EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

The Visualization Process

Scientific Visualization – Summer Semester 2021

Jun.-Prof. Dr. **Michael Krone**

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- Overview of the visualization process
- Visualization pipeline
- Visualization scenarios
- Presentational visualization
- Data types and classification of visualization techniques

Overview of the Visualization Process

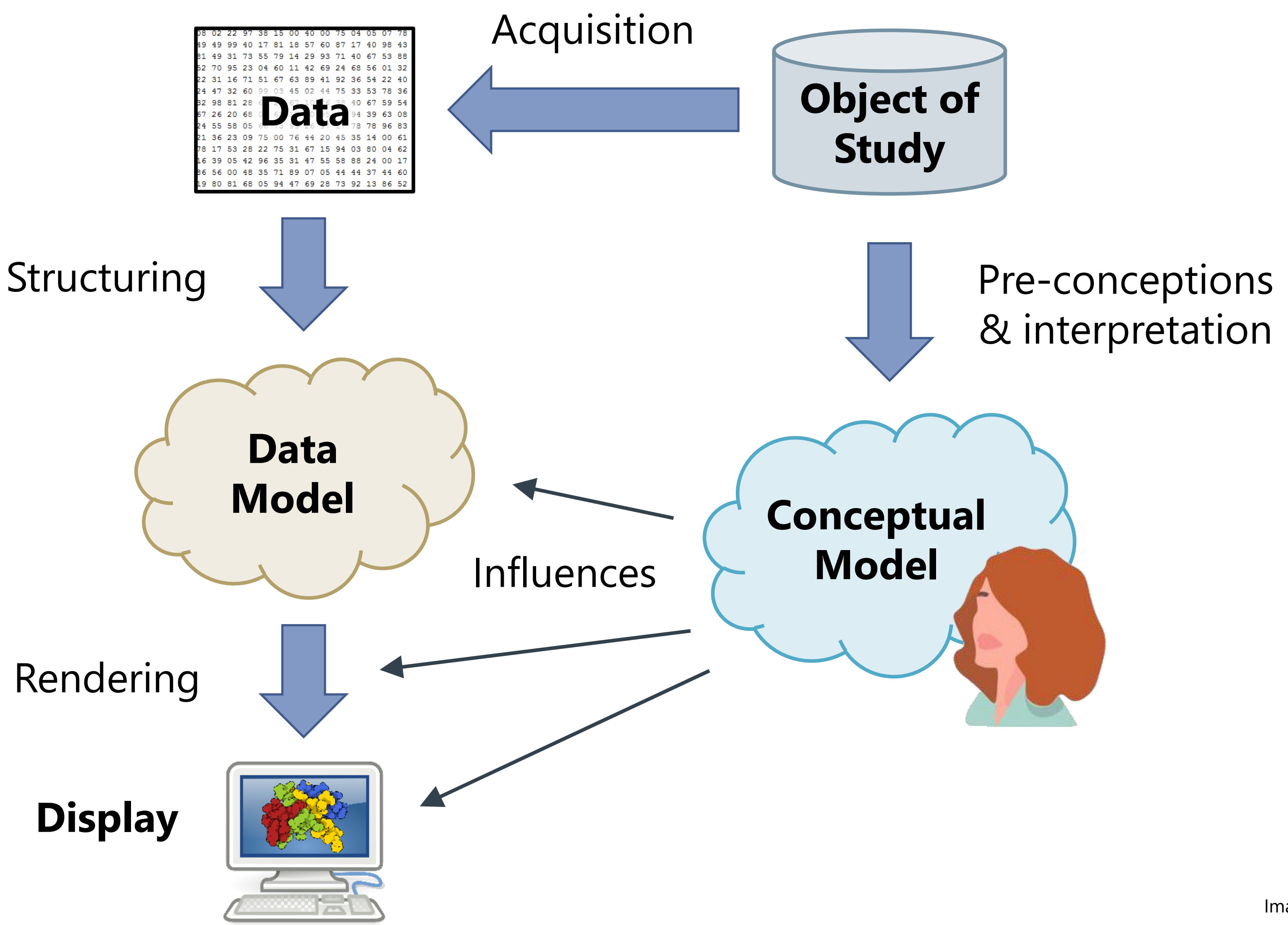


Image adapted from Weiskopf/Machiraju/Möller.

Goals of Visualization Process

- Presentation
  - Starting point: facts to be presented are fixed a priori
  - Process: choice of appropriate presentation techniques
  - Result: high-quality visualization of the data to present facts
- Confirmatory analysis
  - Starting point: hypotheses about the data
  - Process: goal-oriented examination of the hypotheses
  - Result: visualization of data to confirm or reject the hypotheses
- Exploratory analysis
  - Starting point: no hypotheses about the data
  - Process: interactive, usually undirected search for structures, trends
  - Result: visualization of data to lead to hypotheses about the data

[according to F. Mansmann: Visual Analytics Tutorial]

Visualization: Confirmatory/Exploratory Analysis

Anscombe's Quartet: Raw Data

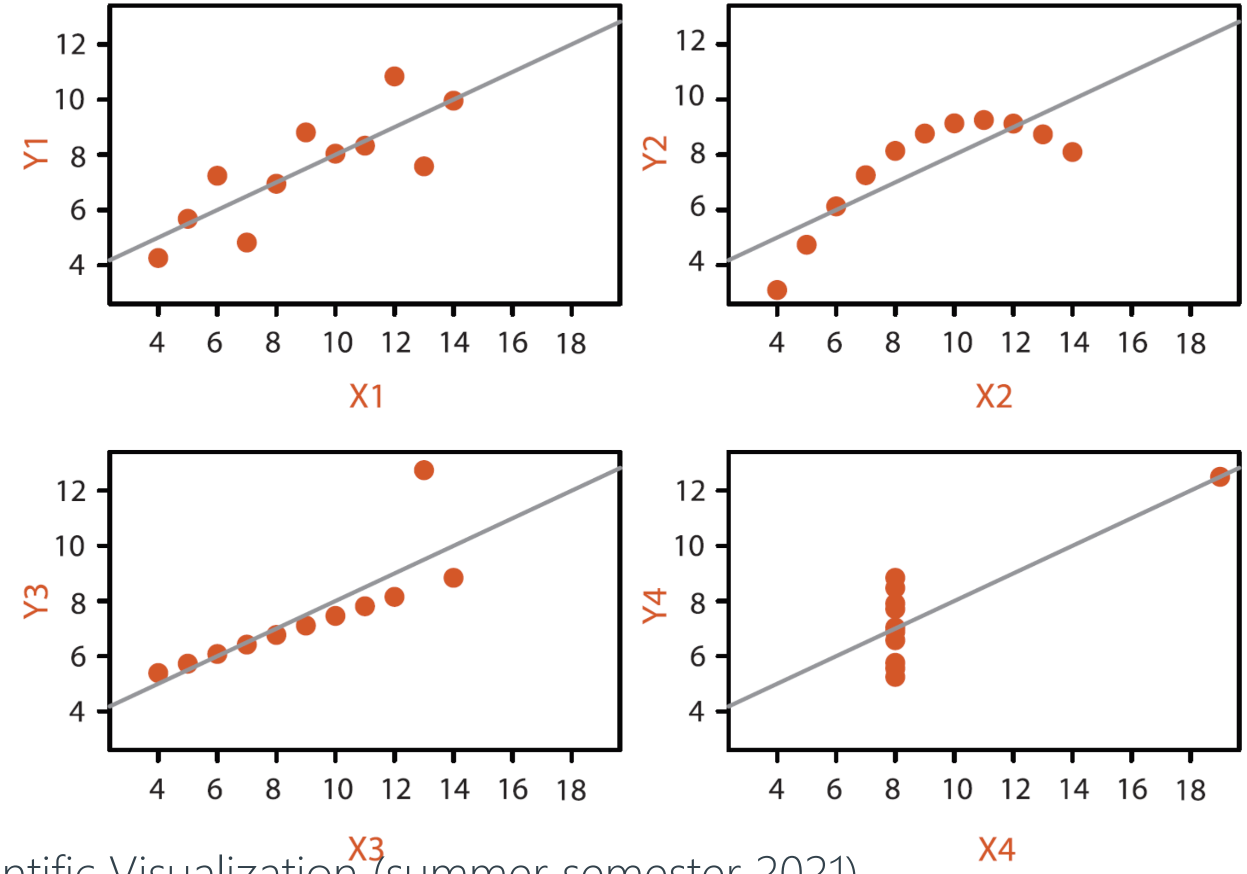
	1		2		3		4	
	X	Y	X	Y	X	Y	X	Y
	10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
	8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
	13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
	9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
	11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
	14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
	6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
	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
Mean	9.0	7.5	9.0	7.5	9.0	7.5	9.0	7.5
Variance	10.0	3.75	10.0	3.75	10.0	3.75	10.0	3.75
Correlation	0.816		0.816		0.816		0.816	

