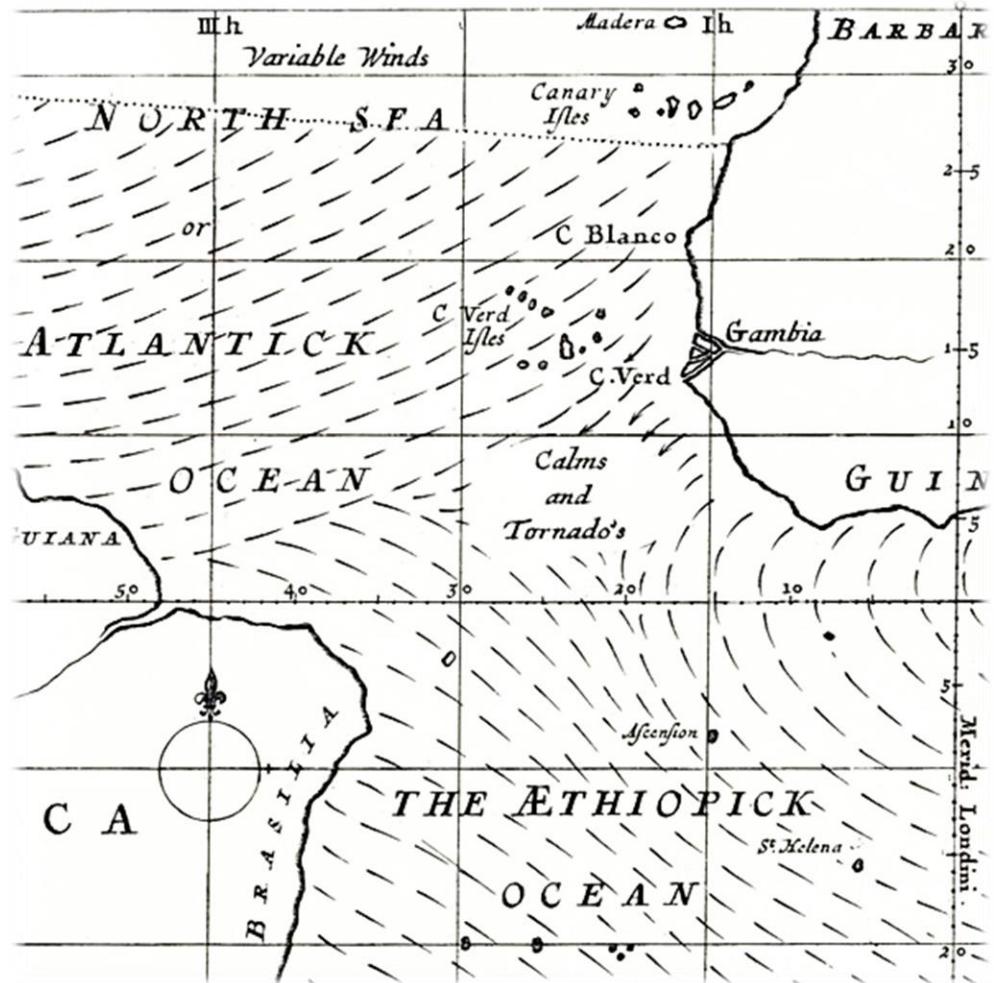


Illustrations by Leonardo DaVinci (1452-1519)

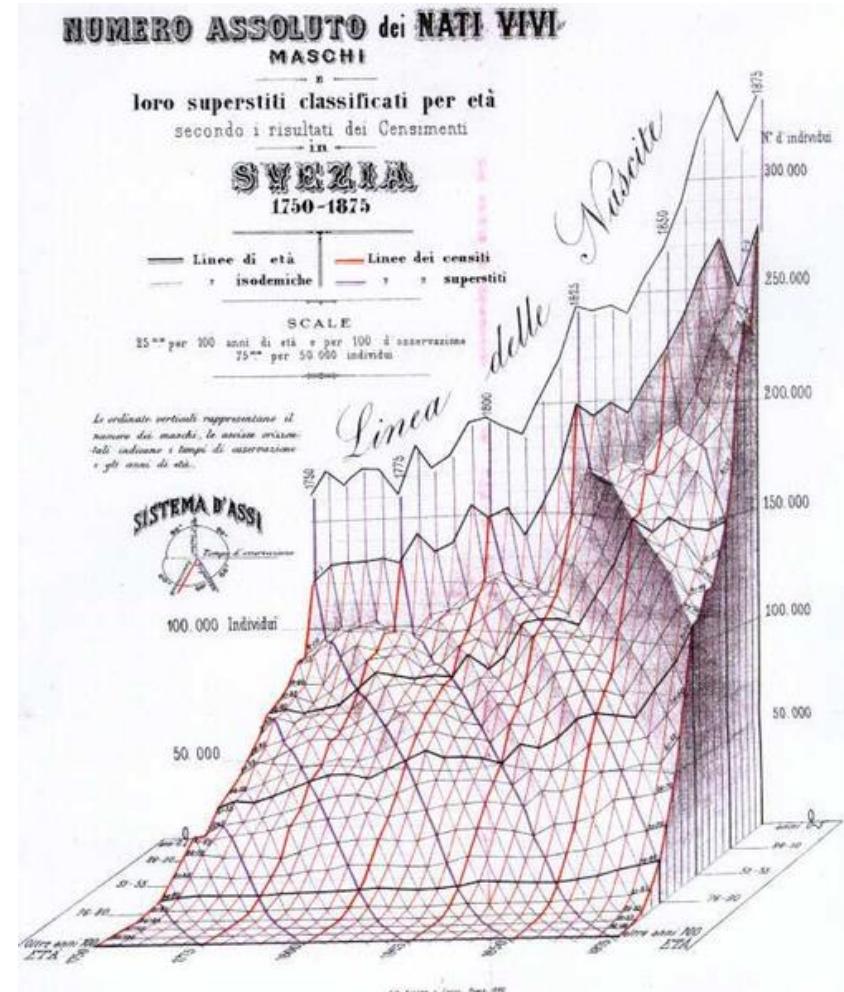
William Curtis (1746-1799)



History

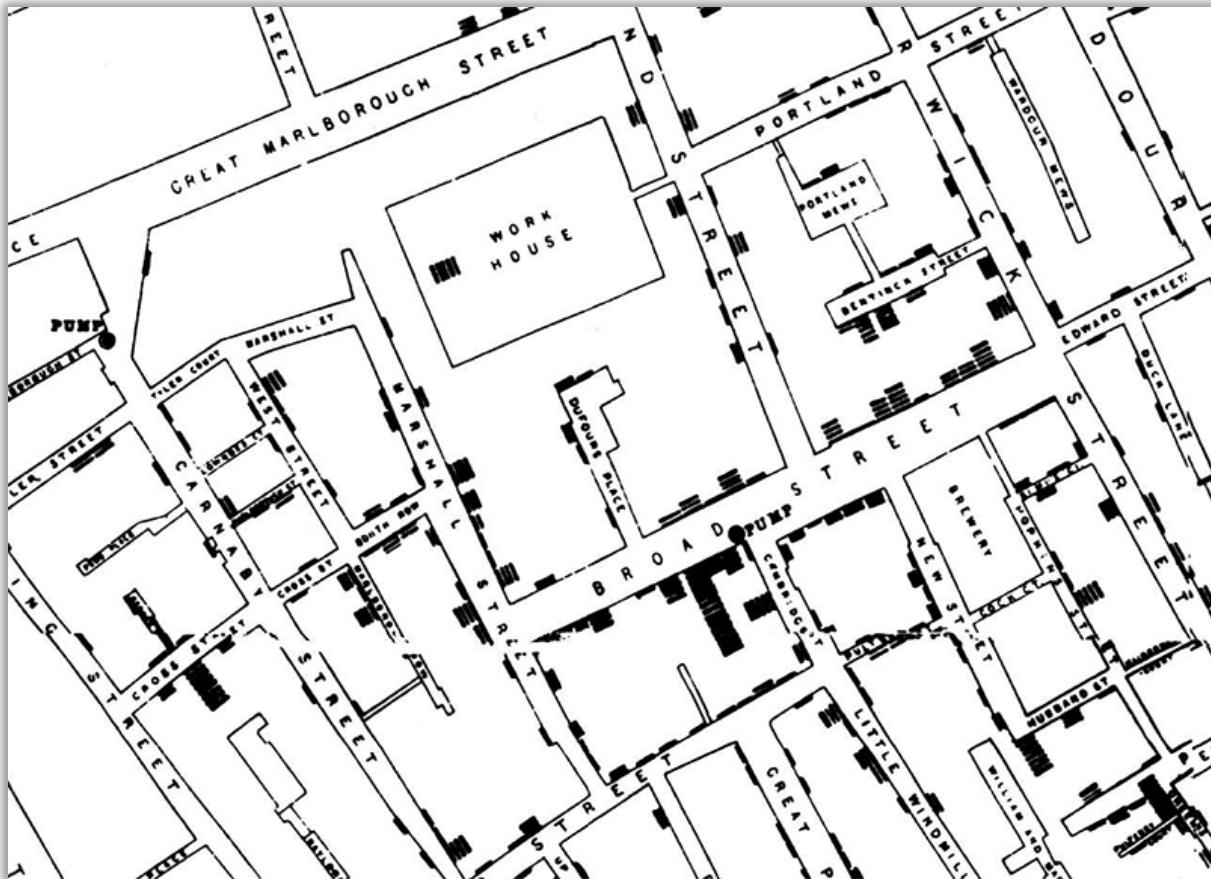


Vector visualization (1686)



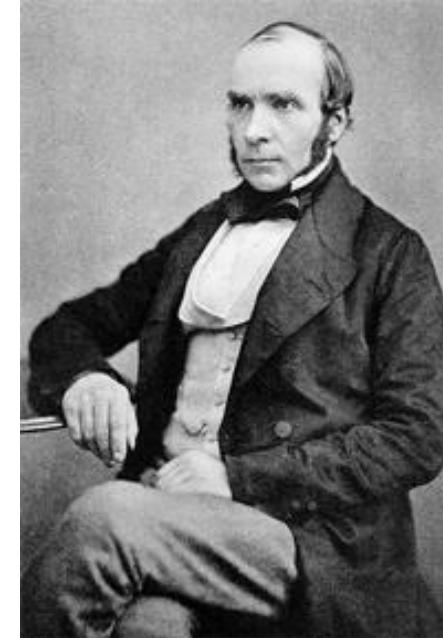
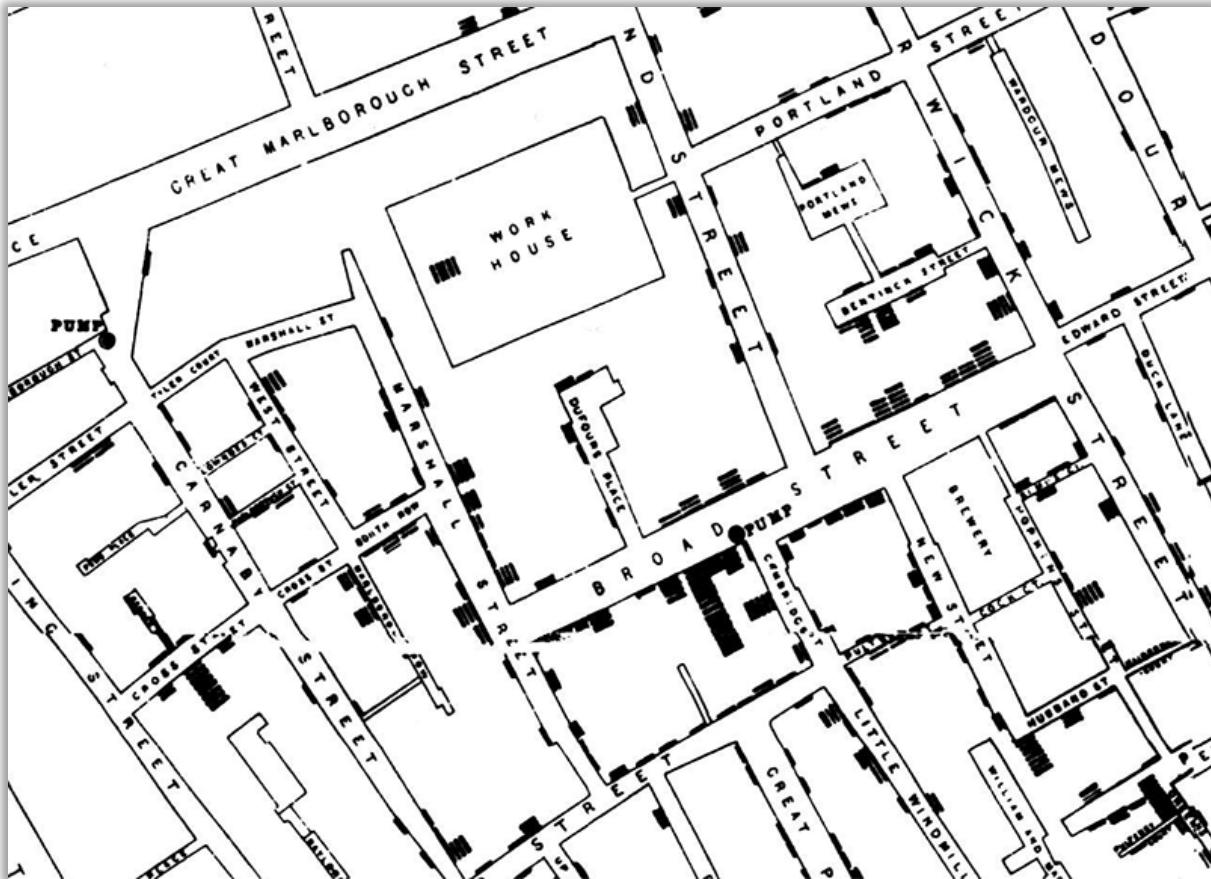
Height field (1879)

History



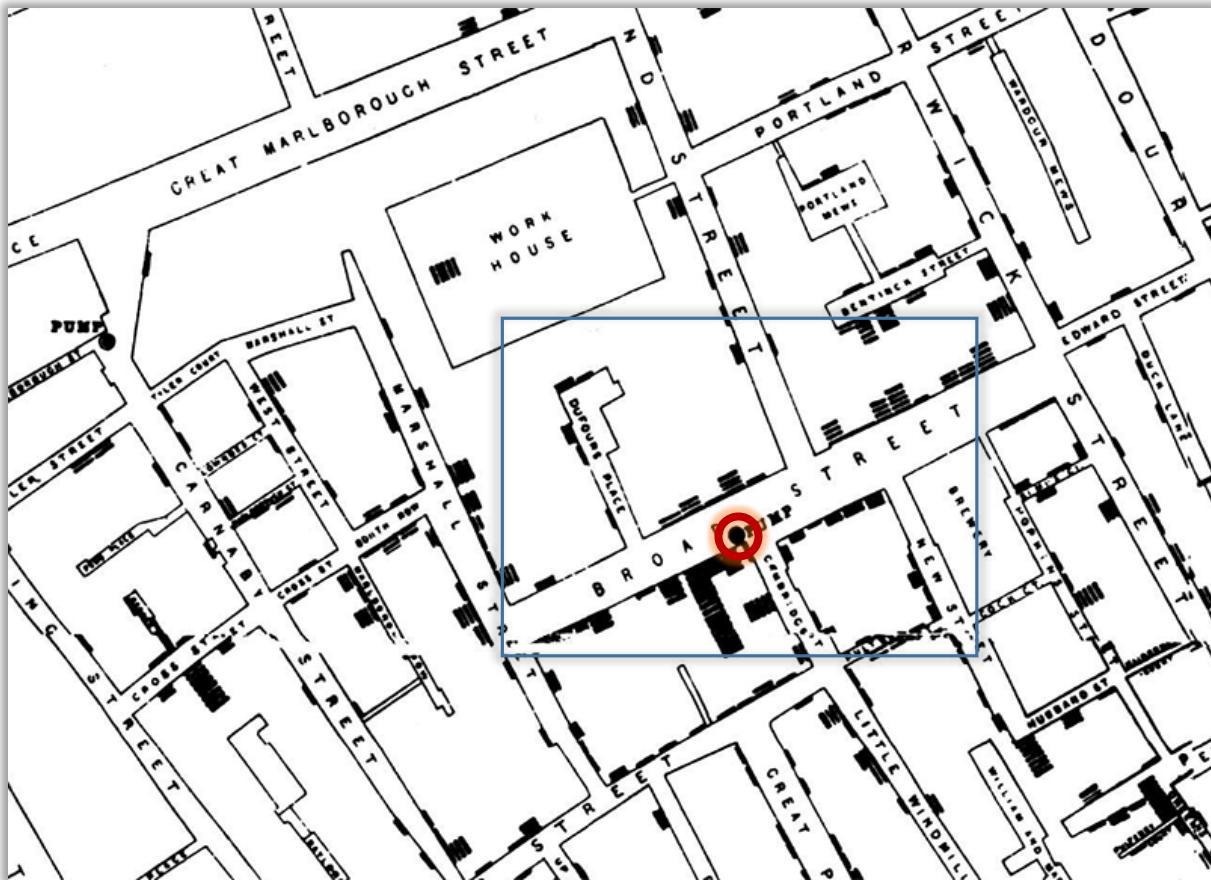
Cholera outbreak in Soho, London
John Snow (1854)

History

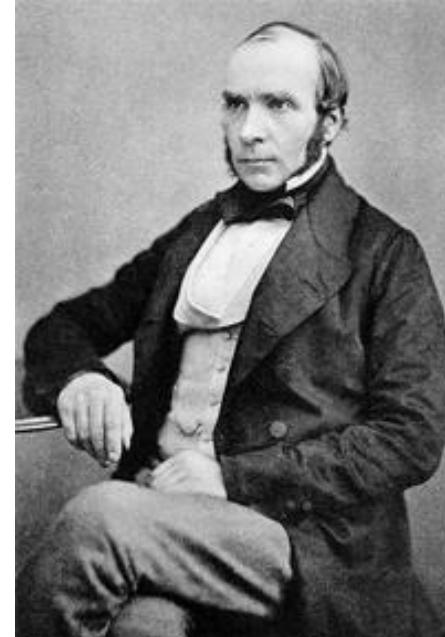


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History

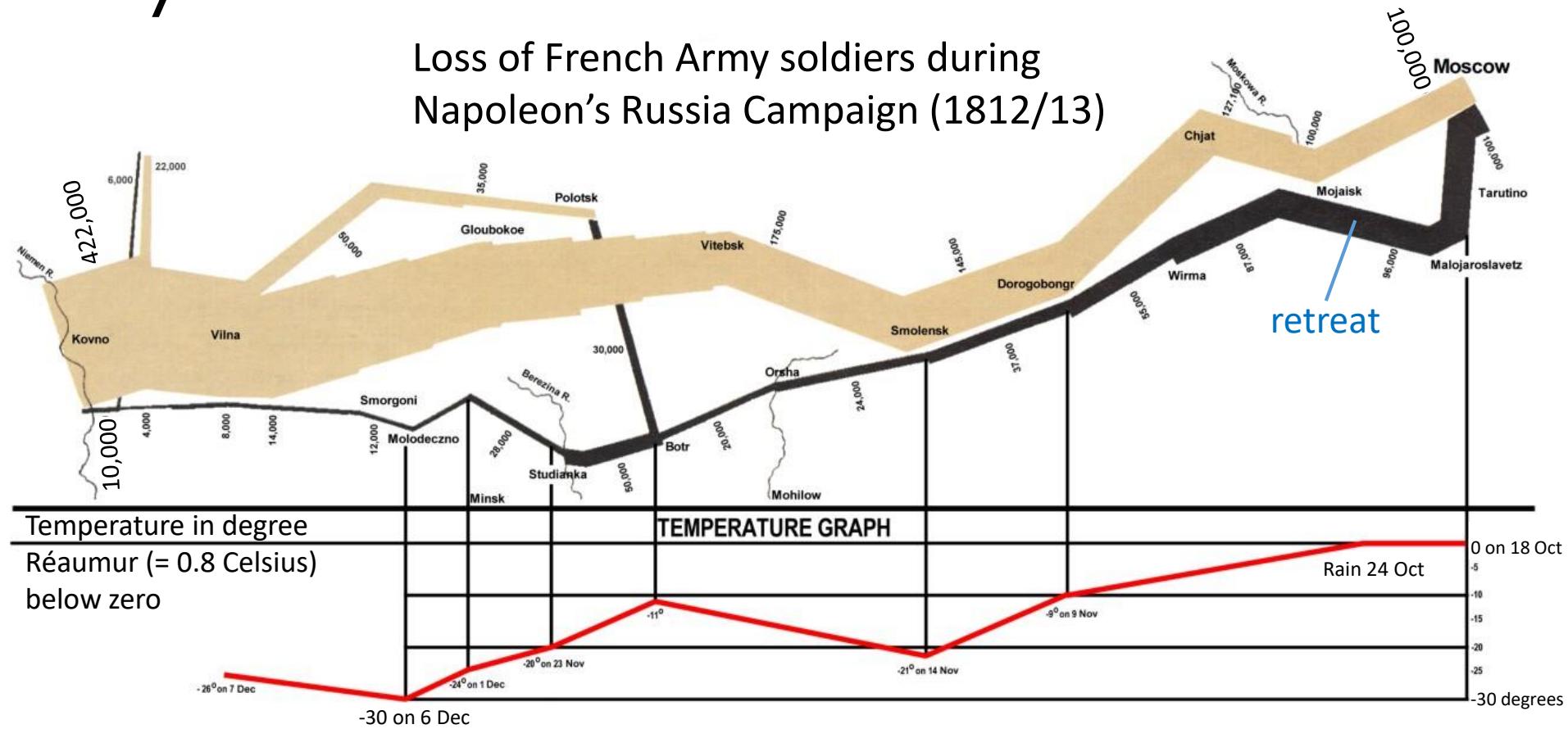


Cholera outbreak in Soho, London
John Snow (1854)



History

Loss of French Army soldiers during Napoleon's Russia Campaign (1812/13)

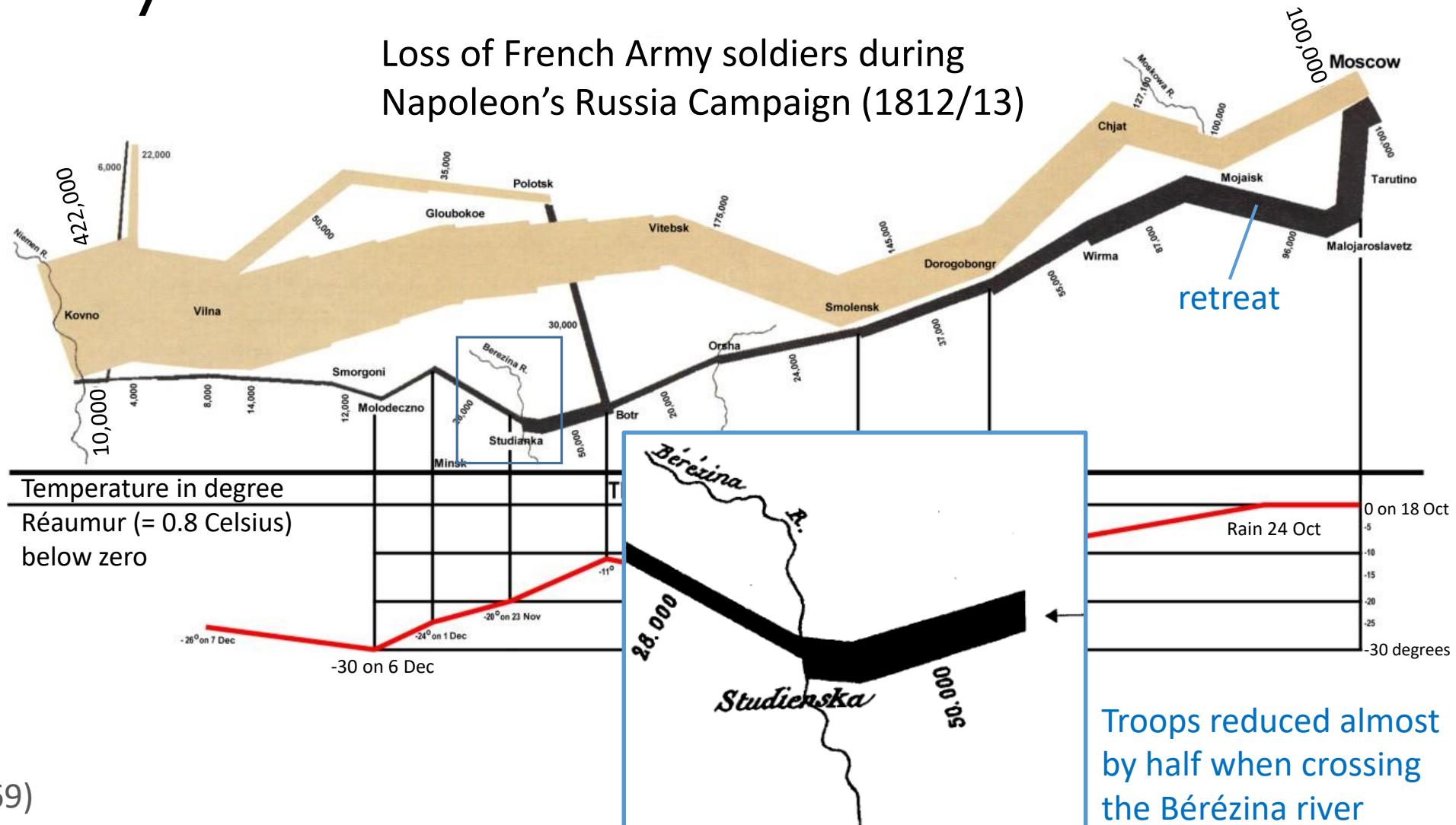


Map encodes size of army (width of band), location & direction of movement, split and reunion of troops, and temperature during retreat

C.J. Minard (1869)

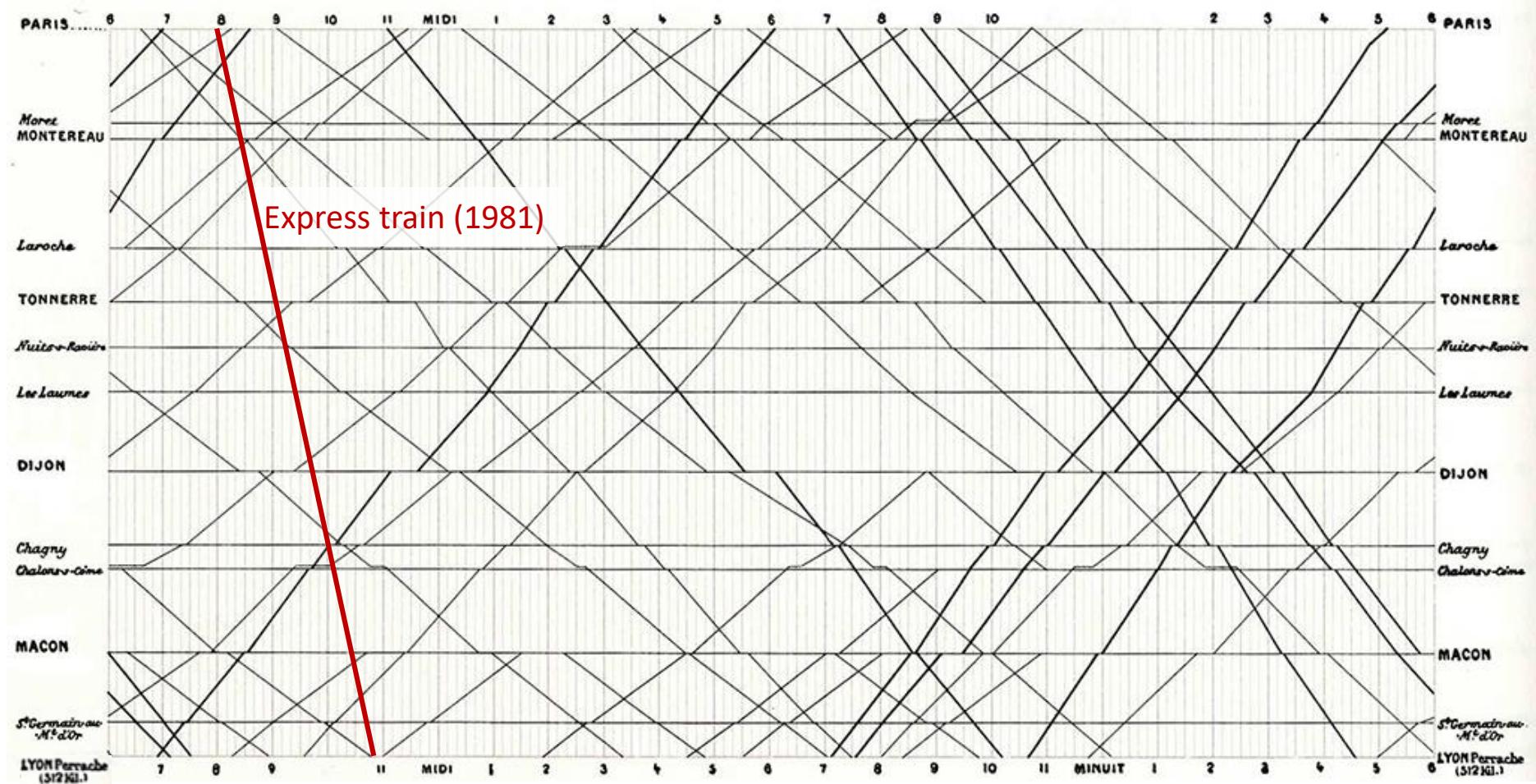
History

Loss of French Army soldiers during Napoleon's Russia Campaign (1812/13)



C.J. Minard (1869)

History



Train schedule between Paris and Lyon
E.J. Marey (1880)

History of Modern Visualization

History of Modern Visualization

“The purpose of computing
is **insight**, not numbers”
(Hamming 1962)

- Computer simulations access to new worlds
 - Real experiments are too expensive, too dangerous, etc.
 - Arbitrary large, small time scales, and spatial dimensions

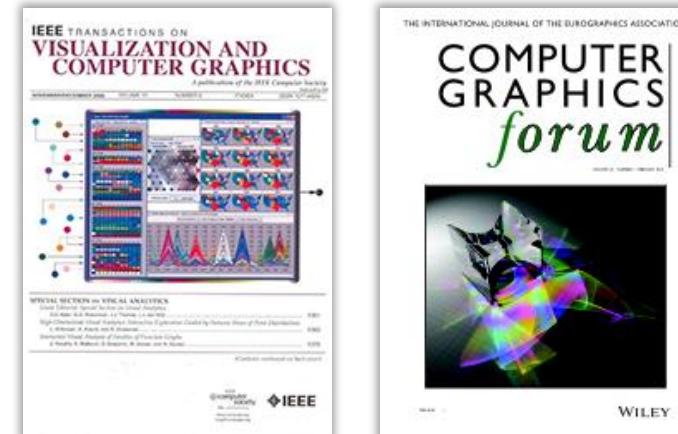


History of Modern Visualization

- Direct implications
 - The data flood from super computer simulations can only be dealt with visually
 - Needs a visualization specialist and an interdisciplinary team
 - New developments in hard/software, nets, etc. are necessary
- Advantages in the long term will be
 - Faster insight
 - Faster product – development cycles
 - Stronger position in global competition

History of Modern Visualization

- First visualization conference: 1990
- Conferences:
 - IEEE SciVis, IEEE InfoVis,
IEEE VAST
 - IEEE PacificVis, EuroVis, etc.
- Journals
 - IEEE Transactions on Visualization
and Computer Graphics
 - Computer Graphics Forum
 - Computers & Graphics, etc.



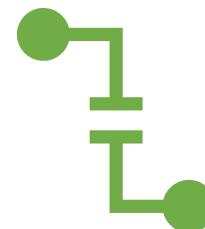
History of Modern Visualization



Scientific Visualization

Physical data, e.g. medical, volume or flow visualization

Spatialization is given (i.e. inherently spatial)



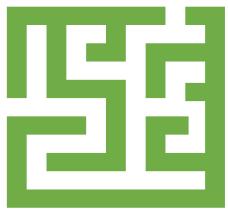
Information Visualization

Abstract data, e.g., hierarchy or software metrics

Spatialization is chosen

Definition: “The use of computer-supported, interactive, visual representations of abstract, nonphysically-based data to amplify cognition.”
[Card et al.: Readings in Information Visualization: Using Vision to Think, 1999]

History of Modern Visualization



Visual Analytics

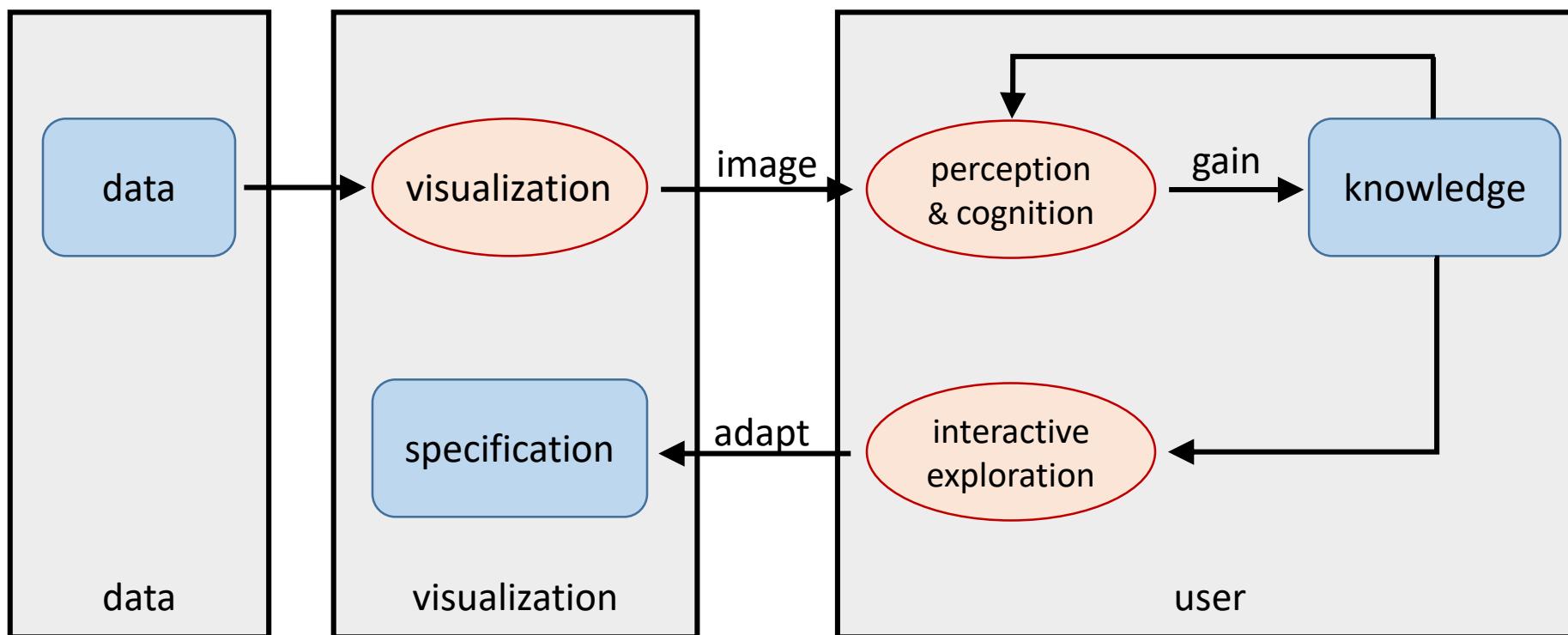
Aims at solving the information overload problem

- “Visual analytics combines automated analysis techniques with interactive visualizations for an effective understanding, reasoning and decision making on the basis of very large and complex data sets.” [Keim et al.:Mastering the Information Age: Solving Problems with Visual Analytics, 2010]

Models, Definitions & Goals

Visualization – Model

- A Simple Model for Visualization [van Wijk 05]



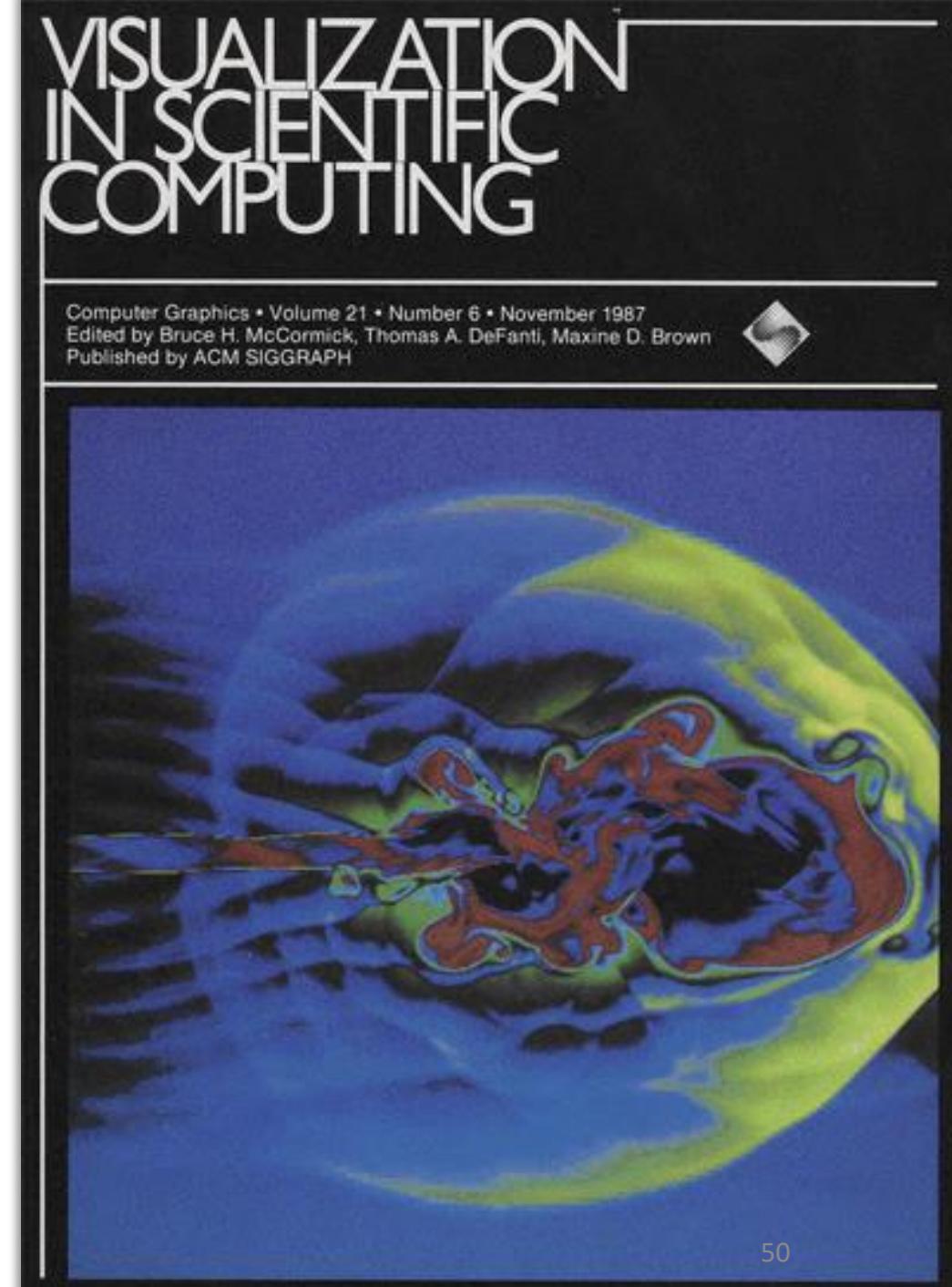
- Ellipses denote processes that transform inputs to outputs
- Boxes denote containers

Visualization – Definitions

- McCormick, DeFanti, Brown 1987:

“Visualization is a method of computing. It **transforms the symbolic into the geometric**, enabling researchers to observe their simulations and computations. Visualization offers a method for **seeing the unseen**. It enriches the process of scientific discovery and fosters profound and unexpected **insights**.

[...] It studies those mechanisms in **humans and computers** which allow them in concert to perceive, use and communicate visual information.”