Anscombe, F. J. Graphs in statistical analysis., 1973

Visualization: Confirmatory/Exploratory Analysis

Oversimplification →

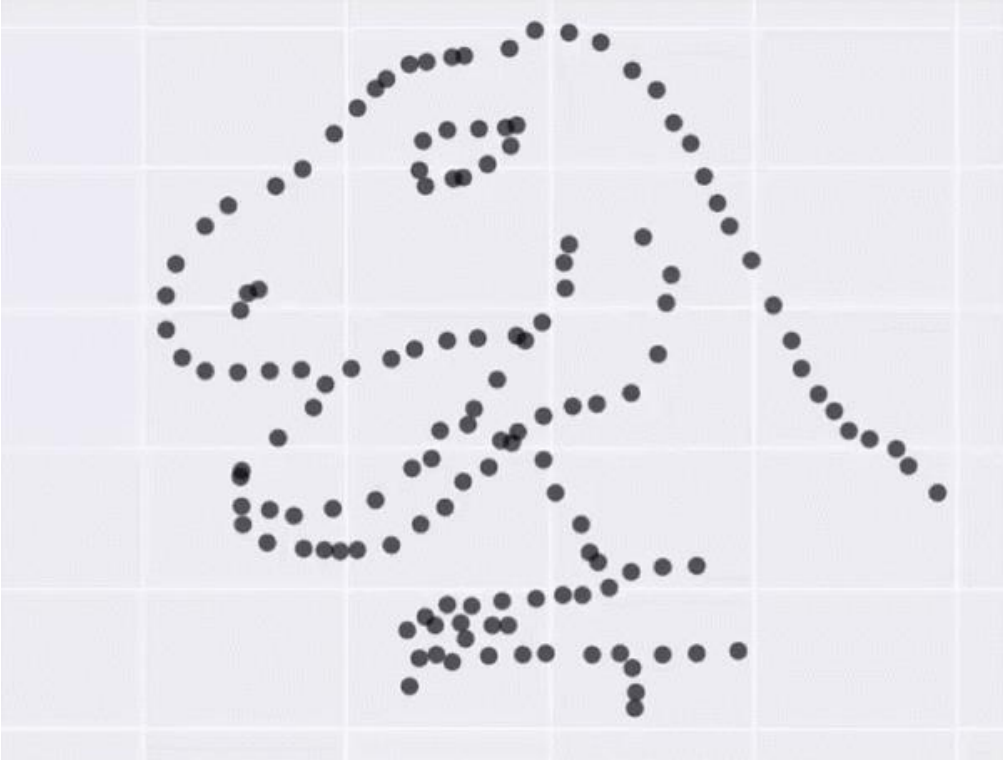
Mean	9.0	7.5	9.0	7.5	9.0	7.5	9.0	7.5
Variance	10.0	3.75	10.0	3.75	10.0	3.75	10.0	3.75
Correlation	0.816		0.816		0.816		0.816	

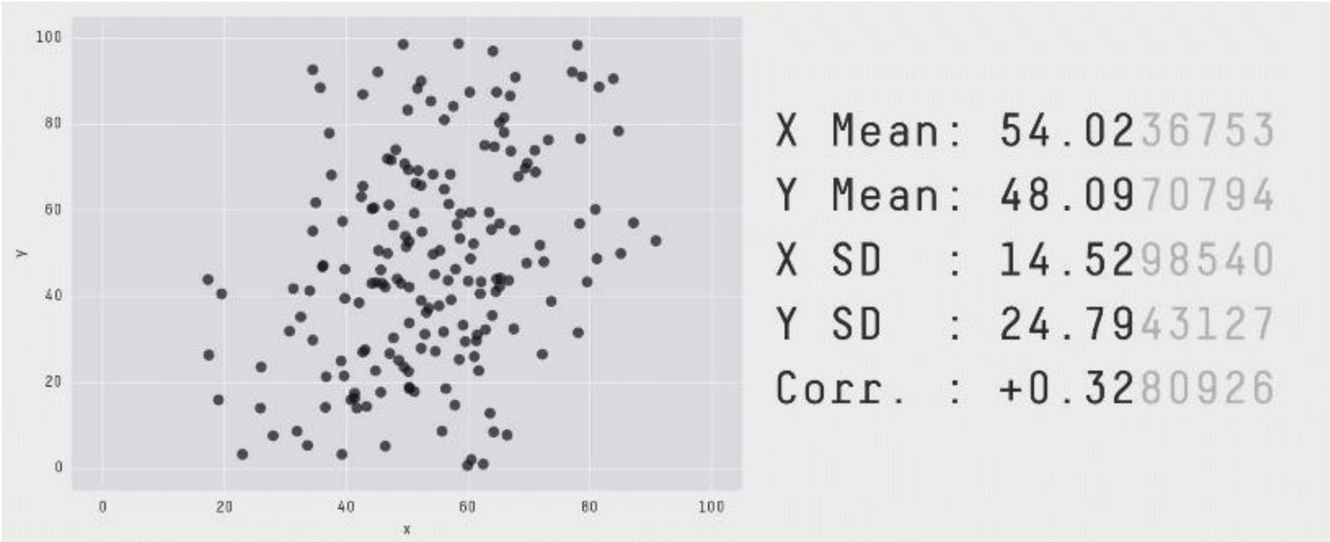


Anscombe, F. J. Graphs in statistical analysis., 1973 [Munzner, 2014]

Visualization: Confirmatory/Exploratory Analysis

J. Matejka, G. Fitzmaurice: “Same Stats, Different Graphs: Generating Datasets with Varied Appearance and Identical Statistics through Simulated Annealing”, ACM SIGCHI Conference on Human Factors in Computing Systems, 2017.





User-Centered View on Exploration

- How is the user doing this ?
  - By acquiring overview information (“global view”)
  - By acquiring detail information (“local view”)
  - By limiting the information space being examined
  - By focusing while maintaining context
  - By navigating through an information space
- How can we help the user ?
  - By representing and presenting information appropriately
  - By providing suitable controls and navigational cues for limiting, focusing, and the control of movement in information space

[according to F. Mansmann: Visual Analytics Tutorial]

Visual Information-Seeking Mantra

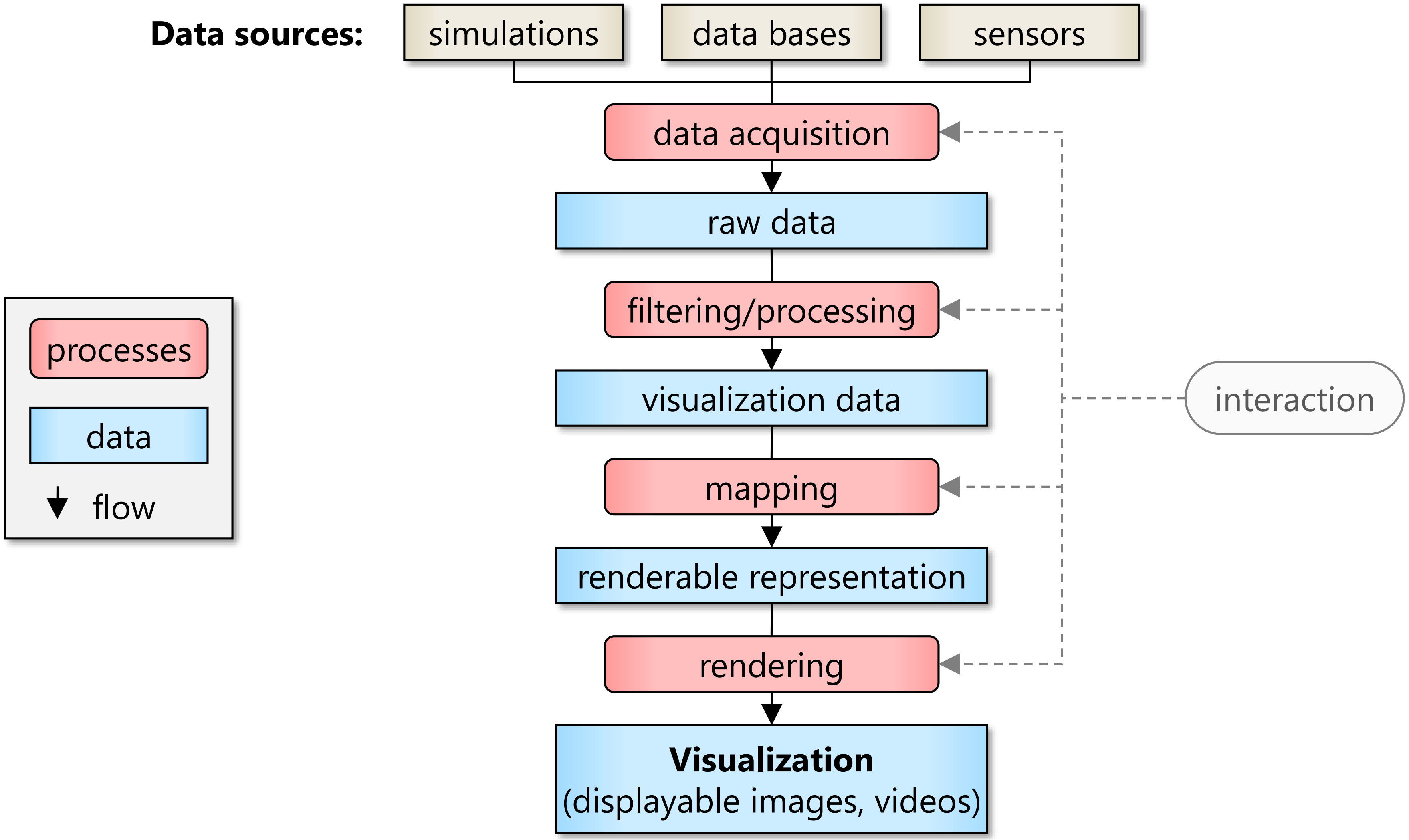
Overview first, zoom and filter, then details-on-demand.

Ben Shneiderman

[Ben Shneiderman, "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations". In Proceedings of the IEEE Symposium on Visual Languages, 336-343, 1996.]