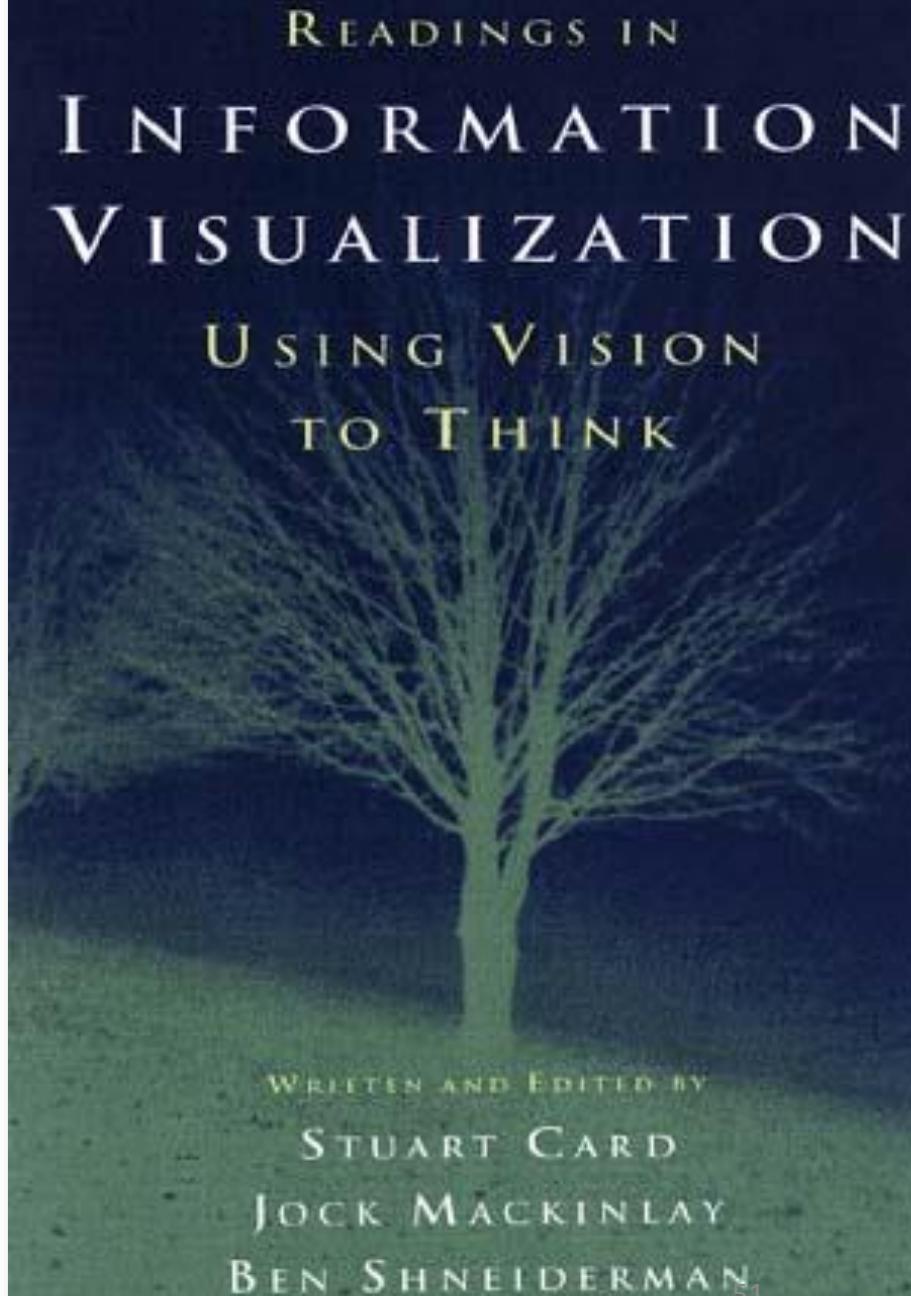


Visualization – Definitions

- Card, MacKinlay, Shneiderman 1999:

“[Information / Scientific] Visualization ...
The use of **computer-supported, interactive,**
visual representations of [abstract/scientific]
data to amplify cognition.”

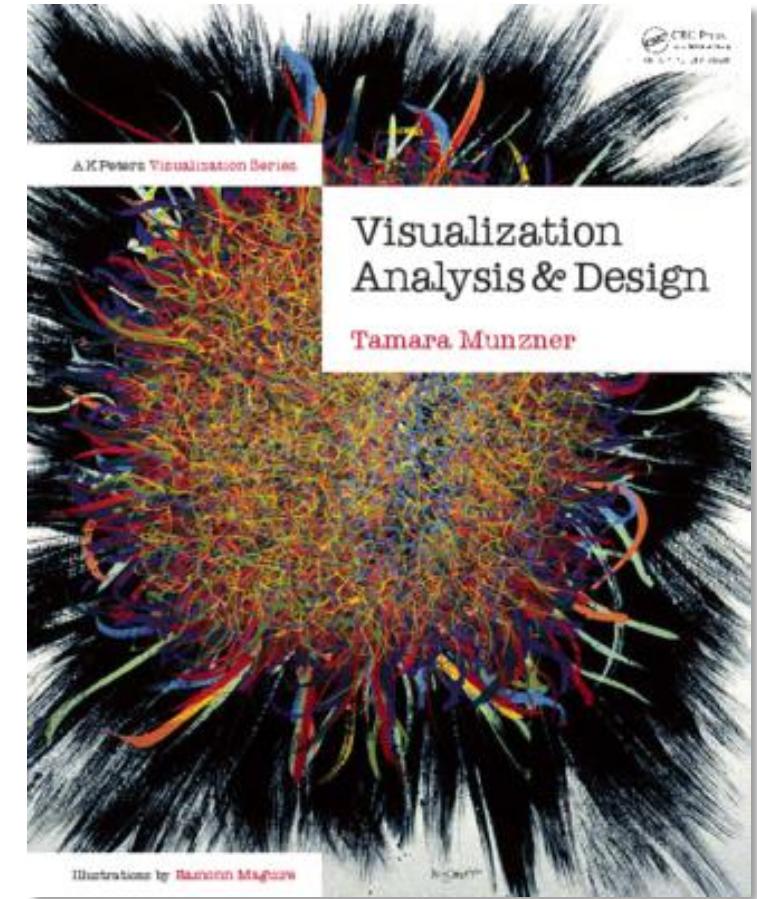
“The purpose of visualization is **insight**,
not pictures.” [B. Shneiderman]



Visualization – Definitions

- Munzner 2014:

“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively”



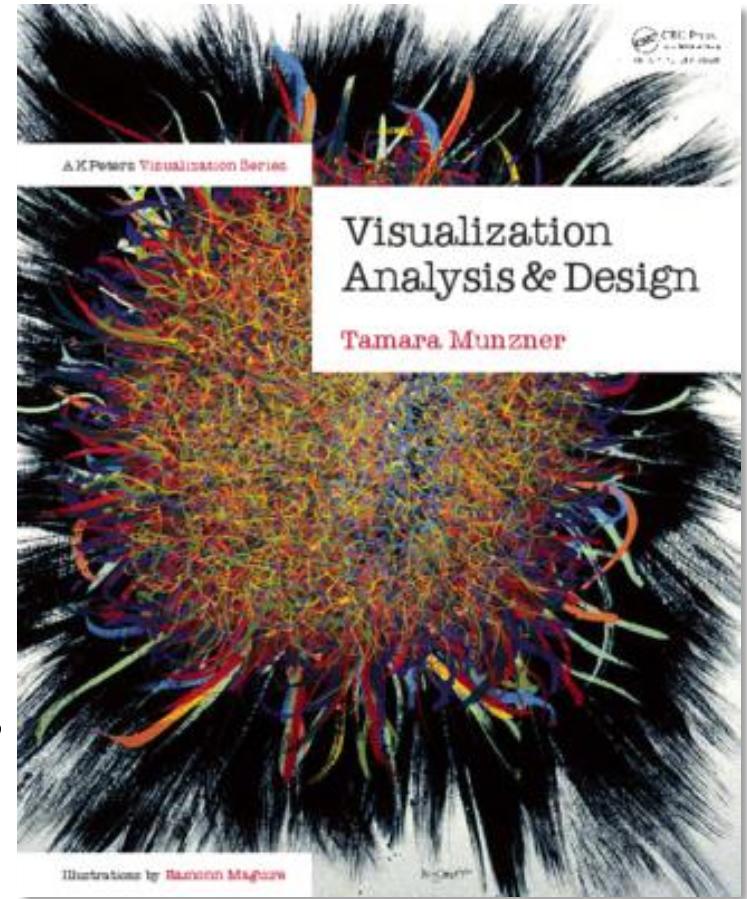
Visualization – Definitions

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“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively”

- Why have a **human** in the loop?

- No need for vis when fully automatic solution exists that **can be trusted**, e.g.,
 - if question can be answered by a compact, precise query
 - if a decision can be automated (e.g., stock market trading)



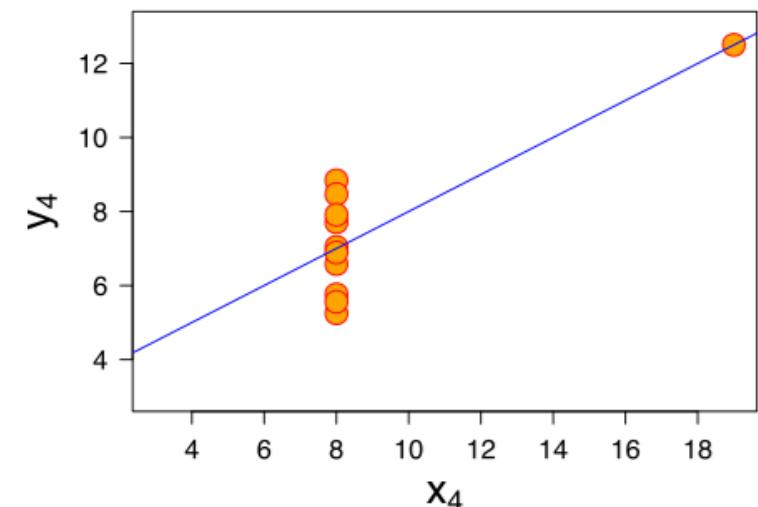
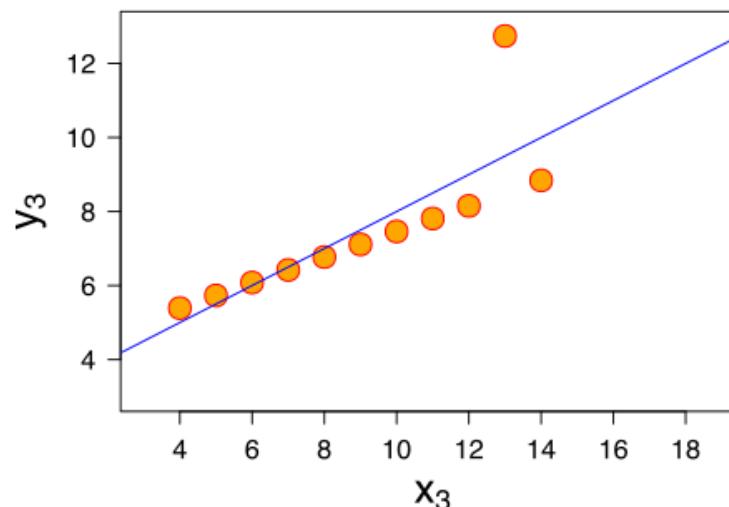
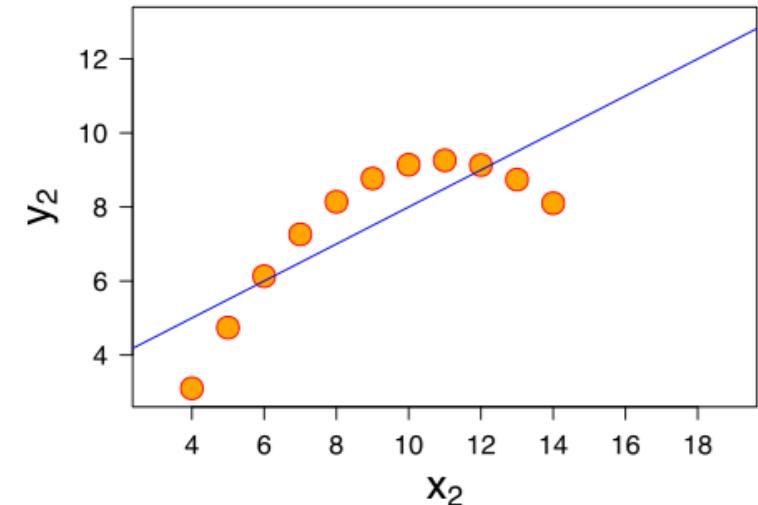
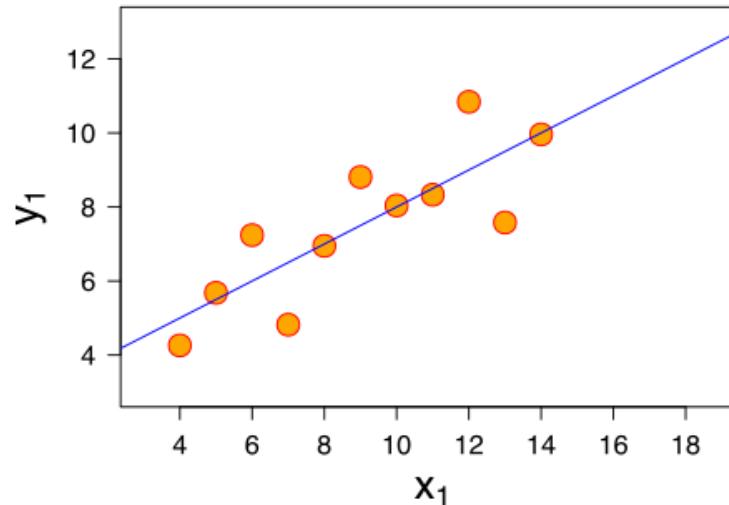
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I		II		III		IV	
x	y	x	y	x	y	x	y
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9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
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Visualization – Definitions

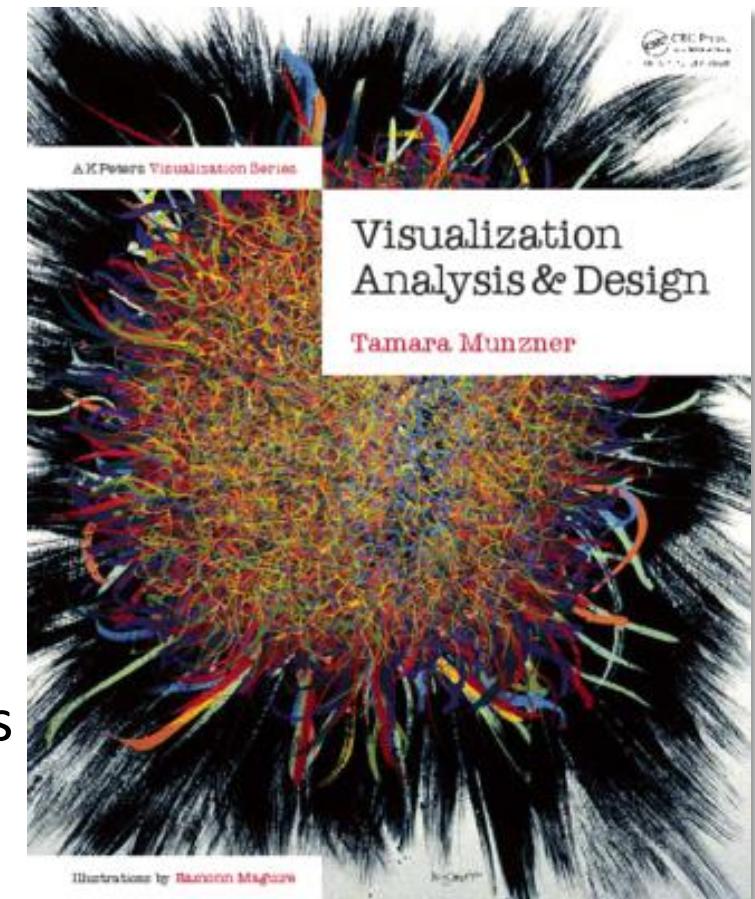
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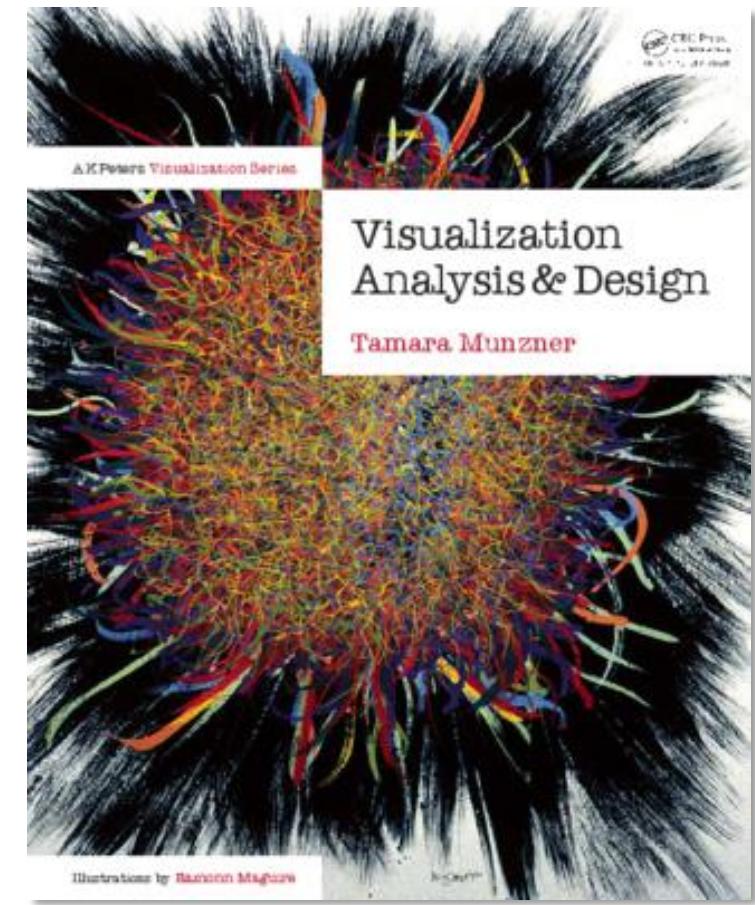
“Visualization is suitable when there is a need to **augment** human capabilities **rather than replace** people with computational decision-making methods.”