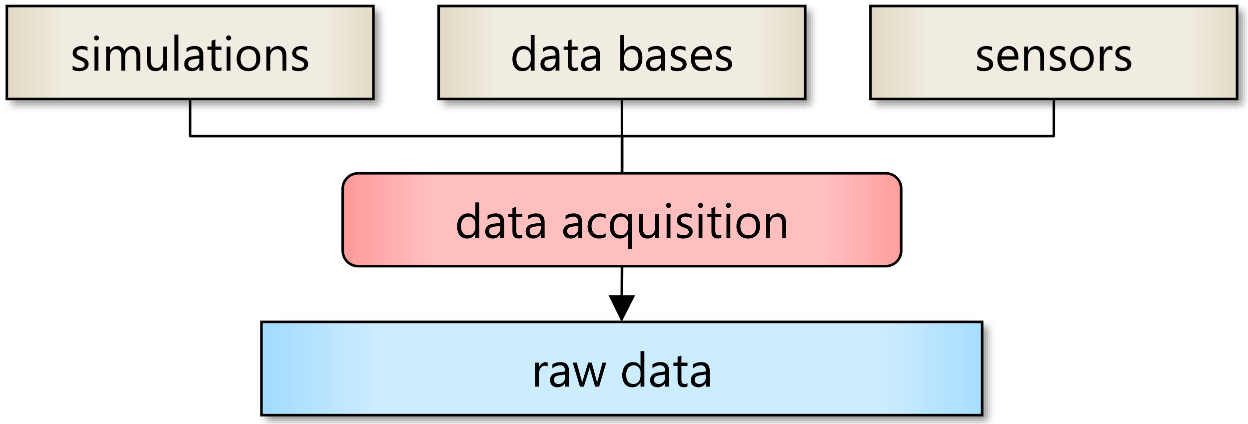
Visualization Pipeline

[Haber, McNabb 1990]



Visualization Pipeline – Data Acquisition

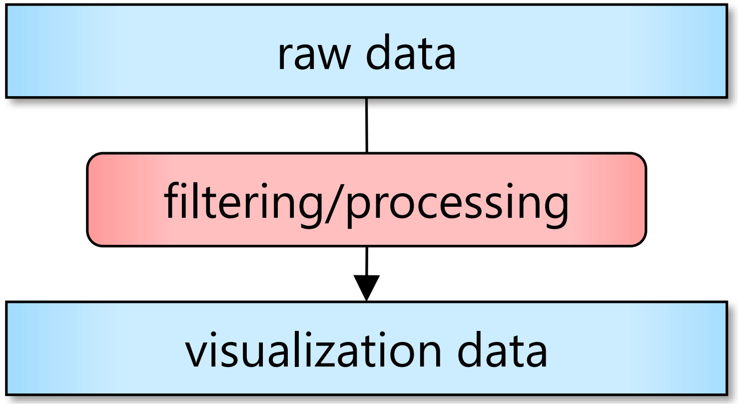
- Data sources
- Data representation
- Time dependency



Visualization Pipeline – Filtering

Data → data

- Data format conversion
- Clipping/cropping/de-noising
- Slicing
- Resampling
- Interpolation/approximation
- Classification/segmentation

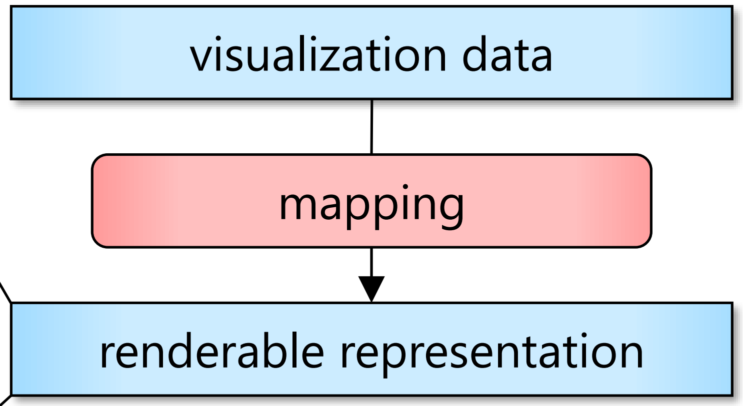


Visualization Pipeline – Mapping

- Data → graphical primitives, triangle meshes
- Scalar field → isoline/isosurface
- 2D field → height field
- 3D field → volume
- Vector field → arrows
- Tensor field → glyphs

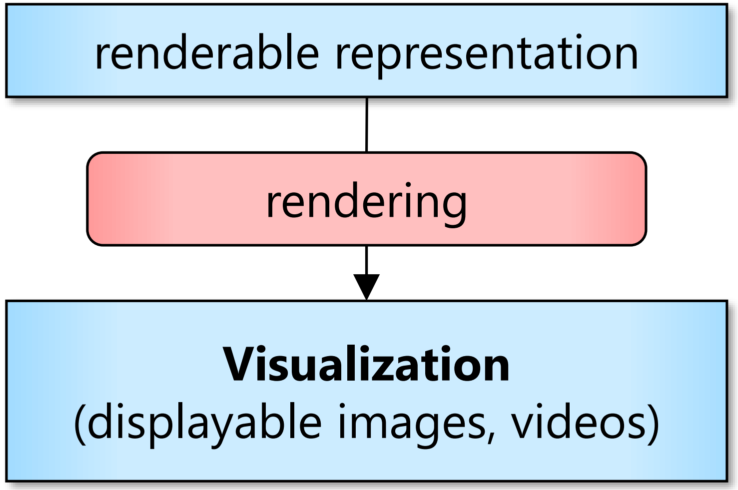
Graphical Primitives:
- Points
- Lines
- Surface
- Volumes

Attributes:
- Color
- Texture
- Transparency



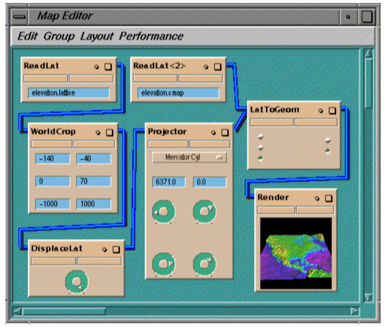
Visualization Pipeline – Rendering

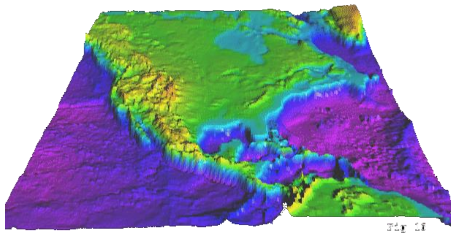
- Geometry, Images, Volumes,…
- Image Synthesis / Rendering Methods
  - e.g.: rasterization (OpenGL, D3D, Vulkan), ray tracing
- “Realism“
  - e.g.: shadows, lighting, shading
- Non-photorealistic rendering



Visualization Pipeline

- **Example:** IRIS Explorer
  - 1992, Silicon Graphics (SGI)
  - Application-building system for collaborative scientific visualization
  - Distributed, heterogeneous environments
  - Visual programming environment
    - Graphical dataflow models





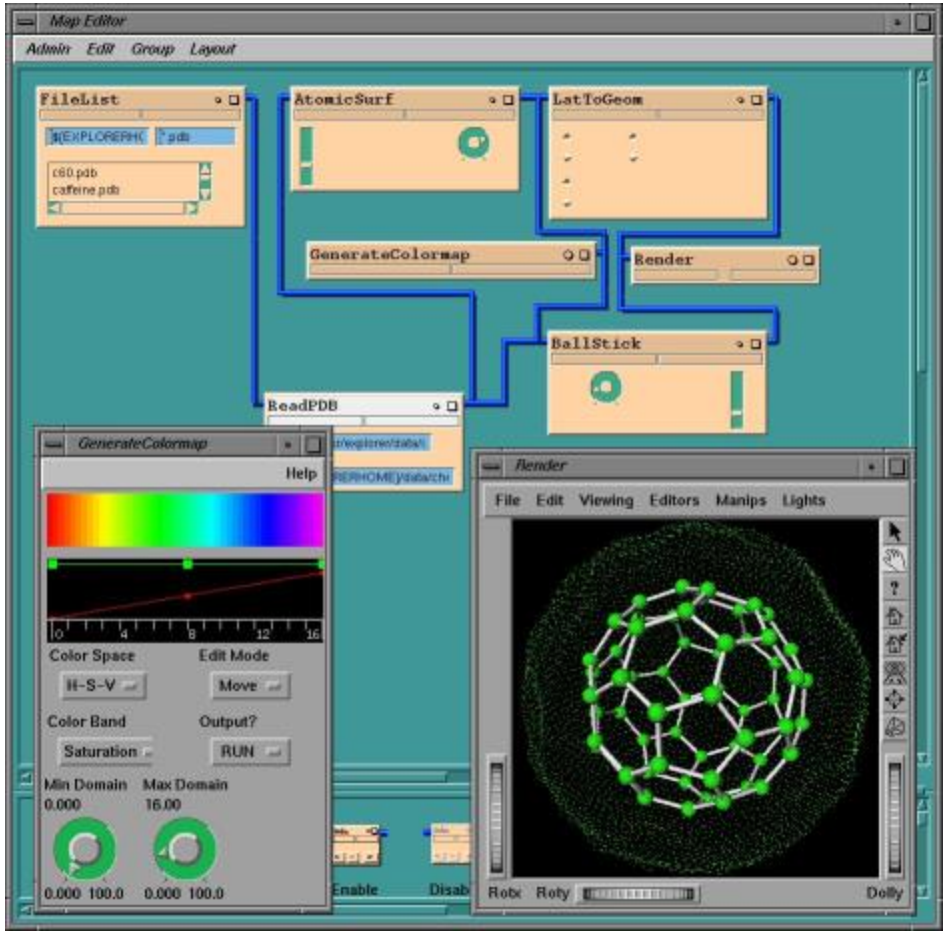
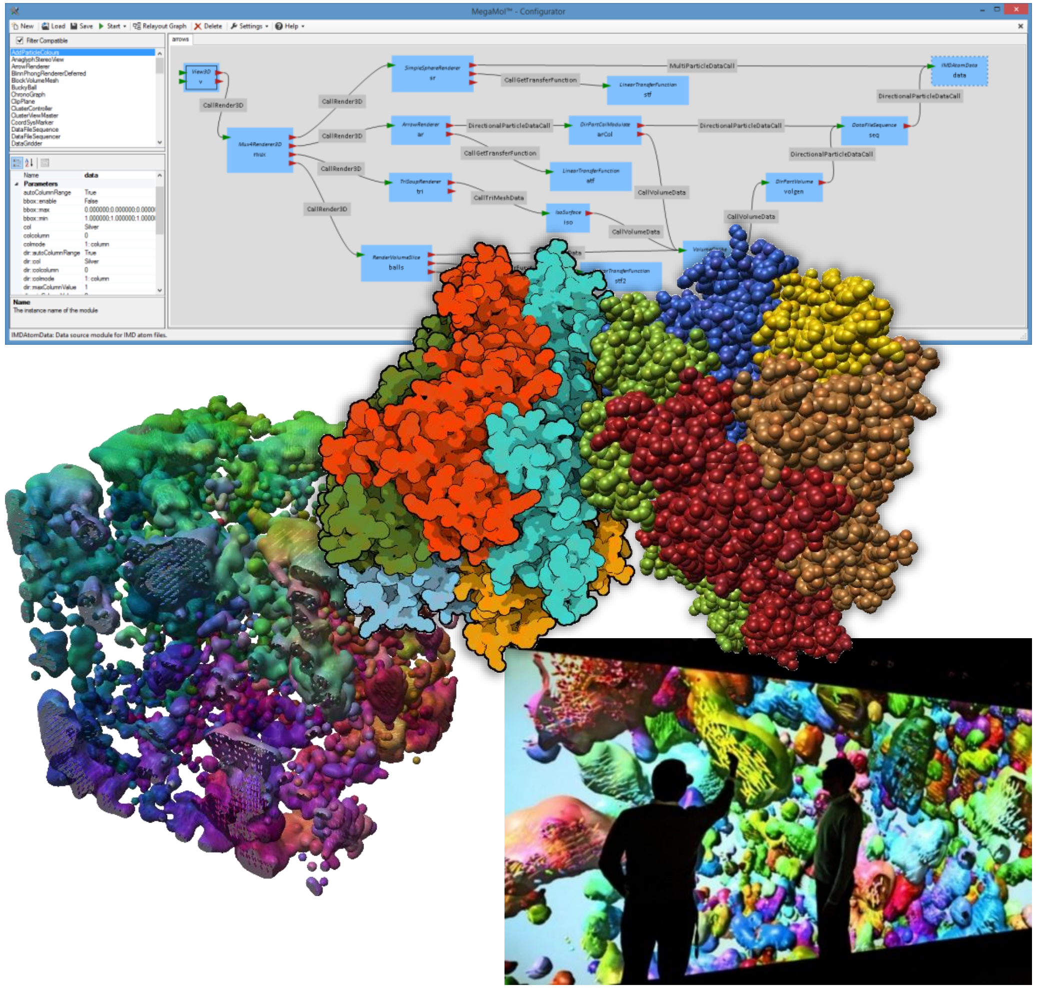