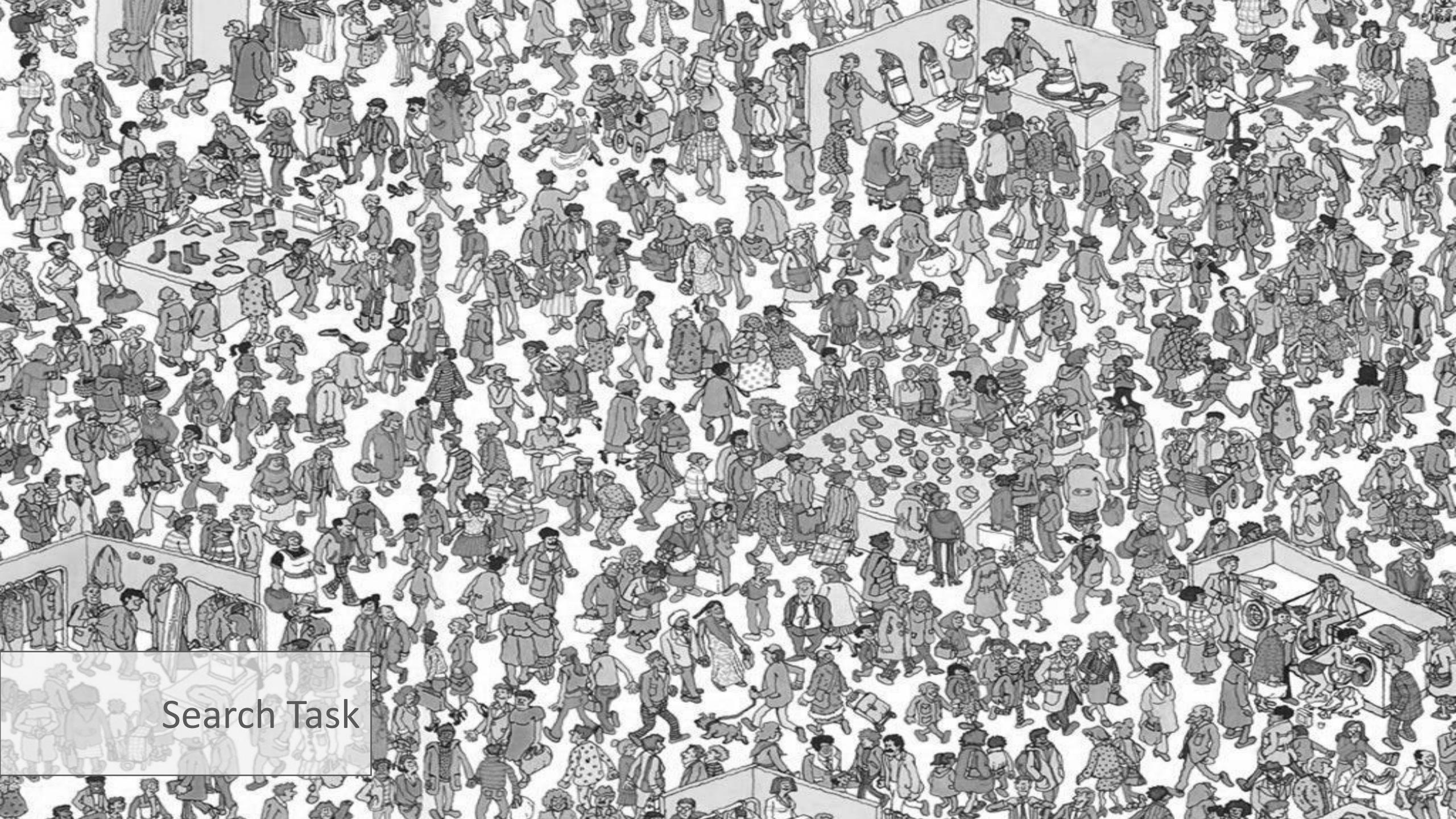


Visualization – Definitions

- Munzner 2014:

“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively”
- Why have a **computer** in the loop?
 - Large datasets are infeasible to draw by hand
 - Goes beyond human capacities / patience
 - Supports interactivity





Search Task

Comparison Task



Visualization – Definitions

- Munzner 2014:

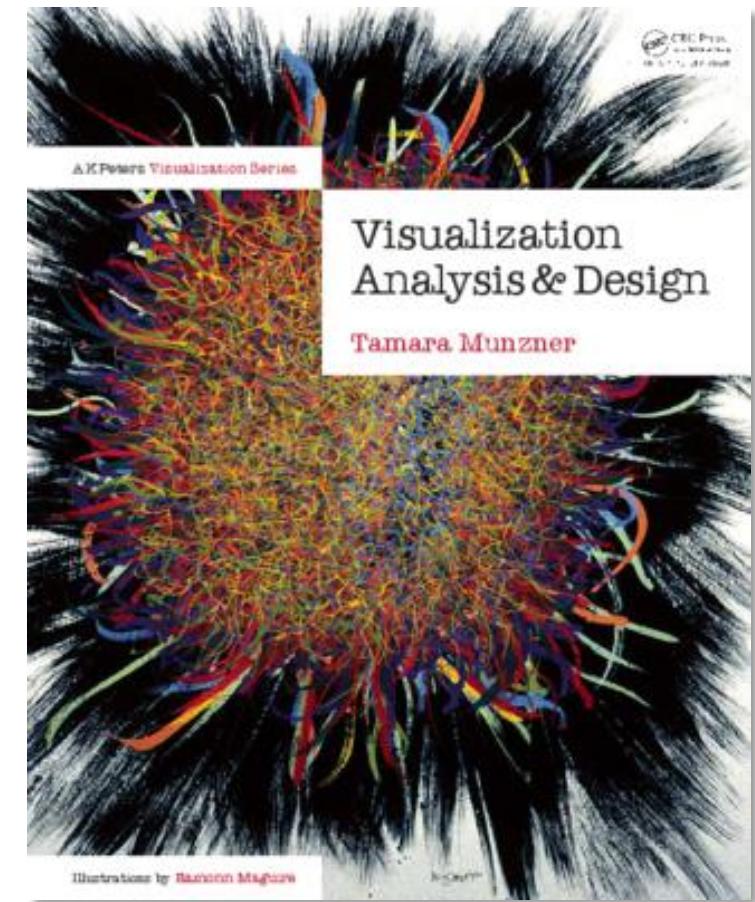
“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively”

- Why use **interactivity**?

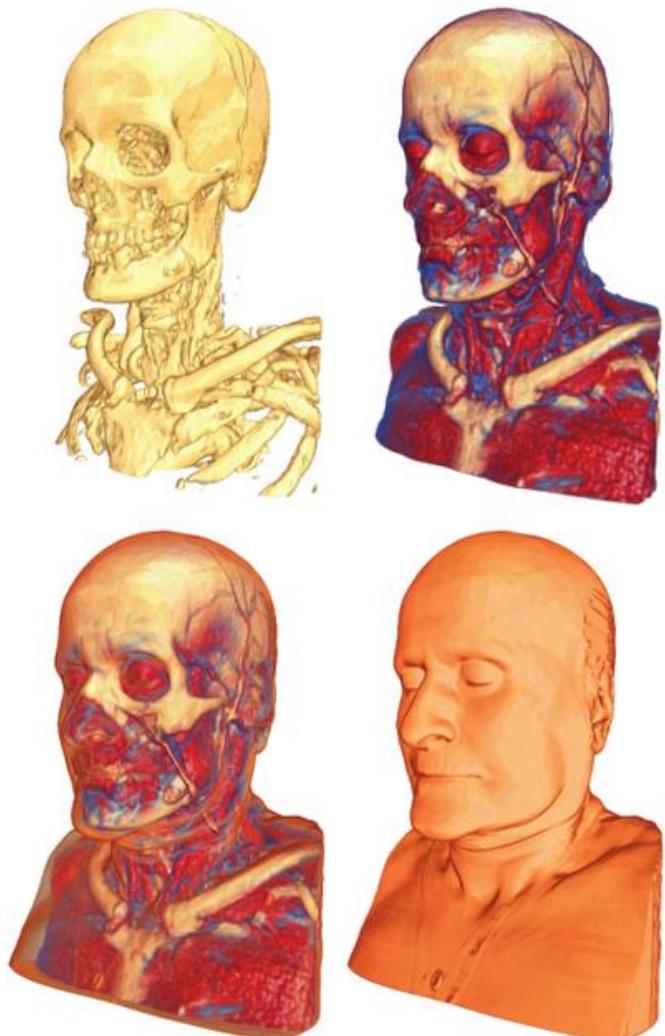
- Handle data complexity
- A single static view can show only one aspect of data

“Overview first, zoom and filter, then details-on-demand.”

[B. Shneiderman]



Interaction



The screenshot shows the 'volumeshop' application window. At the top, there's a toolbar with icons for file operations and a 'Style Transfer Function' button. Below the toolbar is a main area titled 'volume shop' containing a stylized bust of a man's head and shoulders. To the left of the bust is a 'Resources' panel listing various volume types with their dimensions: Volume (256,256,230), Skin (256,256,1), Bone (256,256,1), Muscles (256,256,1), Vessels (256,256,1), Grey (256,256,1), Orange (256,256,1), Black (256,256,1), Gold (282,282,1), Metal (256,256,1), Purple (256,256,1), Escher (256,256,1), Glossy (256,256,1), and Stipples (256,256,1). Below the Resources panel is an 'Environments' section with an 'Environment' tab selected. At the bottom is a 'Style Transfer Function Editor' panel showing a graph with several nodes and connections on a checkered background.

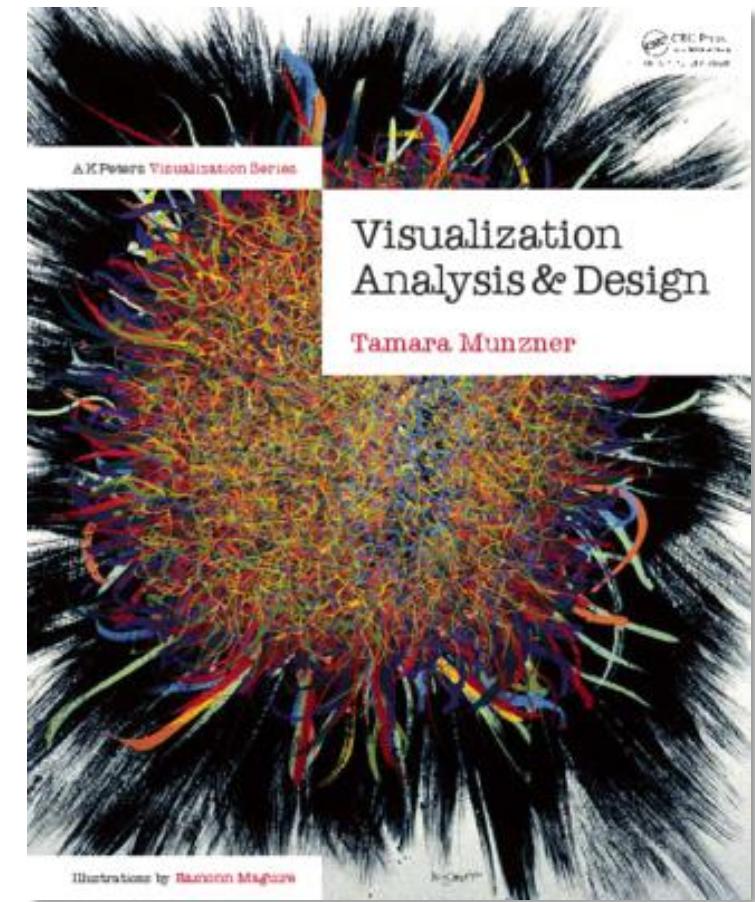
Visualization – Definitions

- Munzner 2014:

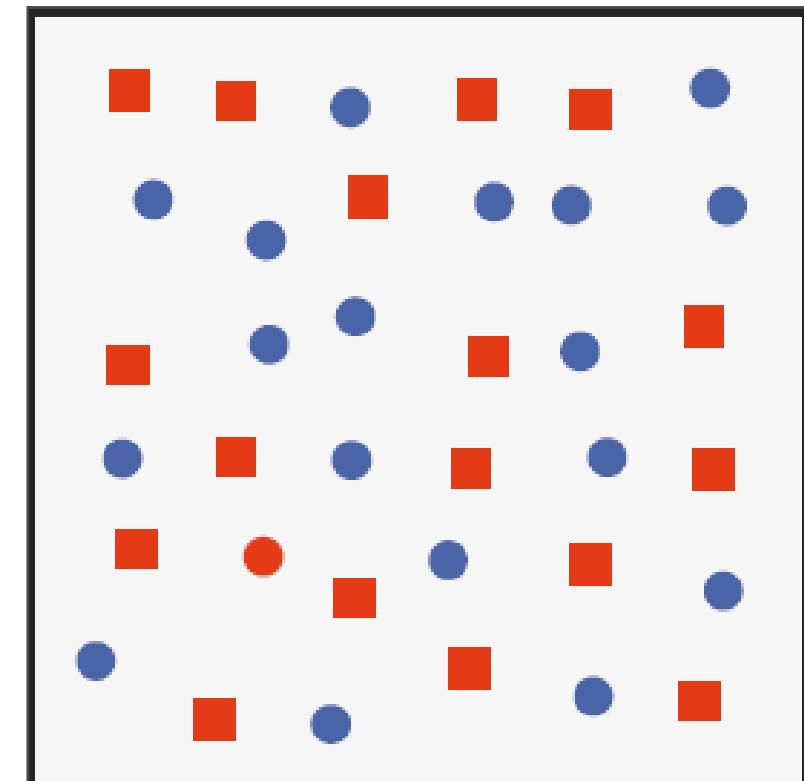
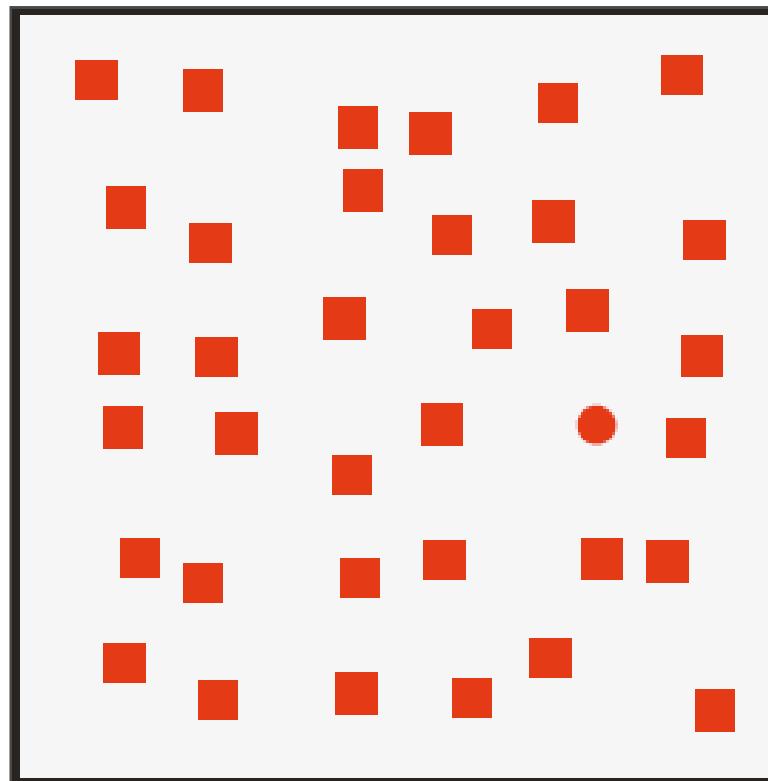
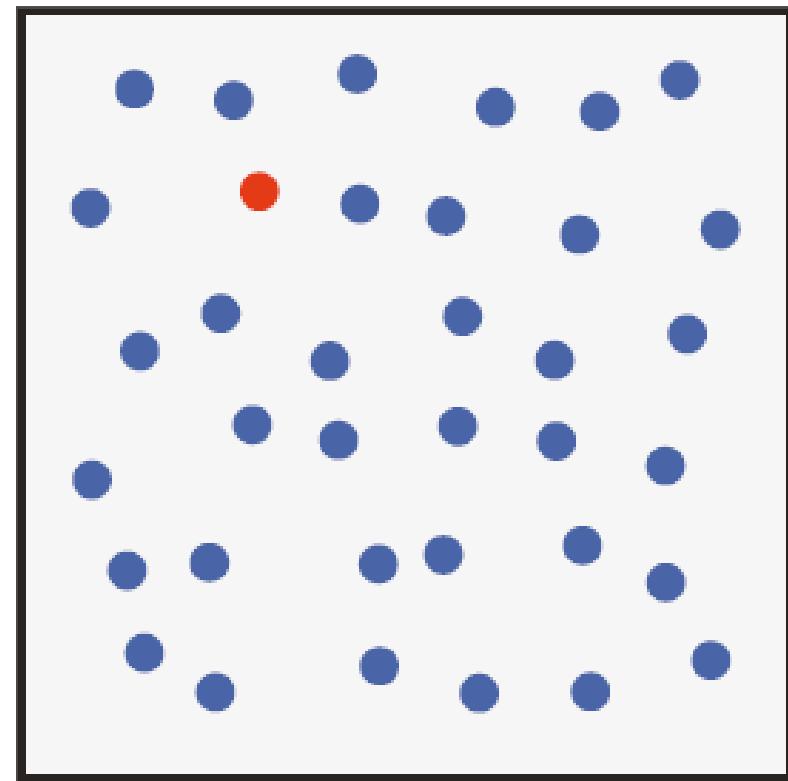
“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively”

- Why depend on **vision**?

- Visual system is high-bandwidth channel to brain
- Detect interesting visual structures & relationships (e.g., anomalies, patterns, or trends)
- Sequential vs. parallel processing (popout)



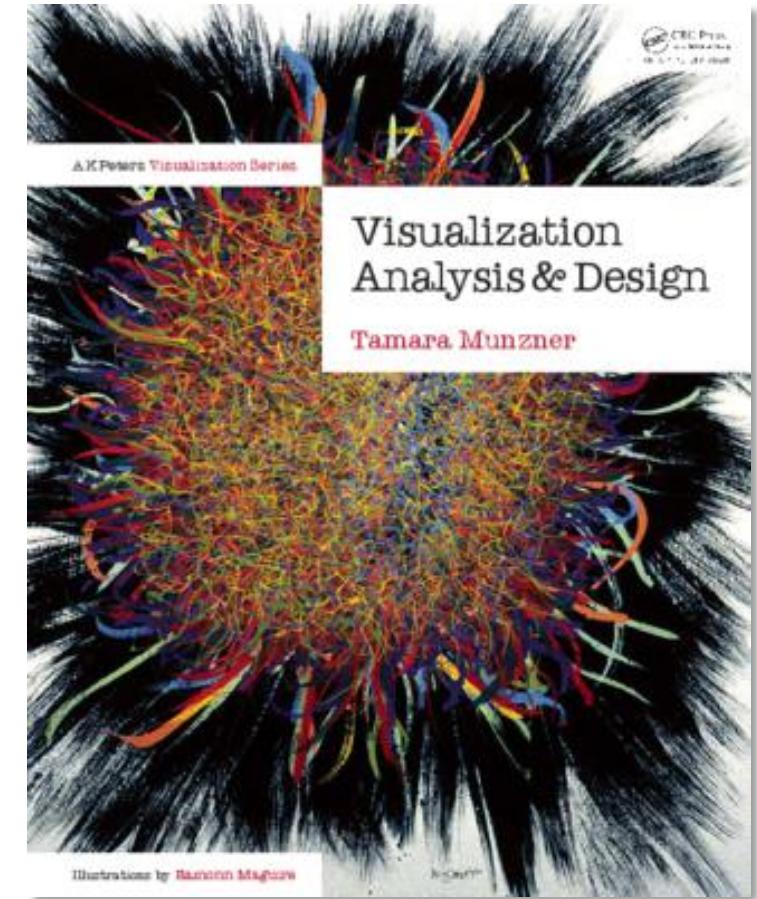
Visualization – Definitions



Visualization – Definitions

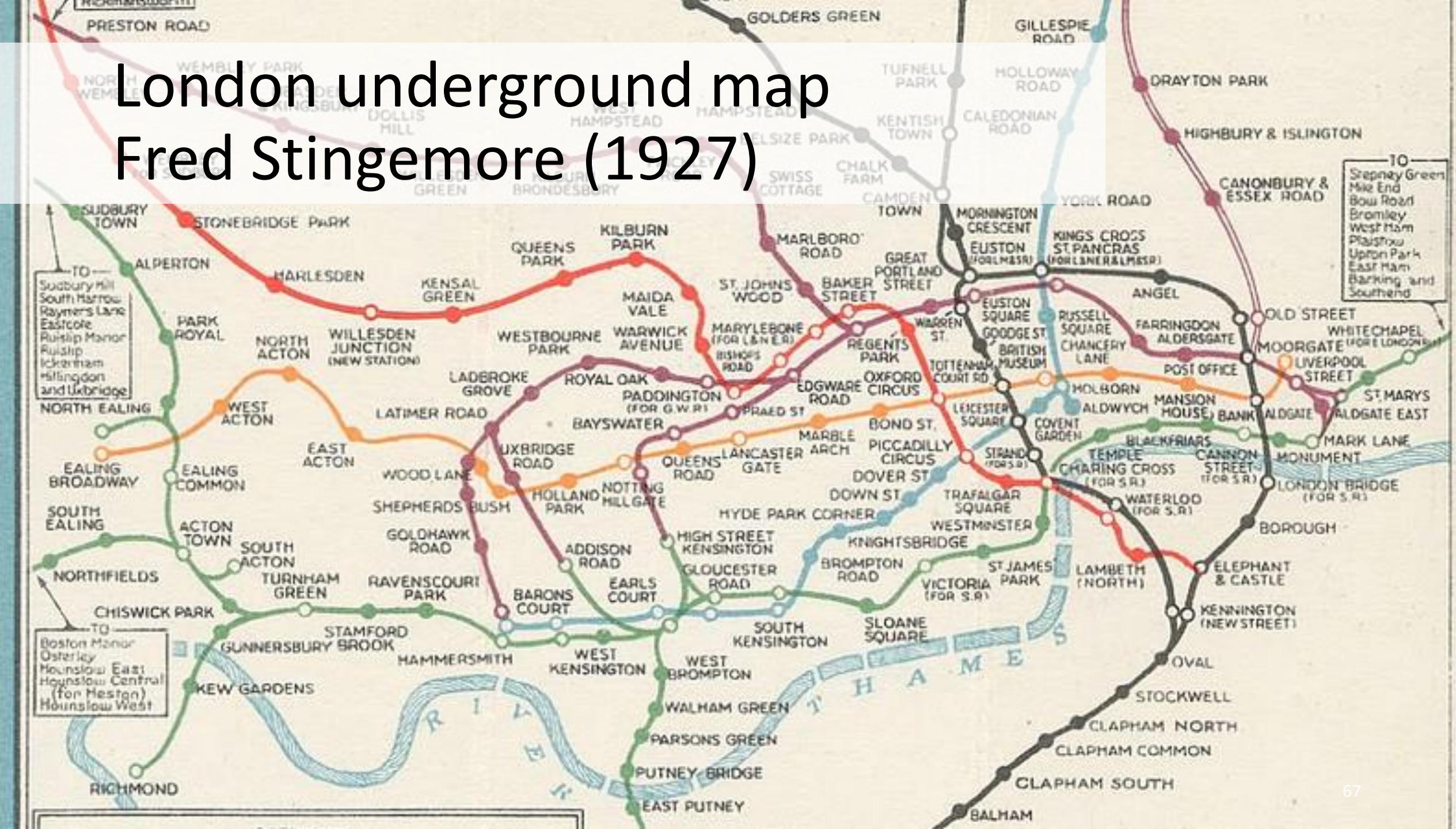
- Munzner 2014:

“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively”
- Why focus on **effectiveness**?
 - What problem do we want to solve?