Image Source: http://yohanan.org/steve/projects/iris-explorer

Visualization Pipeline

- **Example:** MegaMol
  - Started 2006, University of Stuttgart
    - University of Dresden, University of Tübingen
  - Cross-platform scientific visualization prototyping framework (Linux, Windows)
  - Originally designed for large, dynamic particle simulations
    - Has evolved into a general-purpose visualization framework
  - Distributed, heterogeneous environments
  - Visual programming environment
    - Graphical dataflow models

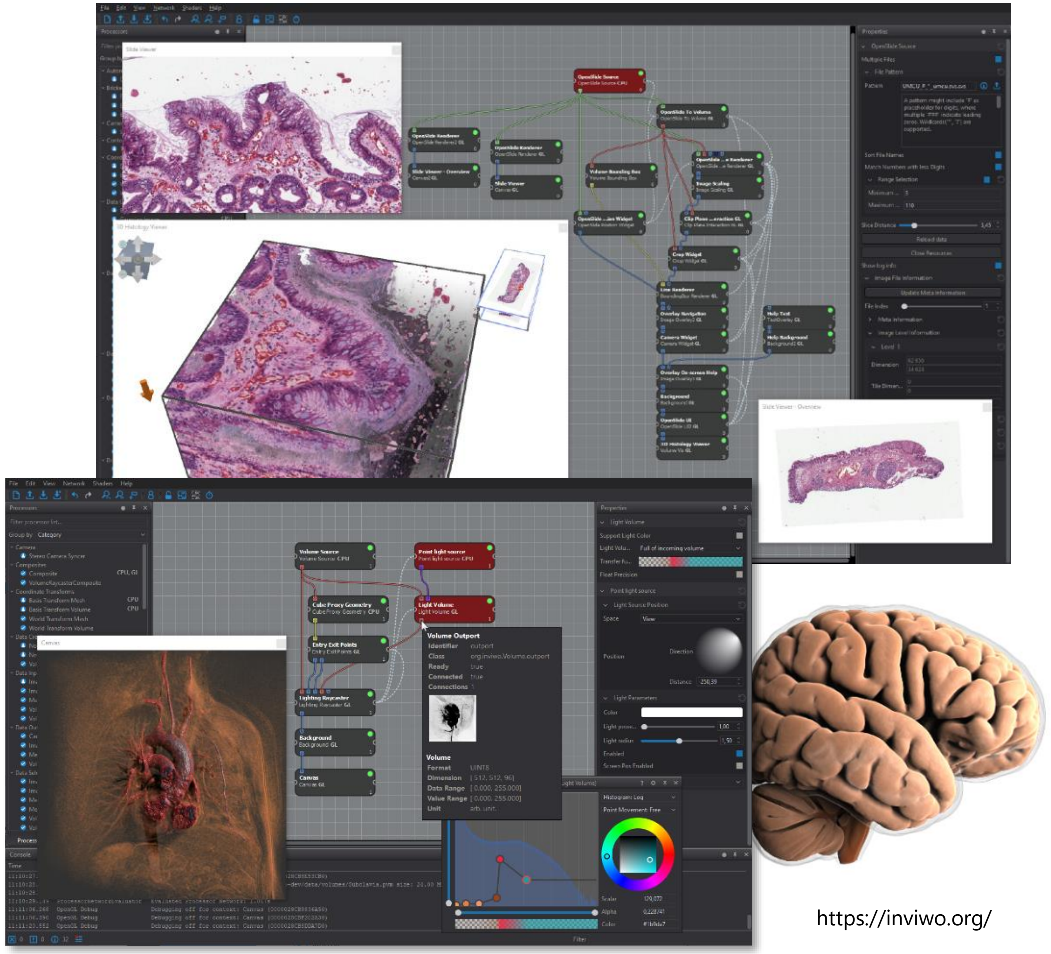


S. Grottel, M. Krone, C. Müller, G. Reina, and T. Ertl, "MegaMol - A Prototyping Framework for Particle-based Visualization," IEEE Trans. Vis. Comput. Graphics, vol. 21, no. 2, pp. 201–214, 2015. https://megamol.org/

Visualization Pipeline

Inviwo

- **Example:** Inviwo
  - Started ~2014
  - Linköping University, Ulm University, KTH Royal Institute of Technology
  - "Free configurable visualizations for scientific data"
    - Initially designed for medical volume rendering
    - Has been extend to geometry/meshes, particles, images, vector fields etc.
  - Visual programming environment
    - Graphical dataflow models
  - Python scripting

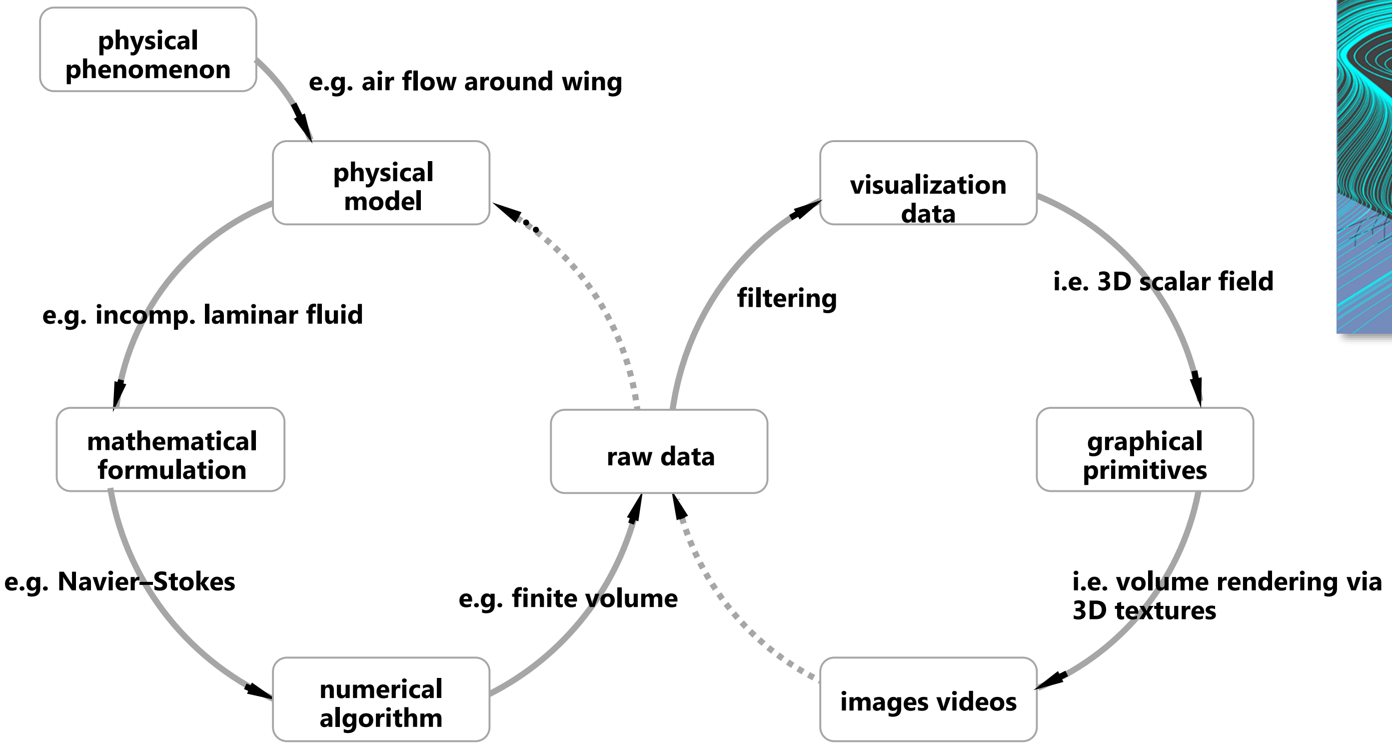


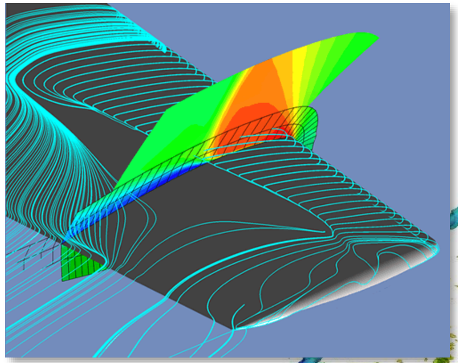
https://inviwo.org/

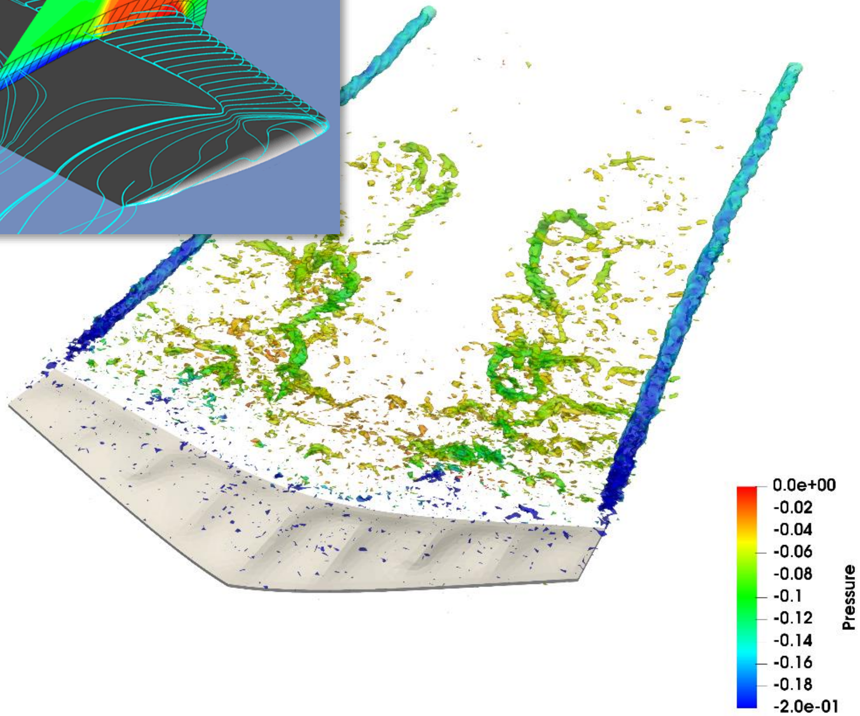
D. Jönsson, P. Steneteg, E. Sundén, R. Englund, S. Kottravel, M. Falk, A. Ynnerman, I. Hotz, and T. Ropinski, "Inviwo - A Visualization System with Usage Abstraction Levels," IEEE Trans. Vis. Comput. Graphics, 2019.

Scenarios – Confirmatory / Exploratory Analysis

- Visualization process only reasonable if visualized data is analyzed
- **Example:** simulation of the air flow around a wing







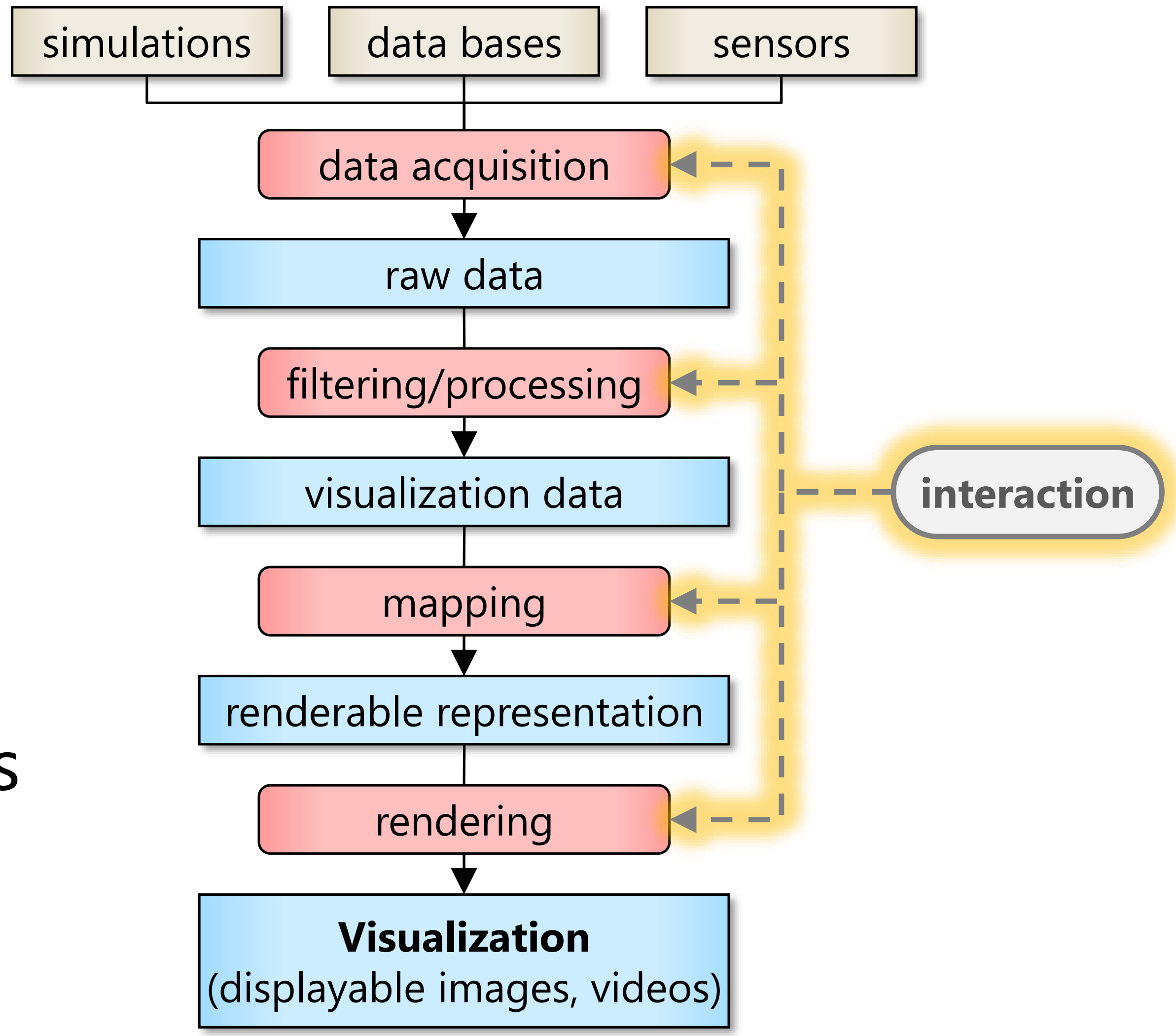
Scenarios – Confirmatory / Exploratory Analysis

- **Optimum:** results of visual analysis have impact on:
  - Data modeling
  - Simulation
  - Visualization