London underground map

Fred Stingemore (1927)



London underground map

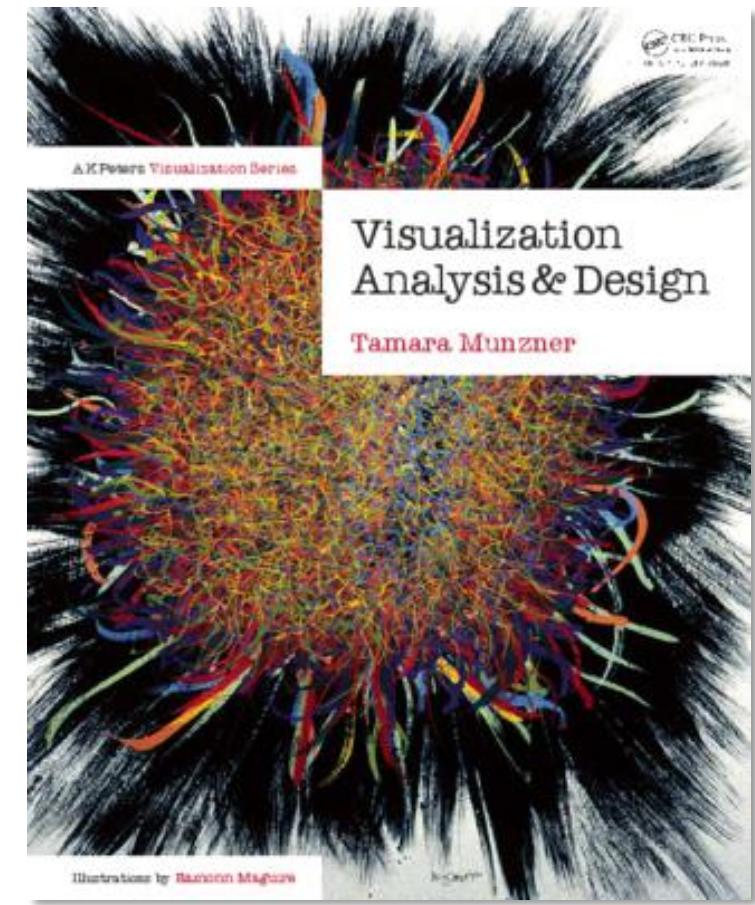
Harry Beck (1933)



Visualization – Definitions

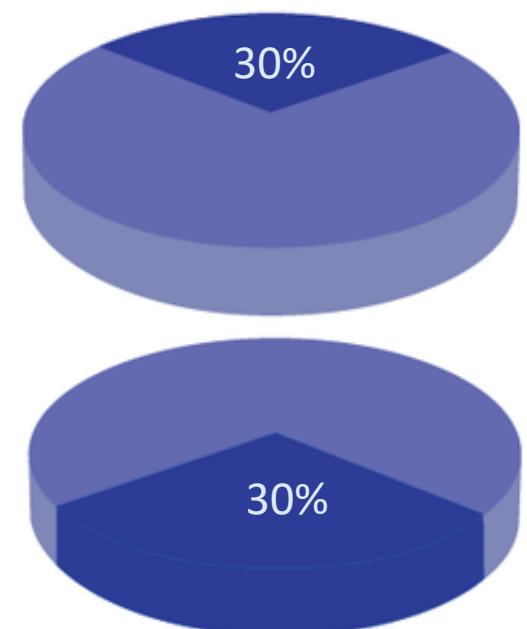
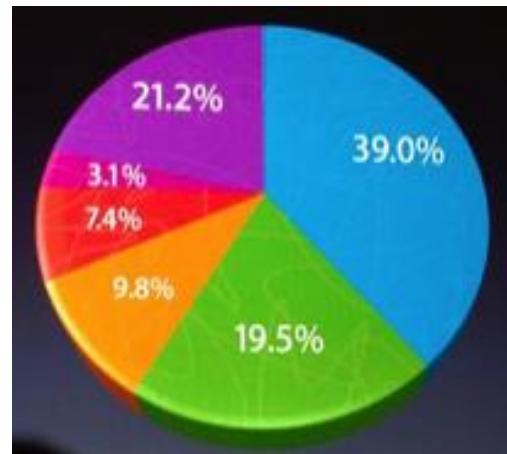
- Munzner 2014:

“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively”
- Why focus on effectiveness?
 - What problem do we want to solve?
 - A tool serving one task can be poorly suited for another one
 - Most possibilities are ineffective
 - Representation should be correct, accurate, and truthful



Visualization – Definitions

Representation should be correct,
accurate, and truthful



Since when is 19.5% bigger than 21.2?

Tufte: Lie Factor

“The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the quantities represented.”

Edward Tufte

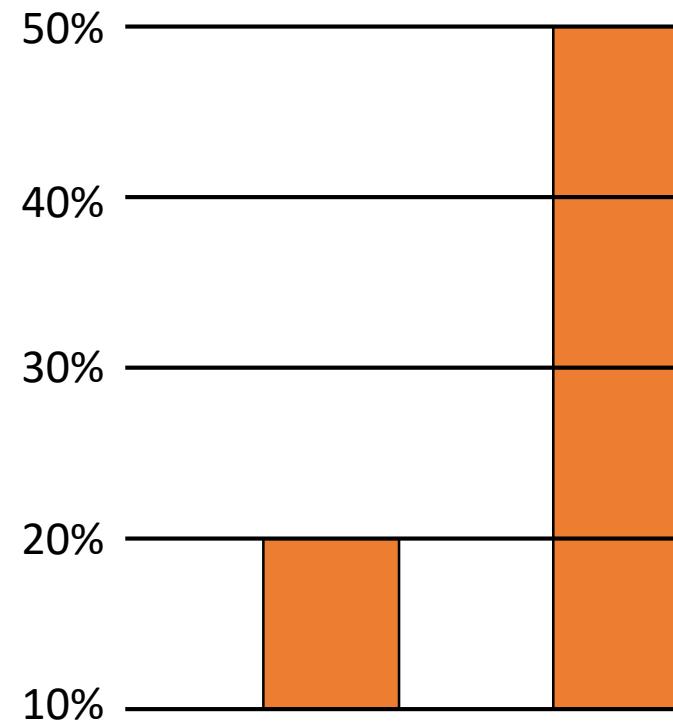
$$\text{Lie factor} = \frac{\text{Size of effect shown in graphic}}{\text{Size of effect in data}}$$

$$\text{Size of effect} = \frac{|2\text{nd value} - 1\text{st value}|}{1\text{st value}}$$

Tufte: Lie Factor

Lie factor = $\frac{\text{Size of effect shown in graphic}}{\text{Size of effect in data}}$

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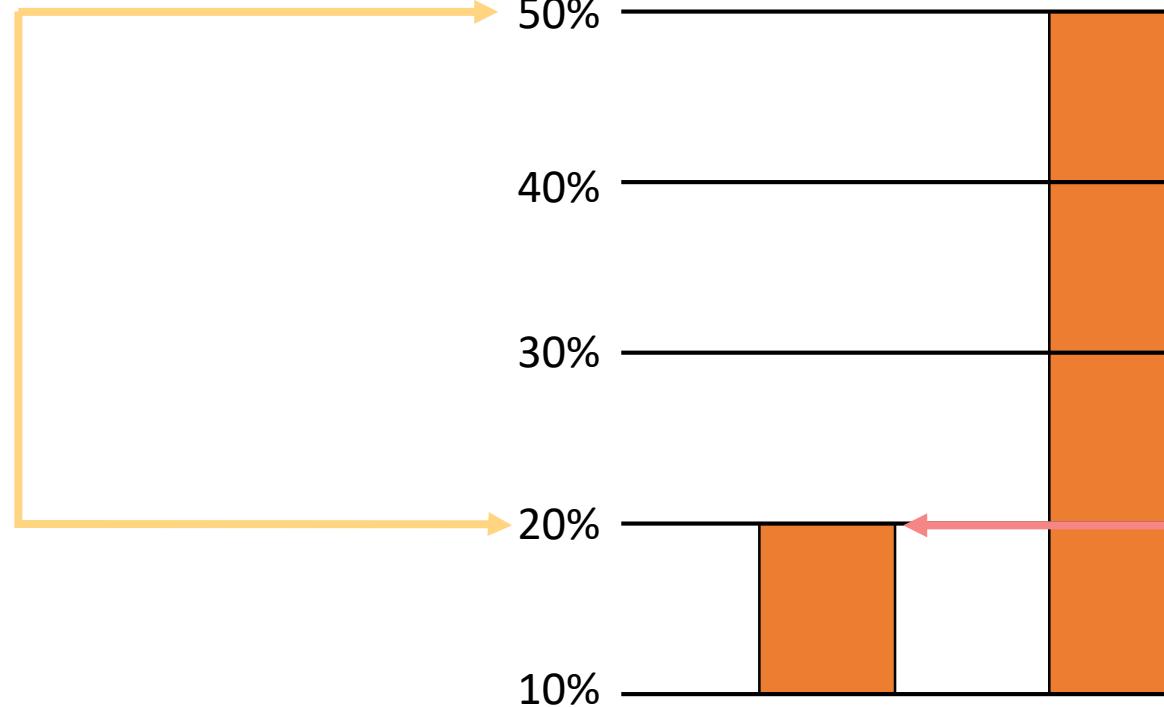


Tufte: Lie Factor

Lie factor = $\frac{\text{Size of effect shown in graphic}}{\text{Size of effect in data}}$

Size of effect = $\frac{|2\text{nd value} - 1\text{st value}|}{1\text{st value}}$

$$\text{Size of effect} = \frac{|50\% - 20\%|}{20\%} = 1.5$$



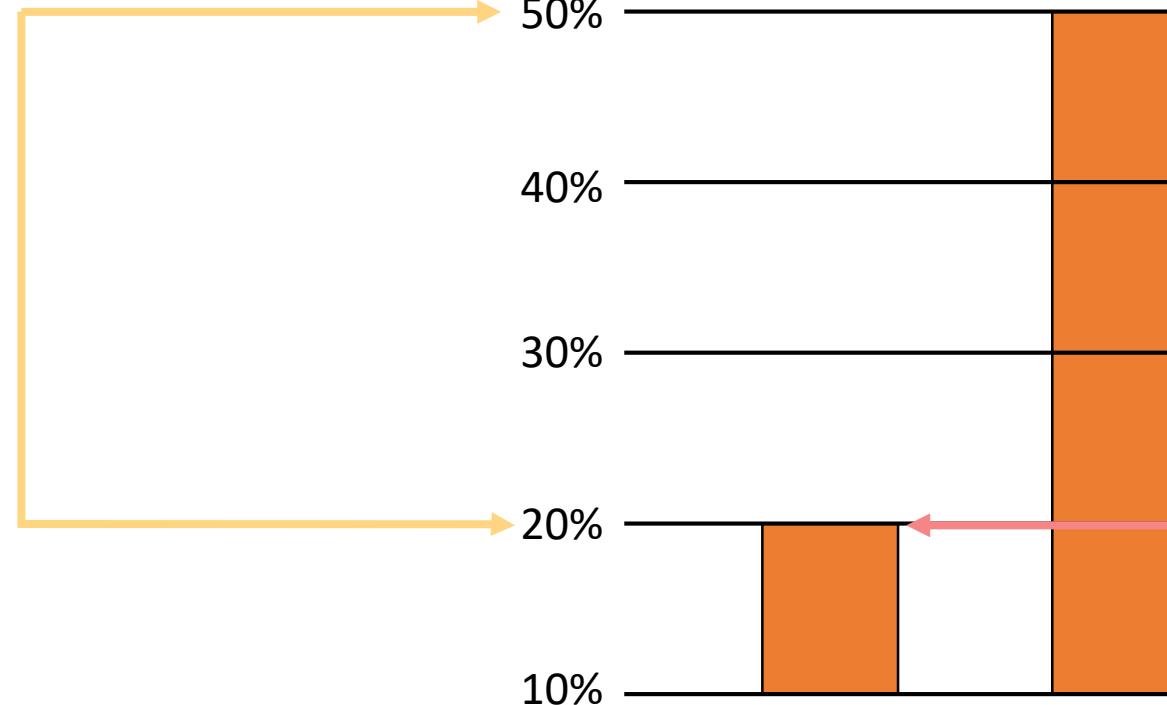
$$\text{Size of effect} = \frac{|4 - 1|}{1} = 3$$

Tufte: Lie Factor

Lie factor = $\frac{\text{Size of effect shown in graphic}}{\text{Size of effect in data}}$

Size of effect = $\frac{|2\text{nd value} - 1\text{st value}|}{1\text{st value}}$

$$\text{Size of effect} = \frac{|50\% - 20\%|}{20\%} = 1.5$$

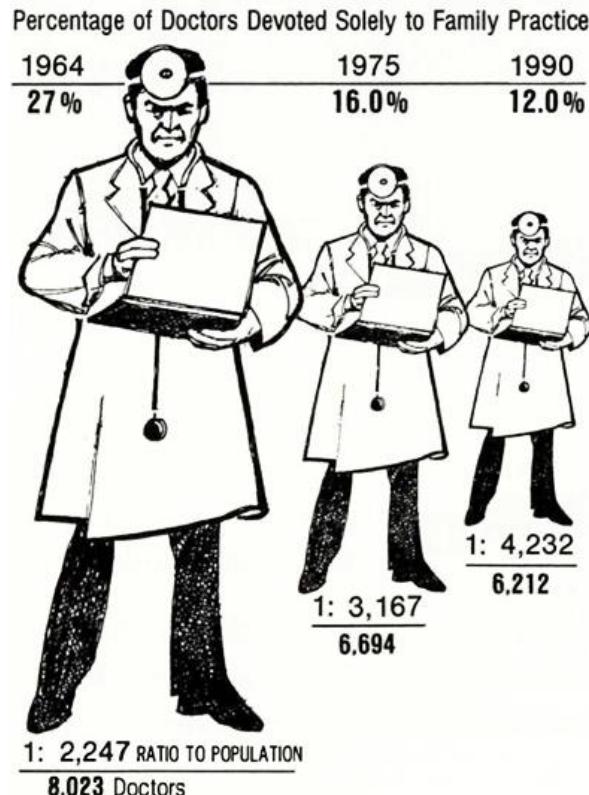


$$\text{Size of effect} = \frac{|4 - 1|}{1} = 3$$

$$\text{Lie factor} = \frac{3}{1.5} = 2$$

Visualization – Definitions

THE SHRINKING FAMILY DOCTOR In California



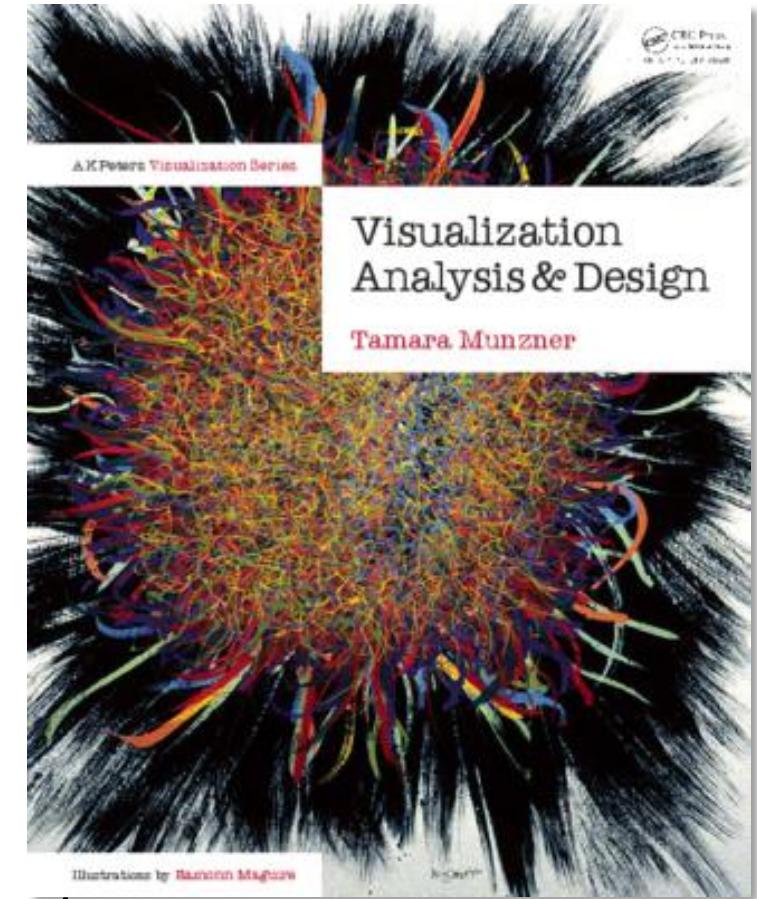
Lie factor = Size of effect shown in graphic
Size of effect in data

Visualization – Definitions

- Munzner 2014:

“Visualization designers must take into account three very different kinds of resource limitations: those of **computers**, of **humans**, and of **displays**”

- Computational limits
 - Processing time / system memory
- Display limits
 - Number of pixels
 - **Information density:** ratio of used space vs. unused whitespace
- Human limits
 - Perception, attention and memory (e.g., change blindness)



Visualization – Definitions

- Change of blindness



Visualization – Definitions

- Change of blindness



Visualization – Definitions

- Change of blindness



Visualization – Definitions



- <https://www.youtube.com/watch?v=ubNF9QNEQLA>

A classic whodunit scene set in a Victorian-style room. In the foreground, a man in a dark suit lies face down on the floor, suggesting he is dead or unconscious. A red police tape cordons off the area around him. To the left, a large bouquet of red flowers sits on a surface. In the center background, the words "WHODUNNIT?" are written in large, bold, yellow letters. The room is filled with various characters: a man in a top hat and coat stands near the flowers; another man in a suit and bowler hat stands behind the victim; a woman in a maid's uniform stands to the right; and other figures are visible in the shadows. The room has a fireplace, a painting on the wall, and a deer head mounted on the wall.

WHODUNNIT?

Visualization – Goals

Visualization is good for

- **Visual exploration**
 - find unknown/unexpected
 - generate new hypotheses

Nothing is known
about the data

Visualization – Goals

Visualization is good for

- **Visual exploration**
 - find unknown/unexpected
 - generate new hypotheses
- **Visual analysis (confirmative vis.)**
 - confirm or reject hypotheses
 - information drill-down

Nothing is known
about the data

There are hypotheses

Visualization – Goals

Visualization is good for

- **Visual exploration**
 - find unknown/unexpected
 - generate new hypotheses
- **Visual analysis (confirmative vis.)**
 - confirm or reject hypotheses
 - information drill-down
- **Presentation**
 - effective/efficient communication of results

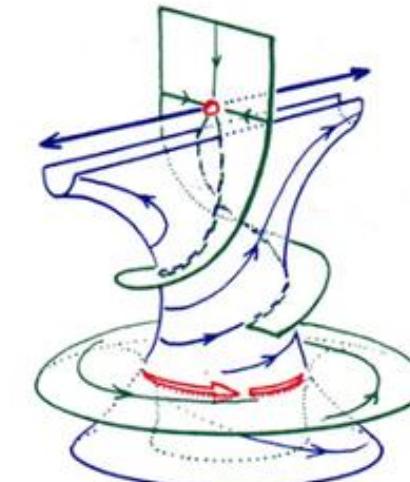
Nothing is known about the data

There are hypotheses

“Everything” is known

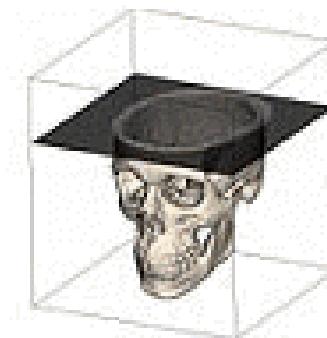
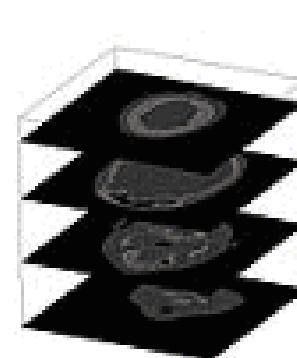
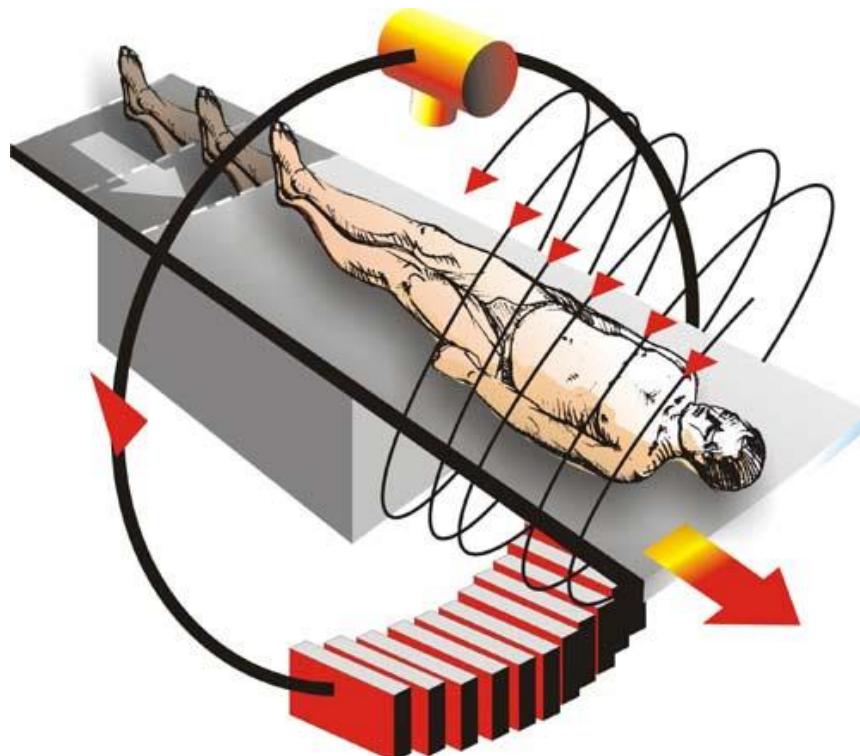
Data Sources

- Data may come from any source with arbitrary size
 - **Challenge**: efficiently visualize large-scale data sets and new data types
- Real world
 - Measurements and observation
- Theoretical world
 - Mathematical and technical models
- Artificial world
 - Data that is designed



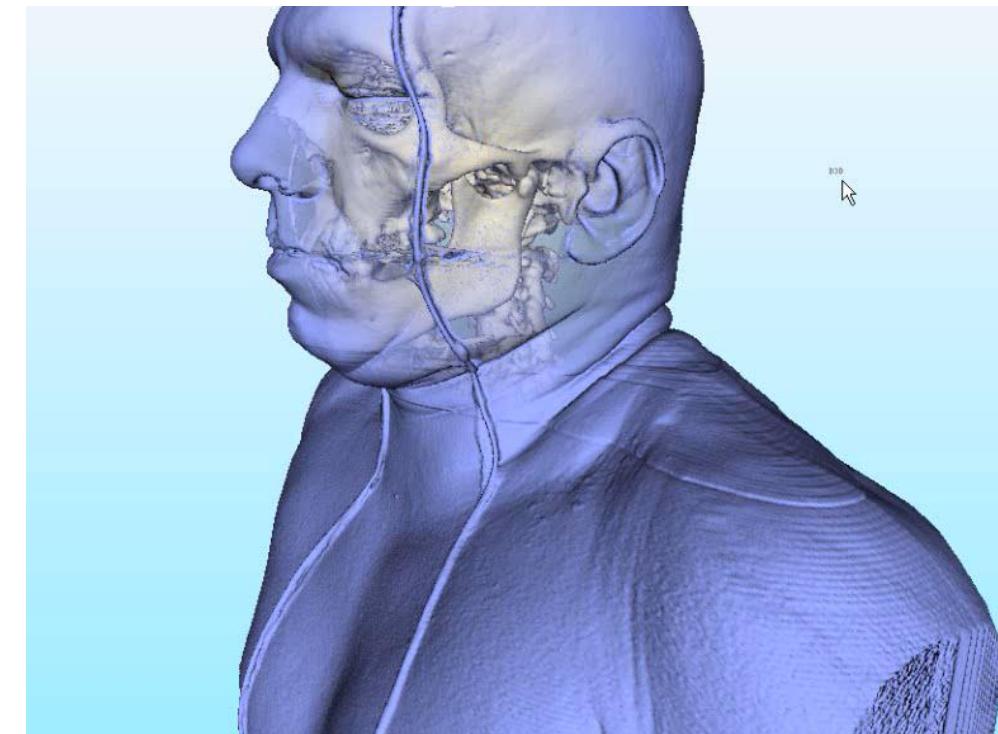
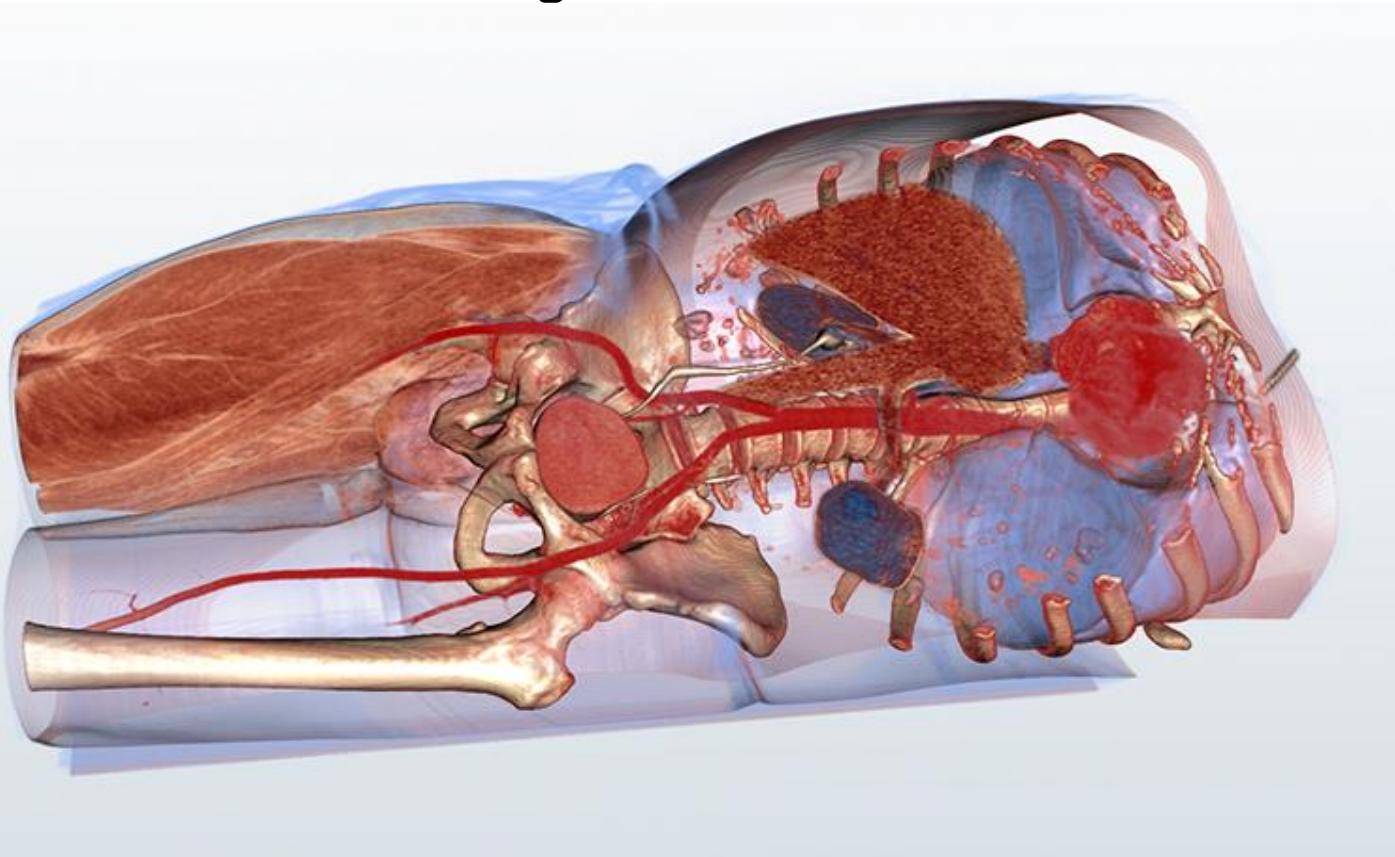
Data Sources – Medical Imaging

- Visualization of medical data sets
 - Provide insight into 3D scans



Data Sources – Medical Imaging

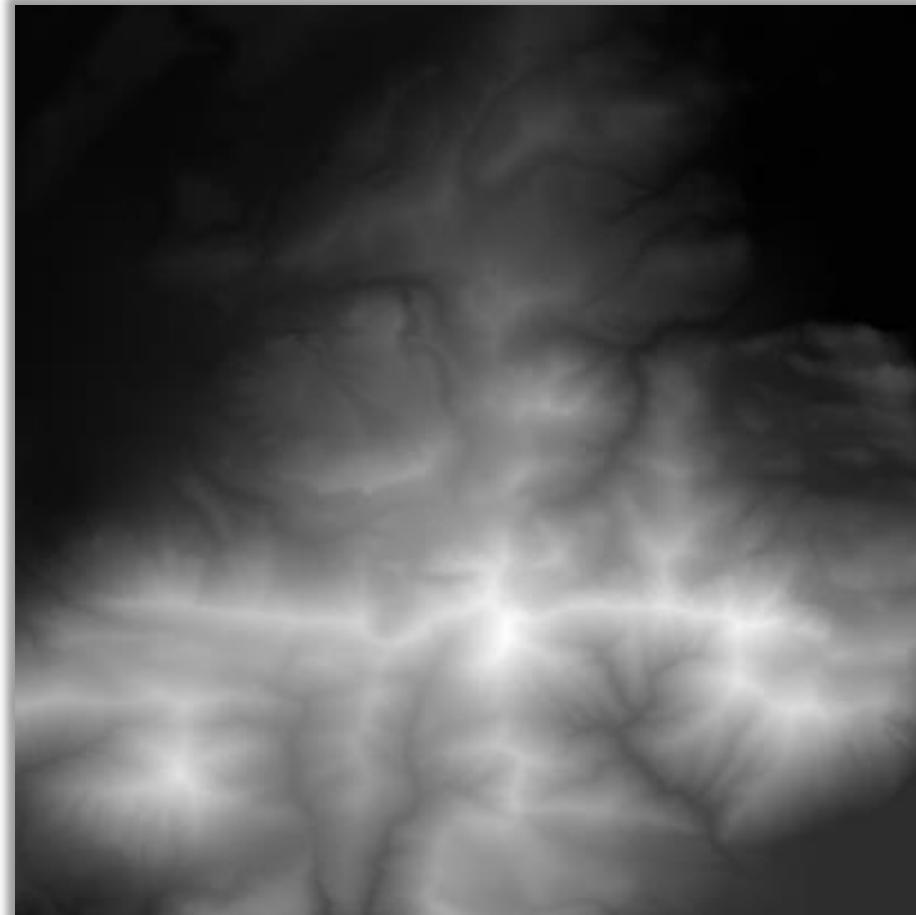
- Visualization of medical data sets
 - Provide insight into 3D scans