→ User can interact with the whole process

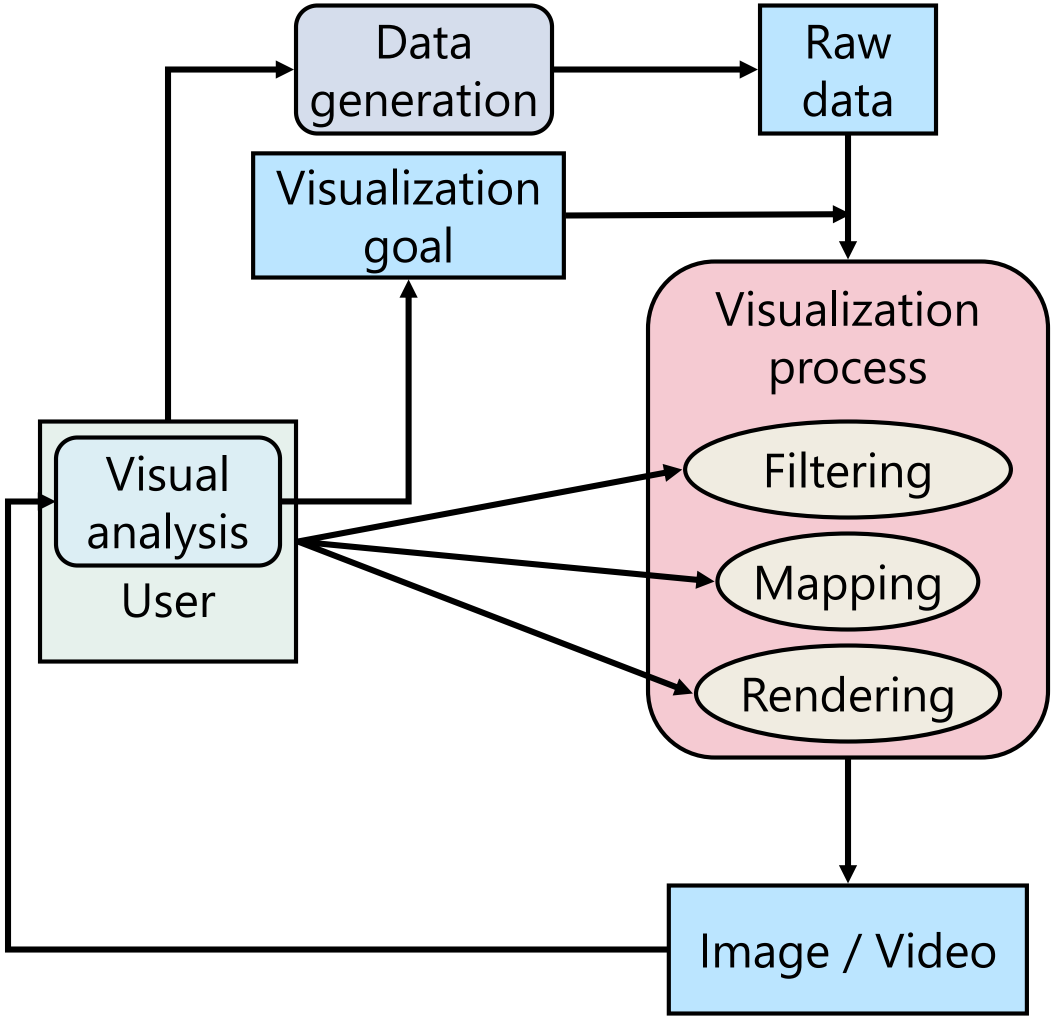
- However: time-consuming processes

→ Tradeoff between functionality and performance needed



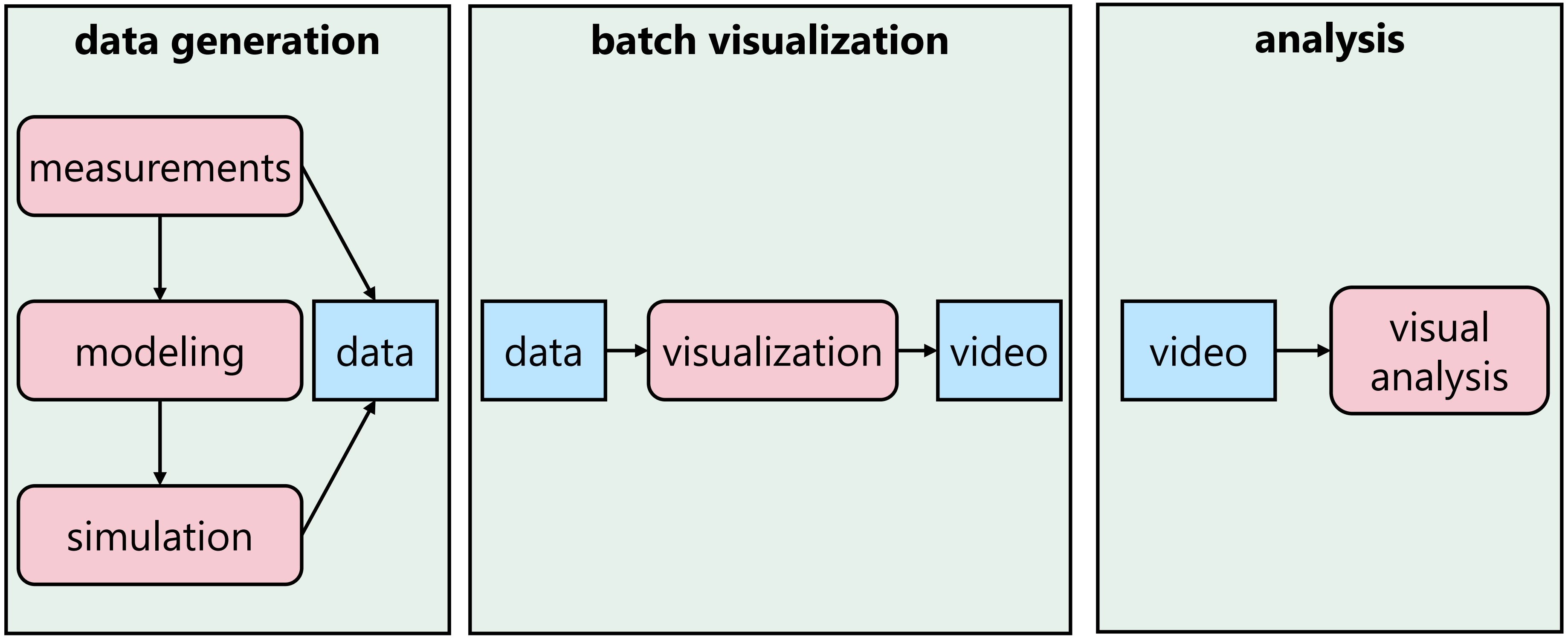
Scenarios – Confirmatory / Exploratory Analysis

- Reference model for visualization



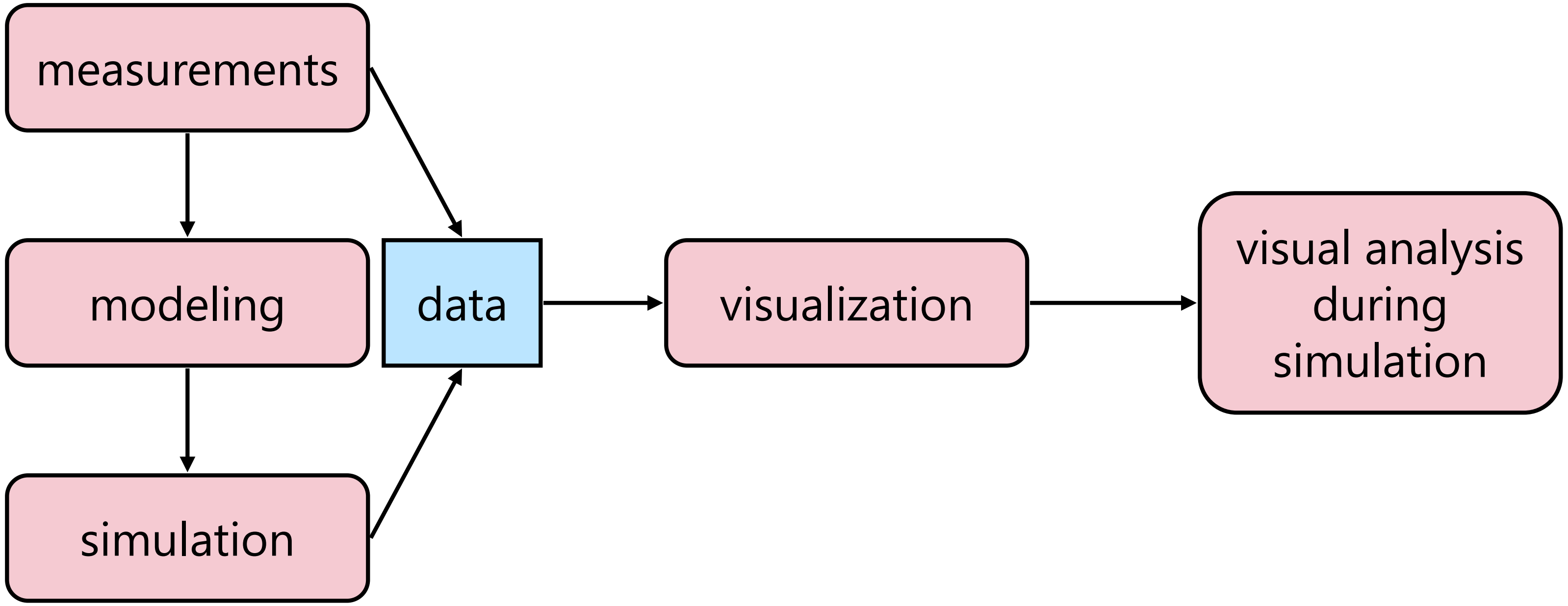
Scenarios – Confirmatory / Exploratory Analysis

- Video/movie mode



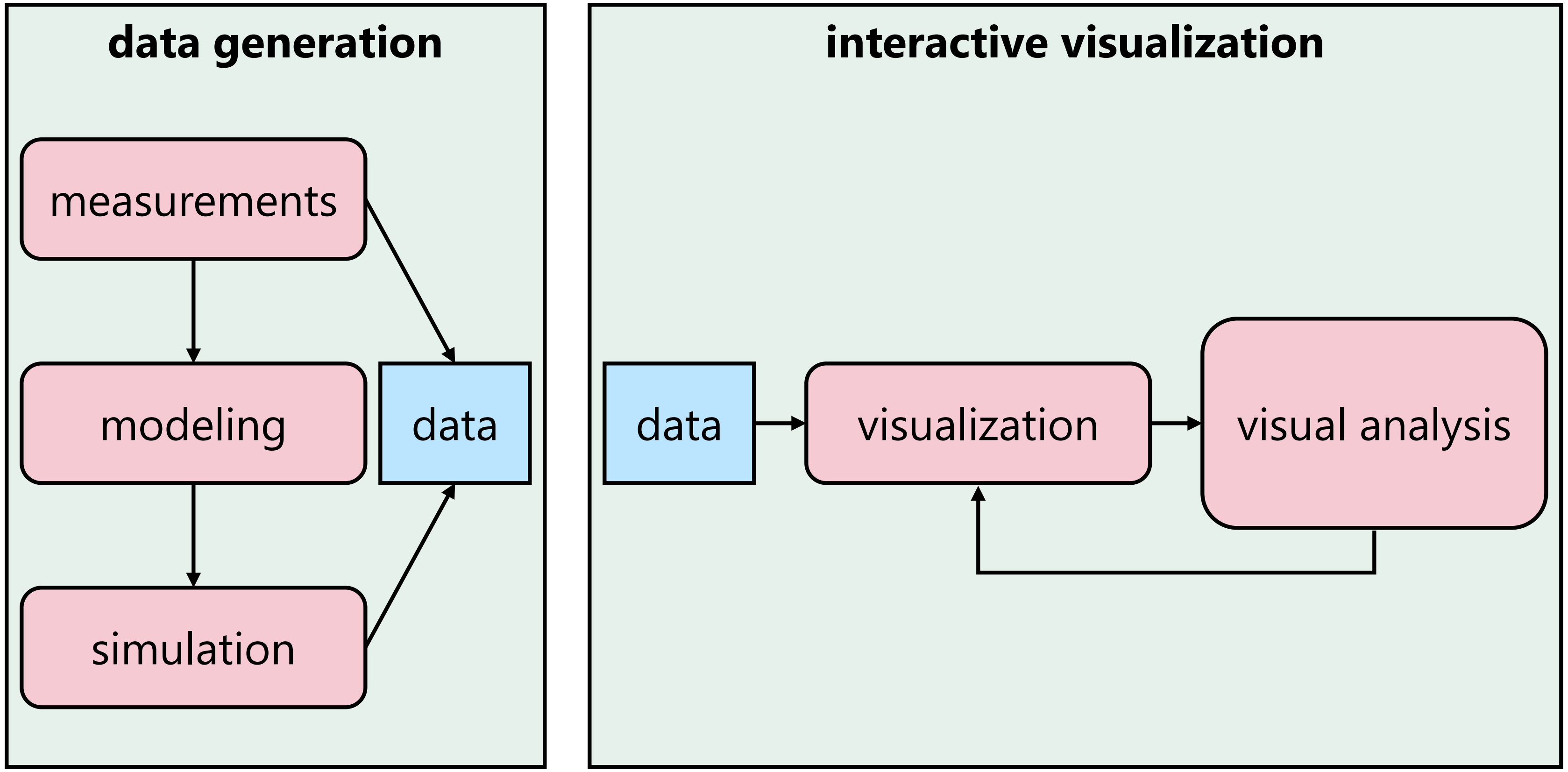
Scenarios – Confirmatory / Exploratory Analysis

- Tracking / monitoring



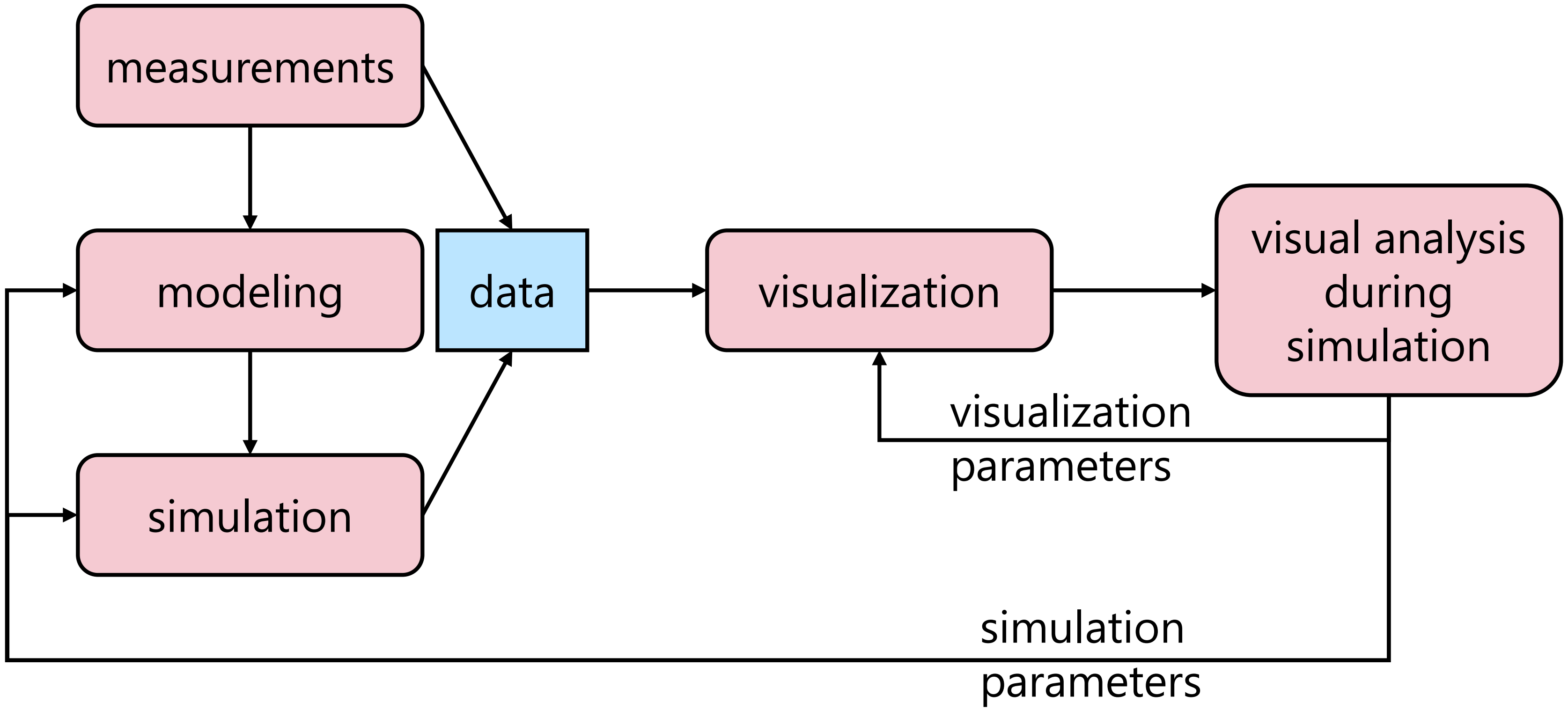
Scenarios – Confirmatory / Exploratory Analysis

- Interactive post processing / visualization



Scenarios – Confirmatory / Exploratory Analysis

- Interactive steering / computational steering



Scenarios – Confirmatory / Exploratory Analysis

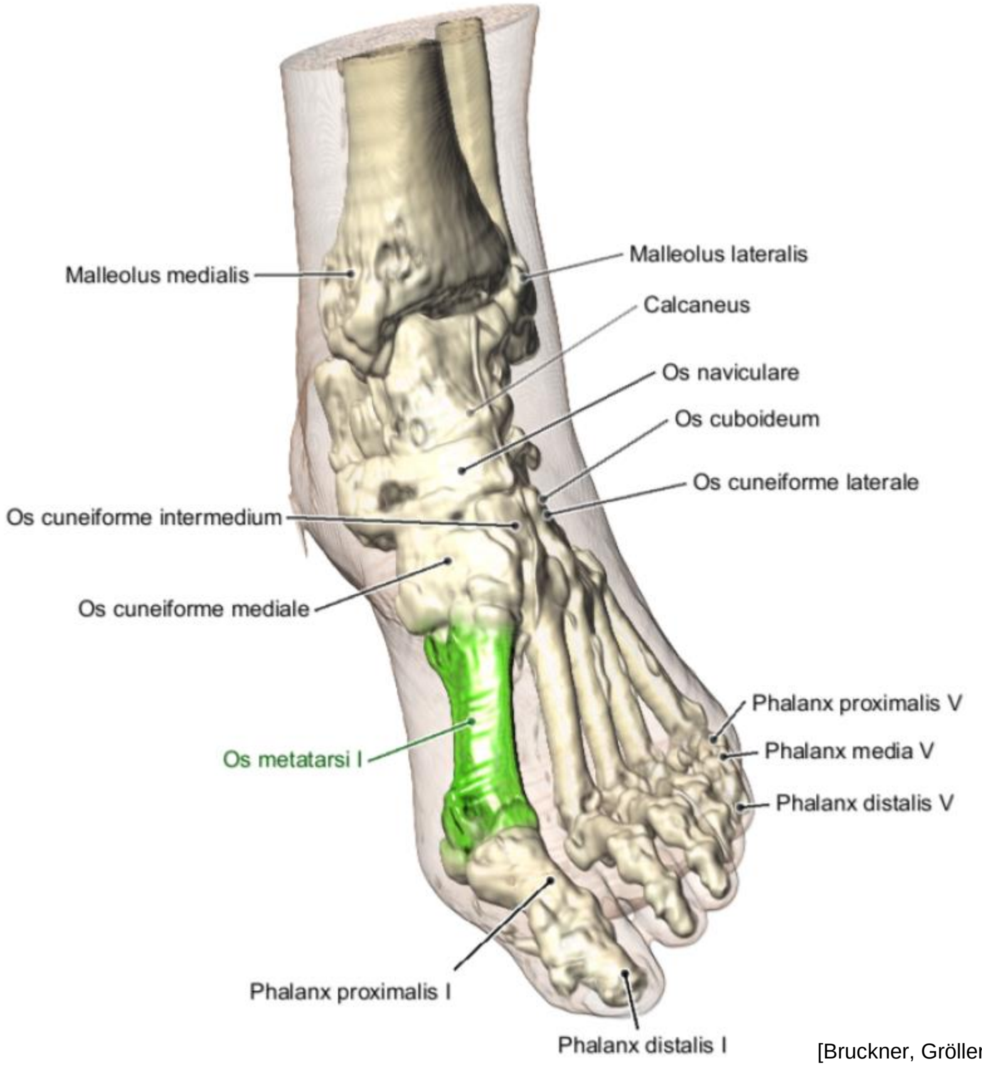
- Measurable goals:
  - Learning time: How long does a regular user need to implement certain tasks?
  - Speed: How fast can some tasks be accomplished?
  - Error rate (ratio success to failure)
  - How many and which kind of errors are made?
  - Time-dependent retention: How well do users keep their knowledge?
- Subjective satisfaction:
  - How do the visualizations please the users?
    - User engagement/motivation → can influence task performance

[according to F. Mansmann: Visual Analytics Tutorial]

Scenarios – Presentational Visualization

- Annotation and labeling is critical
- Provide additional information
- Organize and explain data
- Seek spatial clarity