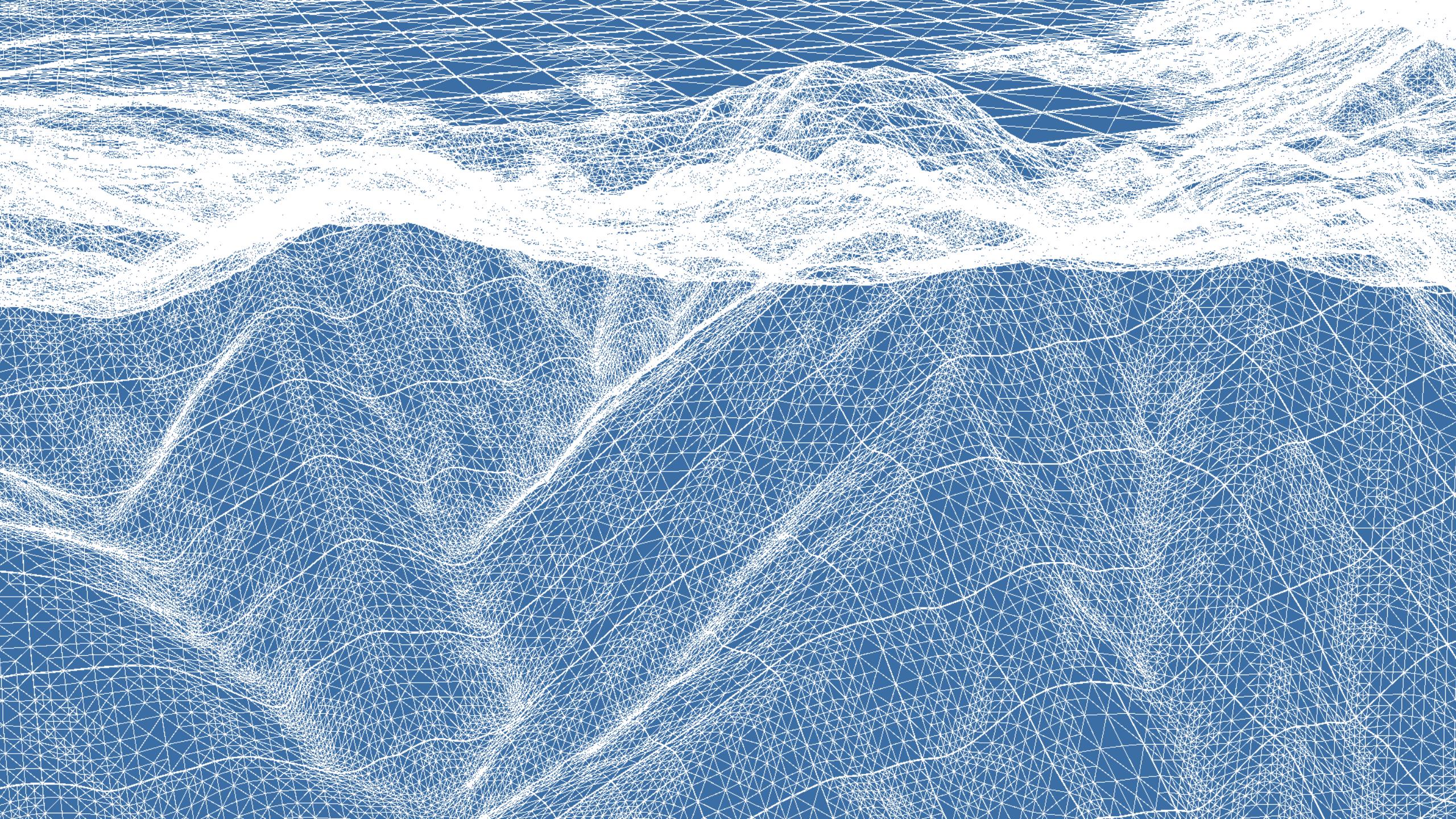
Data Sources – Remote Sensing



Orthophoto

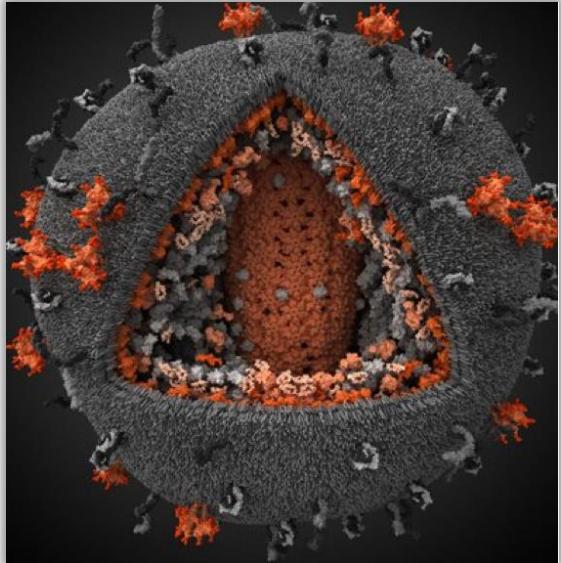


Digital Elevation Map

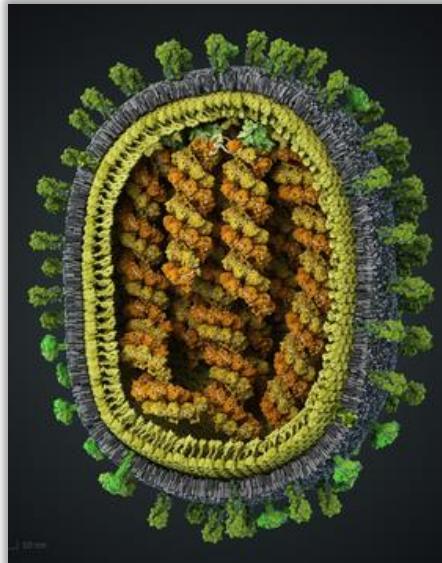




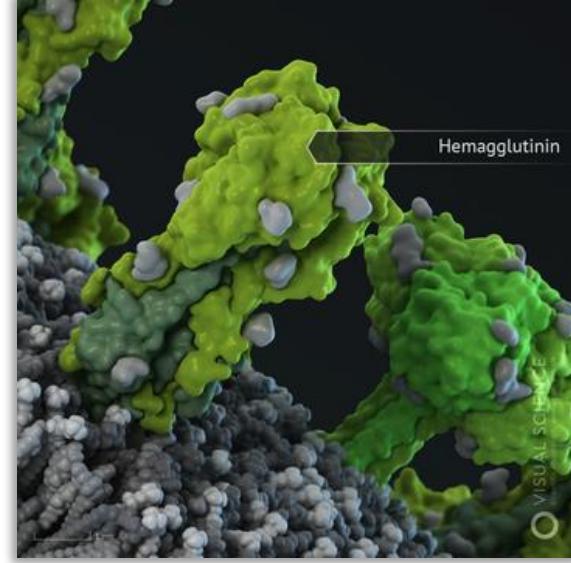
Data Sources – Bio Sciences



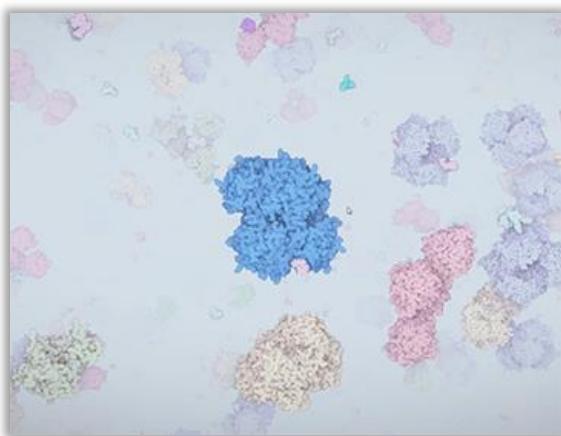
3D HIV model



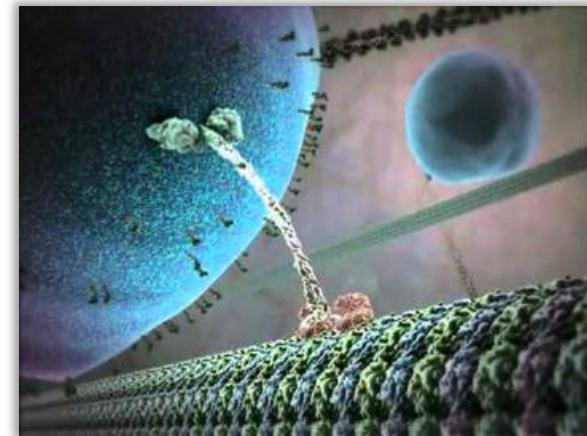
Influenza A/H1N1



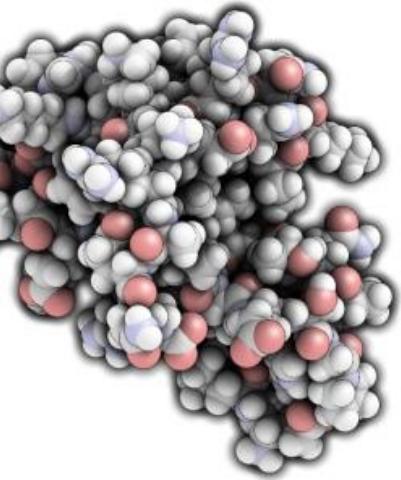
Molecular
visualization



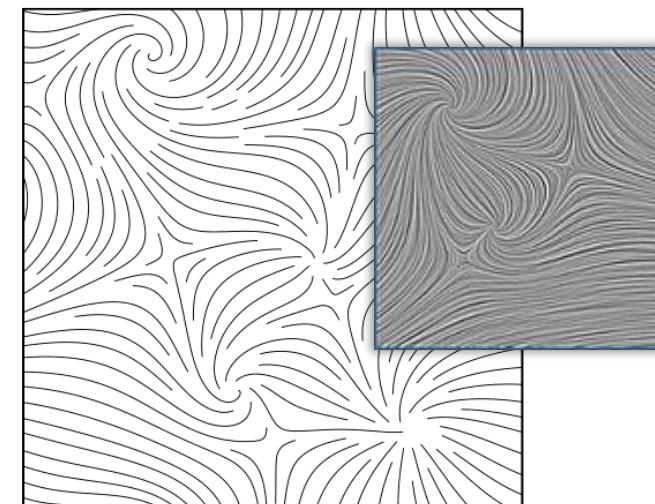
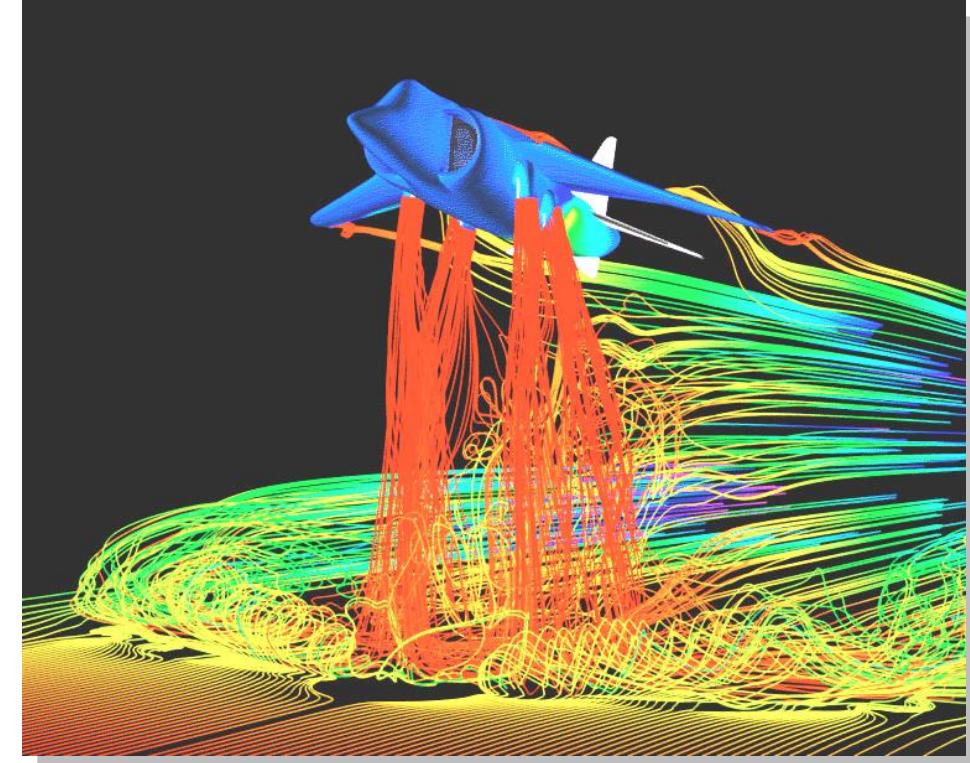
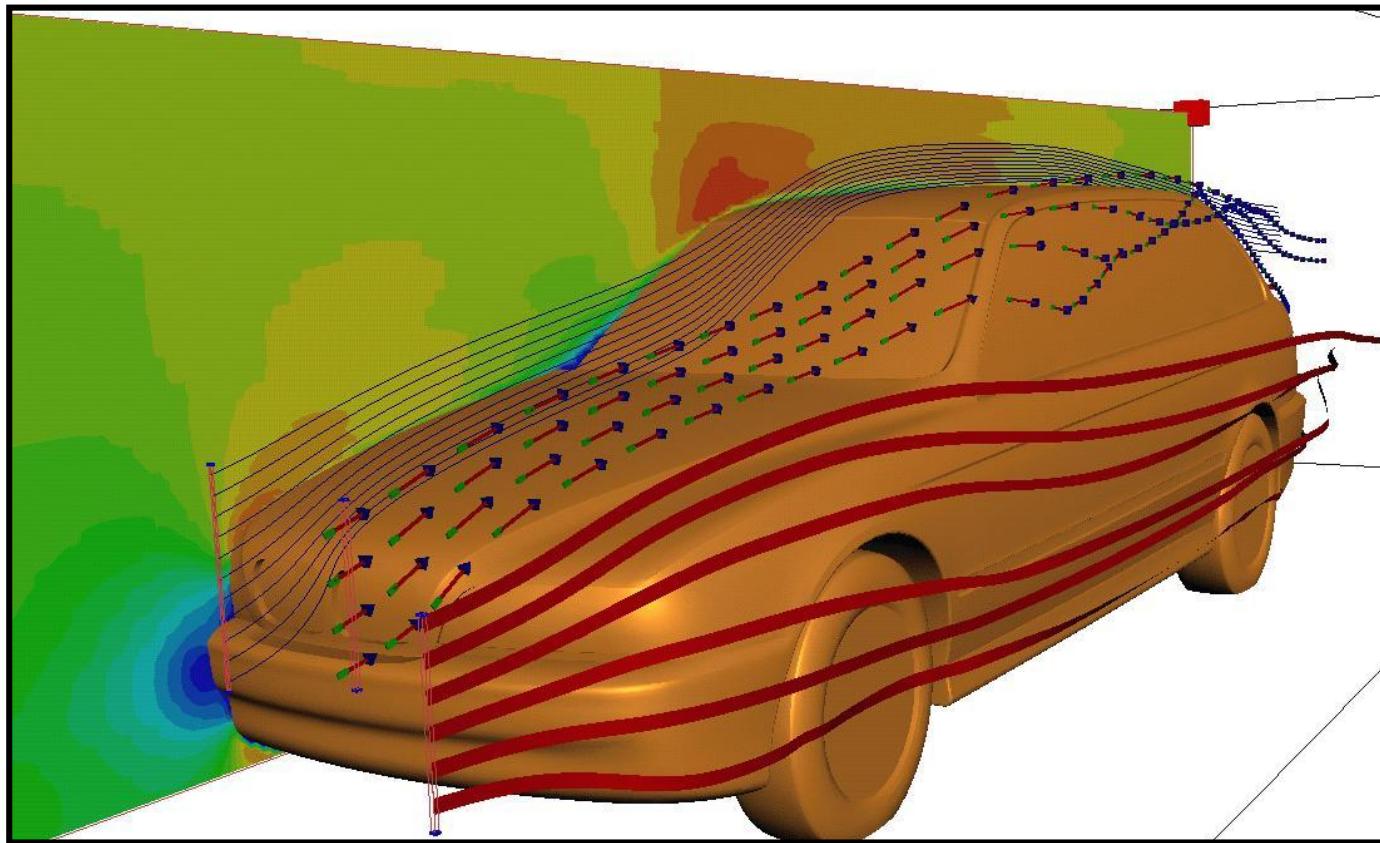
Molecular reactions ([link](#))



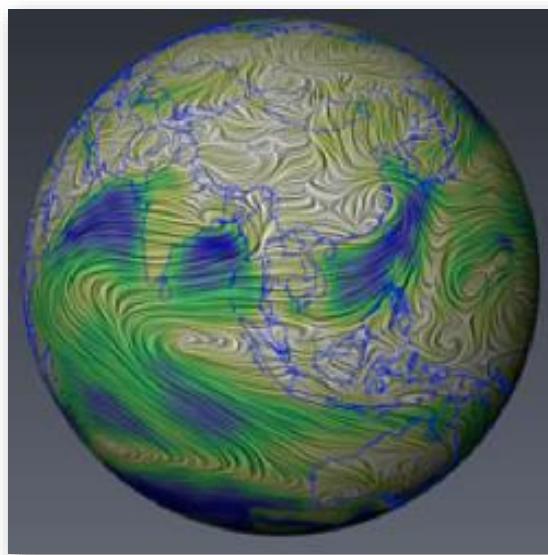
Inner life of a cell ([link](#))



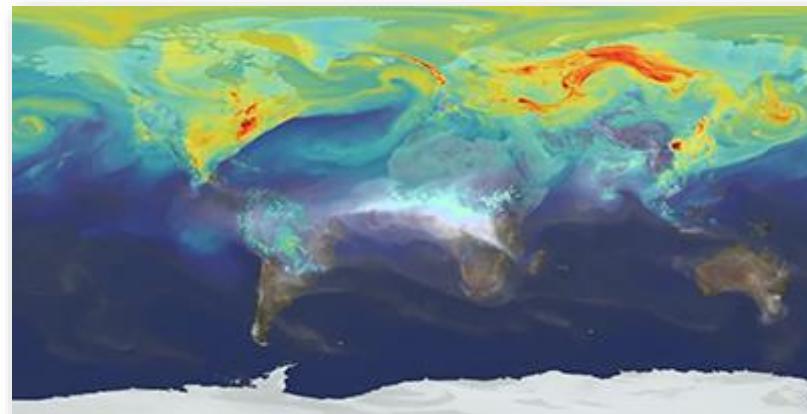
Data Sources – CFD



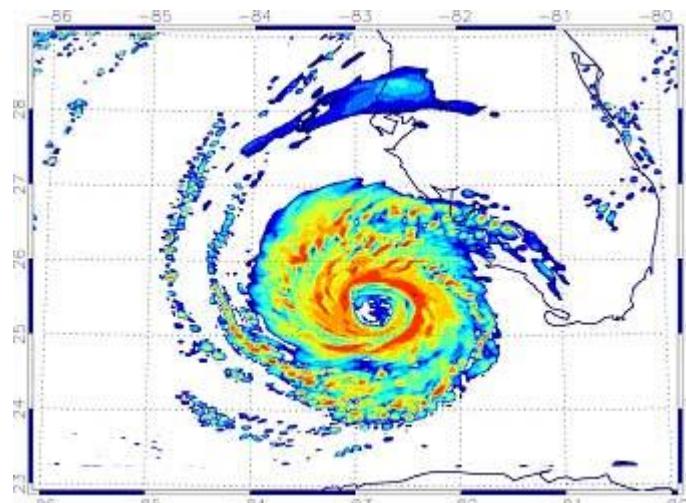
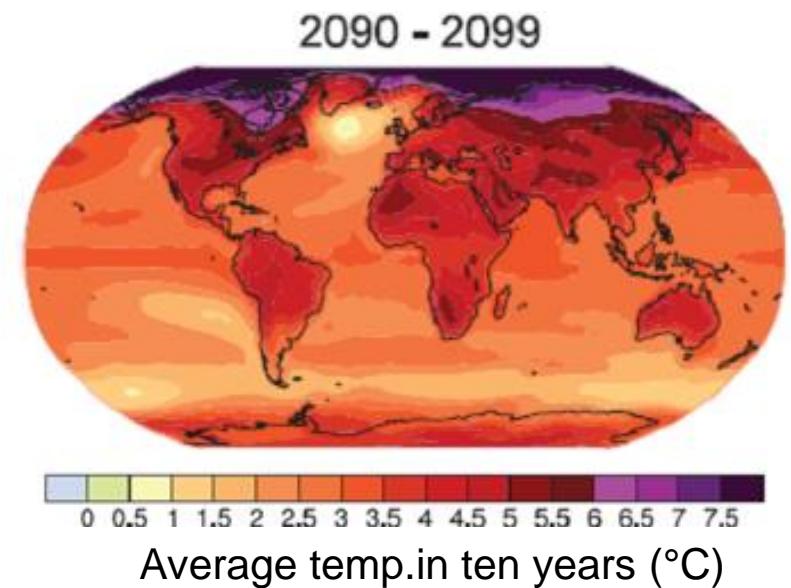
Data Sources – Geo Sciences



Wind flow paths over
Earth's surface



CO₂ in atmospheric flow ([link](#))

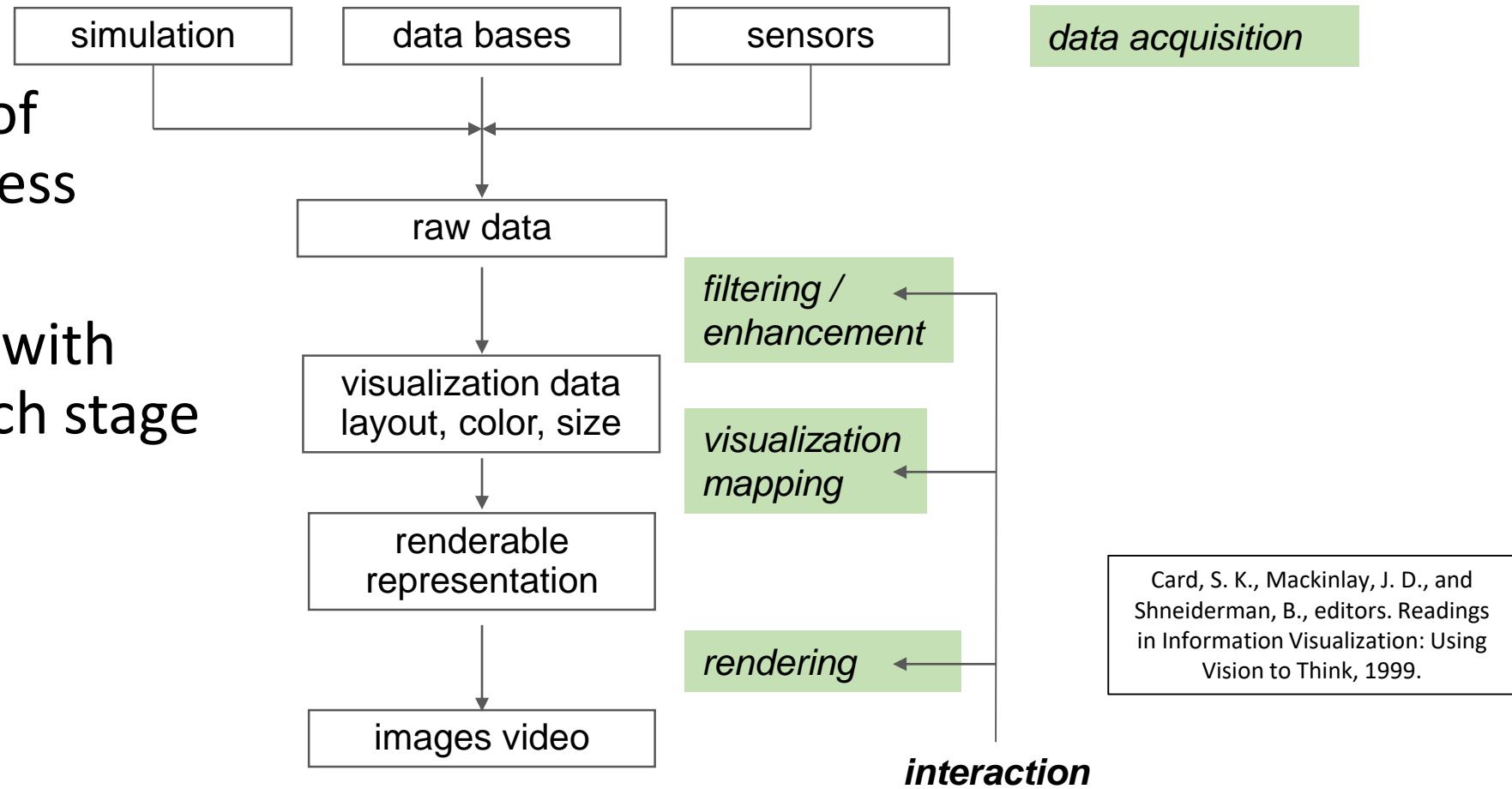


Hurricane visualization

Visualization Pipeline

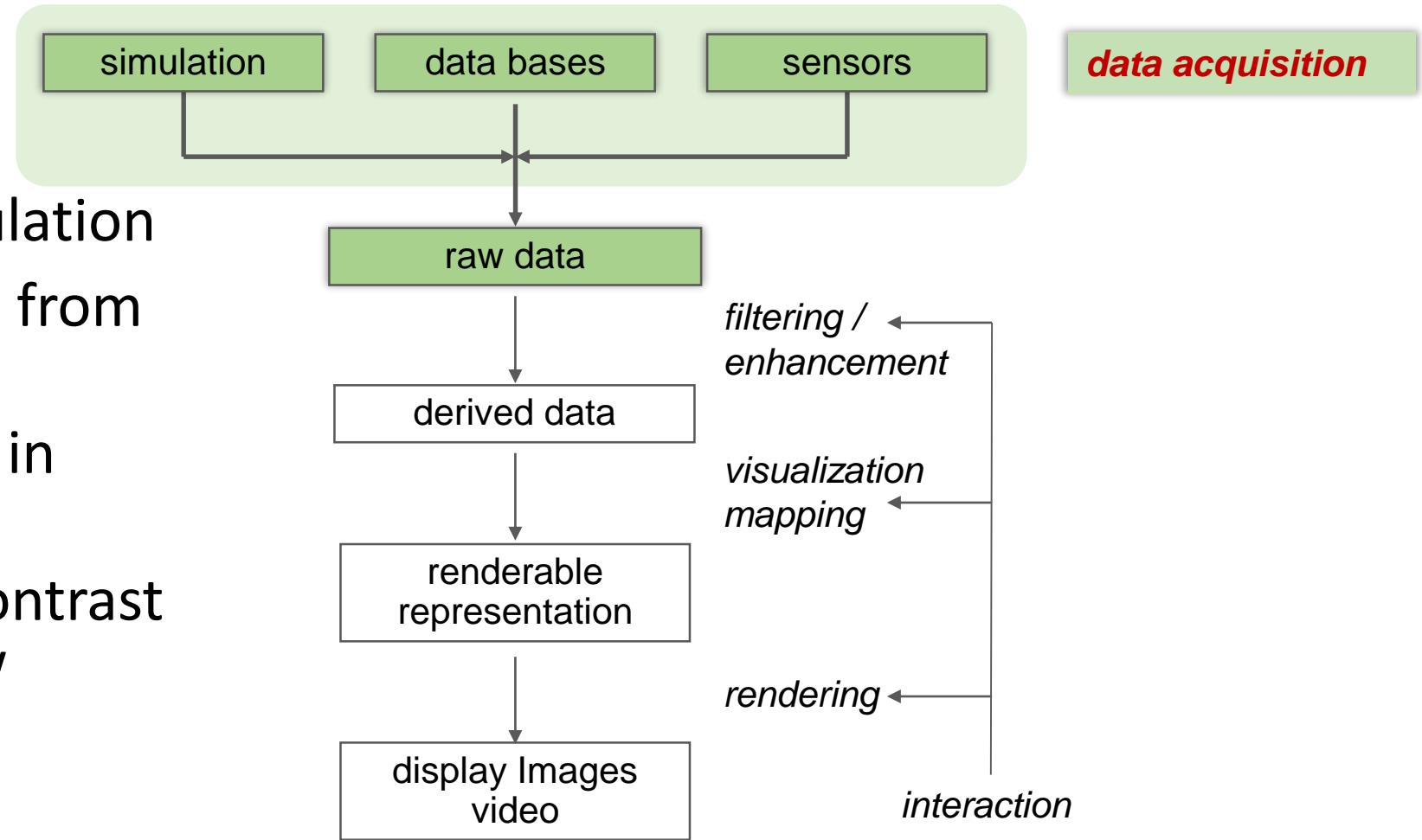
Visualization Pipeline

- A general model of visualization process with 4 stages
- User can interact with the process at each stage



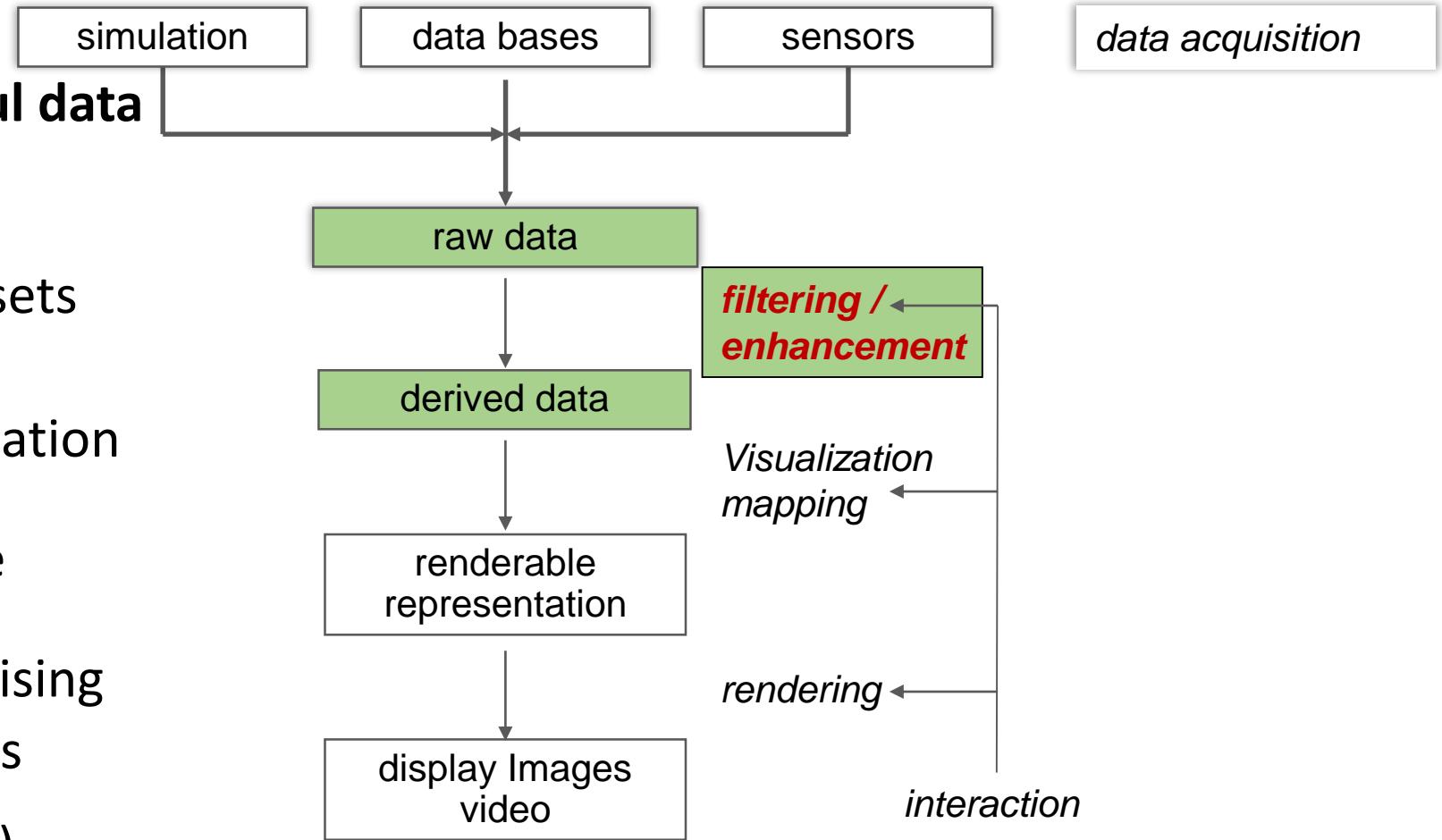
Visualization Pipeline

- **Examples**
- global climate simulation
- projected densities from CT
- images of particles in fluid
- concentration of contrast agent in blood flow
- weather radar data
- sonar data, ...



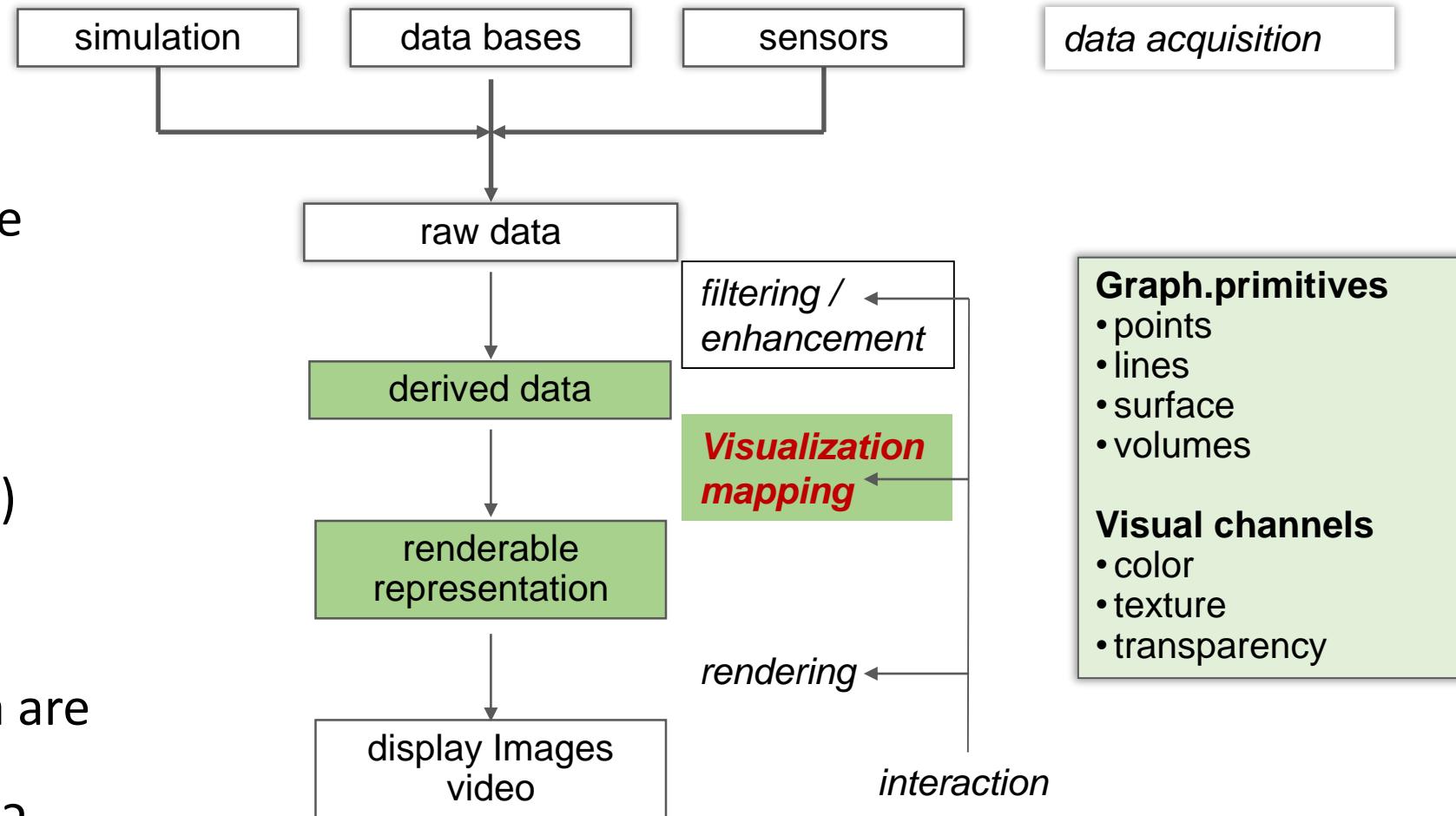
Visualization Pipeline

- **Process to obtain useful data (e.g., 3D volume)**
- data format conversion
- co-registration of data sets
- resampling to grid
- interpolation/approximation of missing values
- data reduction (remove nonrelevant data)
- clipping/cleaning/denoising
- characteristic properties (gradients, curvature, extrema, segmentation)



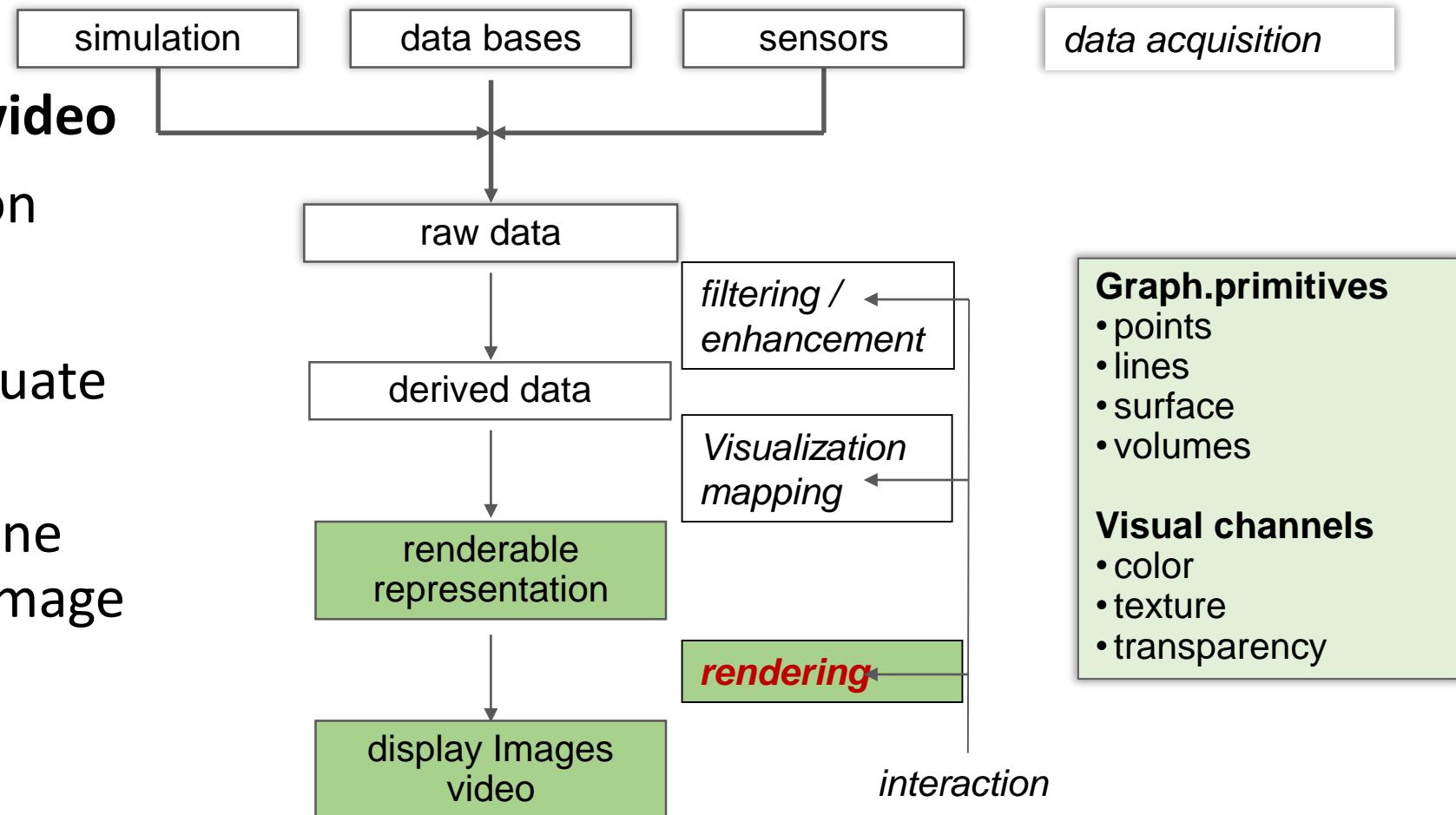
Visualization Pipeline

- **Derived data → graphical primitives**
- scalar field → isosurface
- 2D field → height field
- vector field → vectors
- tensor field → glyphs
- 3D field → volume (C, α)
- **Decide**
 - Which parts of the data are shown?
 - How to represent them?



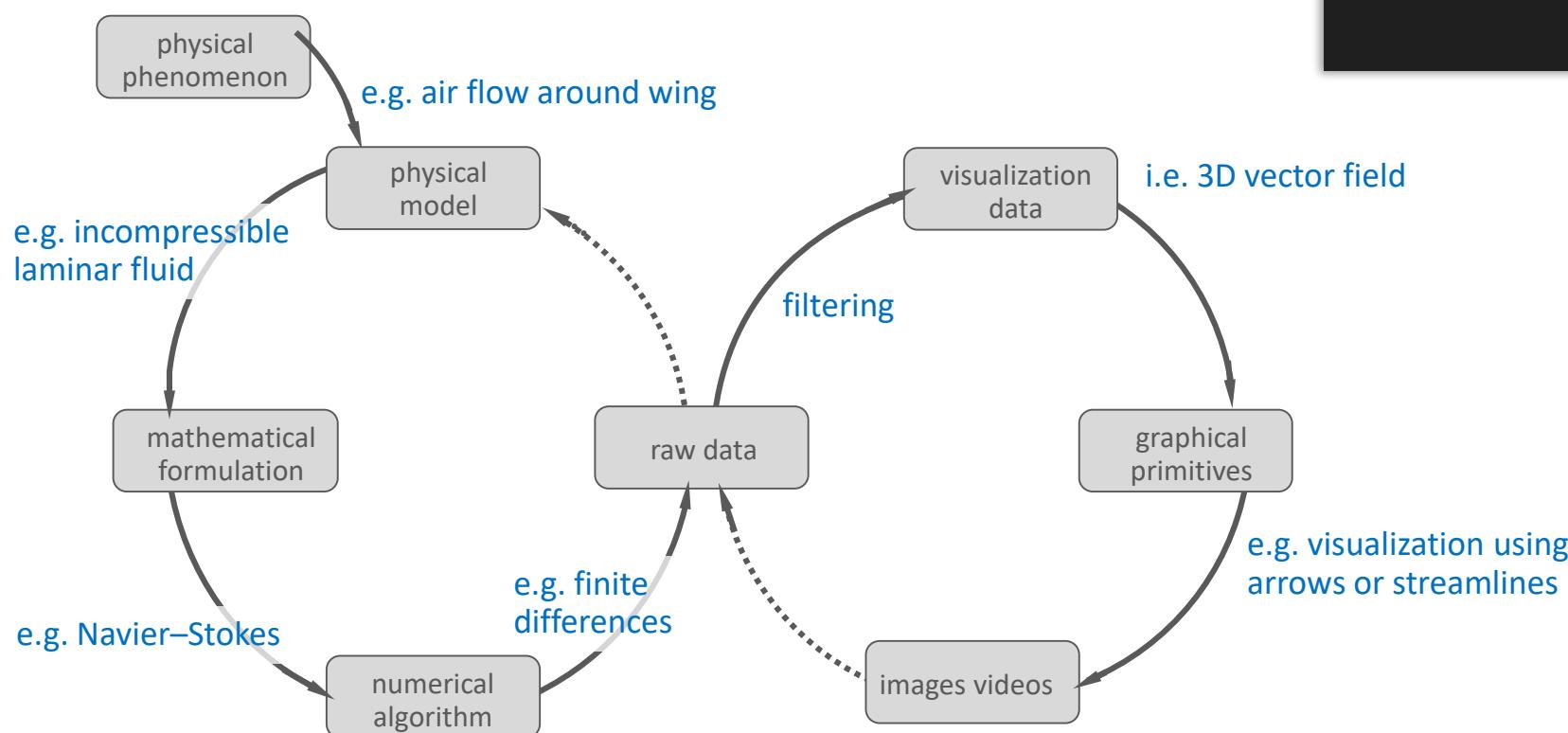
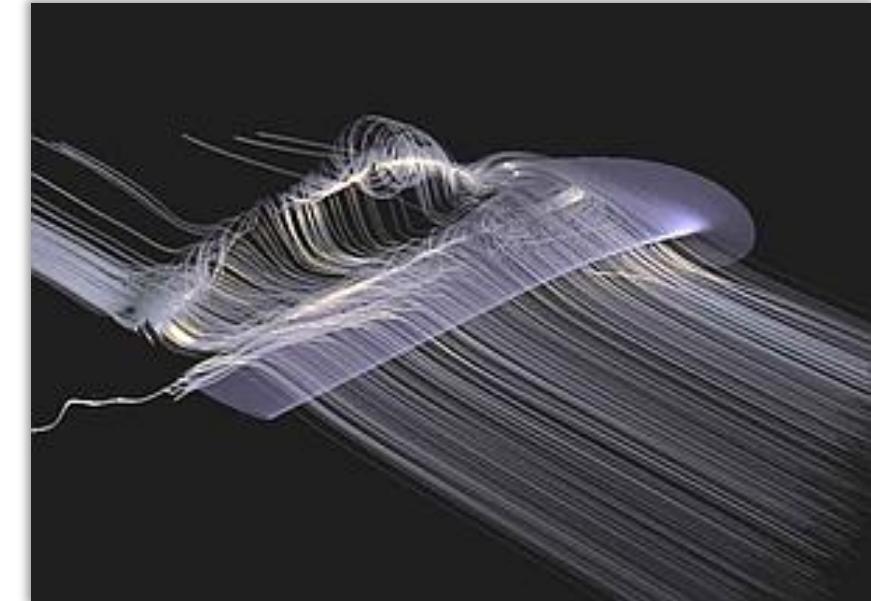
Visualization Pipeline

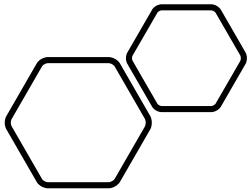
- **Generate 2D image/video**
- viewpoint specification
- visibility calculation
- lighting/shading: evaluate illumination model
- composition: determine contribution to final image
- compute values at sampling points



Visualization Pipeline

- Example: simulation of the flow around an airplane wing





Data, Visualization, Interaction

Data generation/acquisition

- Measuring, simulation, modeling
- Can take very long (measuring, simulation)
- Can be very expensive (simulation, modeling)

Visualization (rest of vis. pipeline)

- Data filtering/enhancement, vis.mapping, rendering
- Depends on computer/implementation: fast or slow

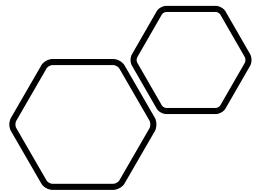
Interaction (user input)

- How can users change parameters, viewpoint, etc.

Thanks

Slide Credits

- Thanks to:
 - Rüdiger Westermann (TU Munich)
 - Tobias Günther (ETH Zurich)
 - Bernhard Preim (OVGU Magdeburg)



Questions???