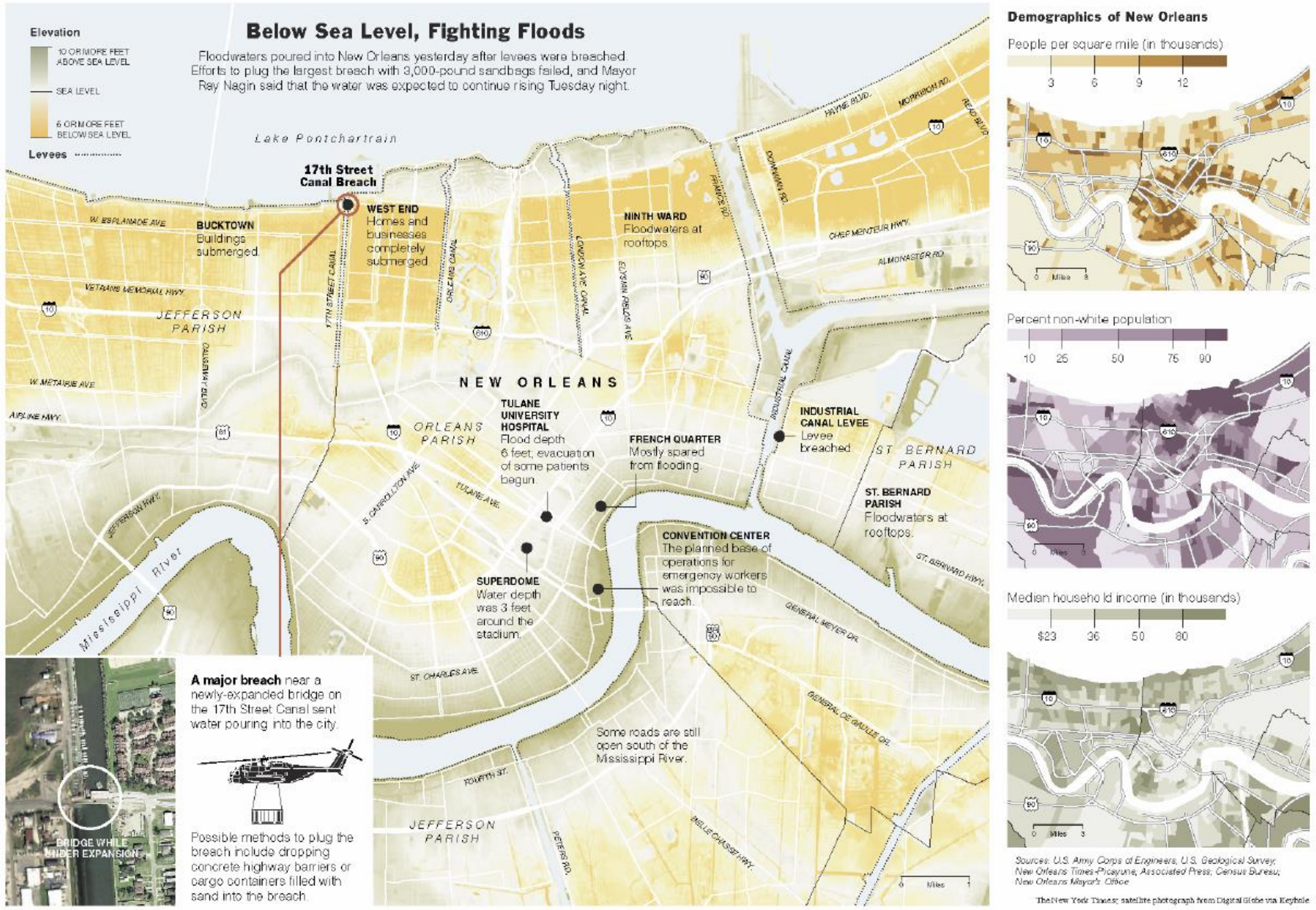
- **Example:**
  Medical/anatomical visualization



[Bruckner, Gröller, 2005]

Scenarios – Presentational Visualization

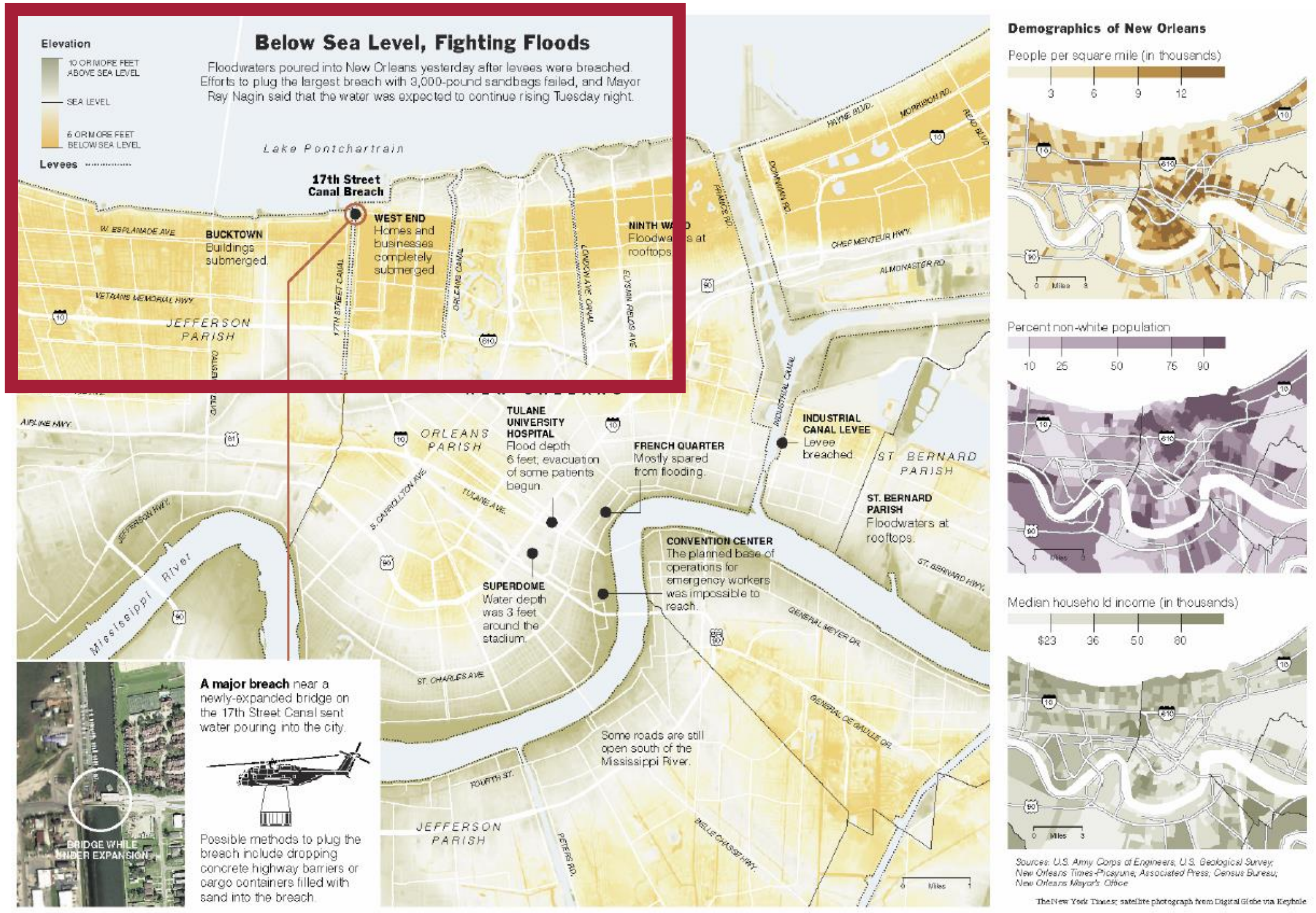
- **Example** from The New York Times



[M. Ericson: Visualizing Data for the Masses: Information Graphics at The New York Times, IEEE InfoVis 2007]

Scenarios – Presentational Visualization

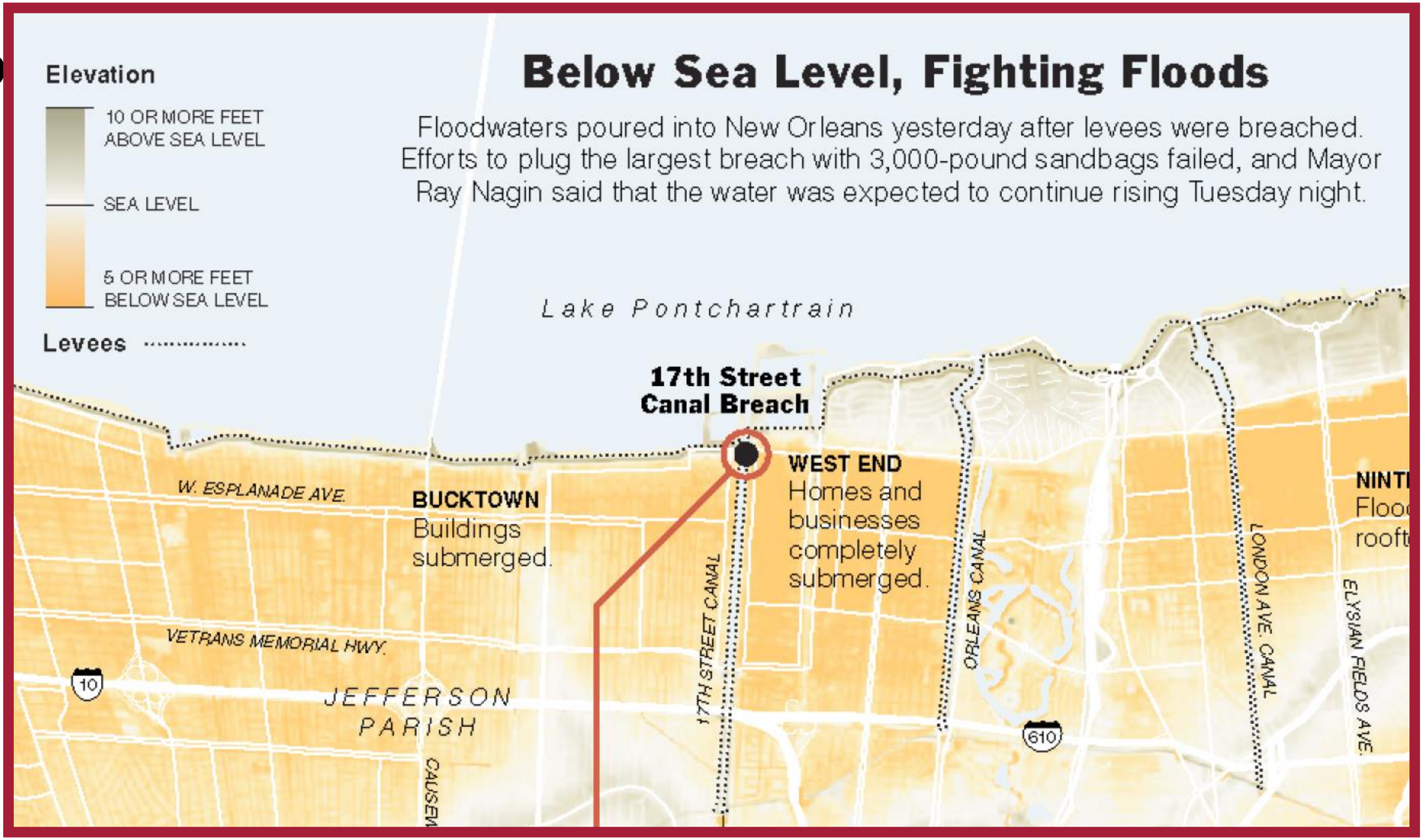
- **Example** from The New York Times



[M. Ericson: Visualizing Data for the Masses: Information Graphics at The New York Times, IEEE InfoVis 2007]

Scenarios – Presentational Visualization

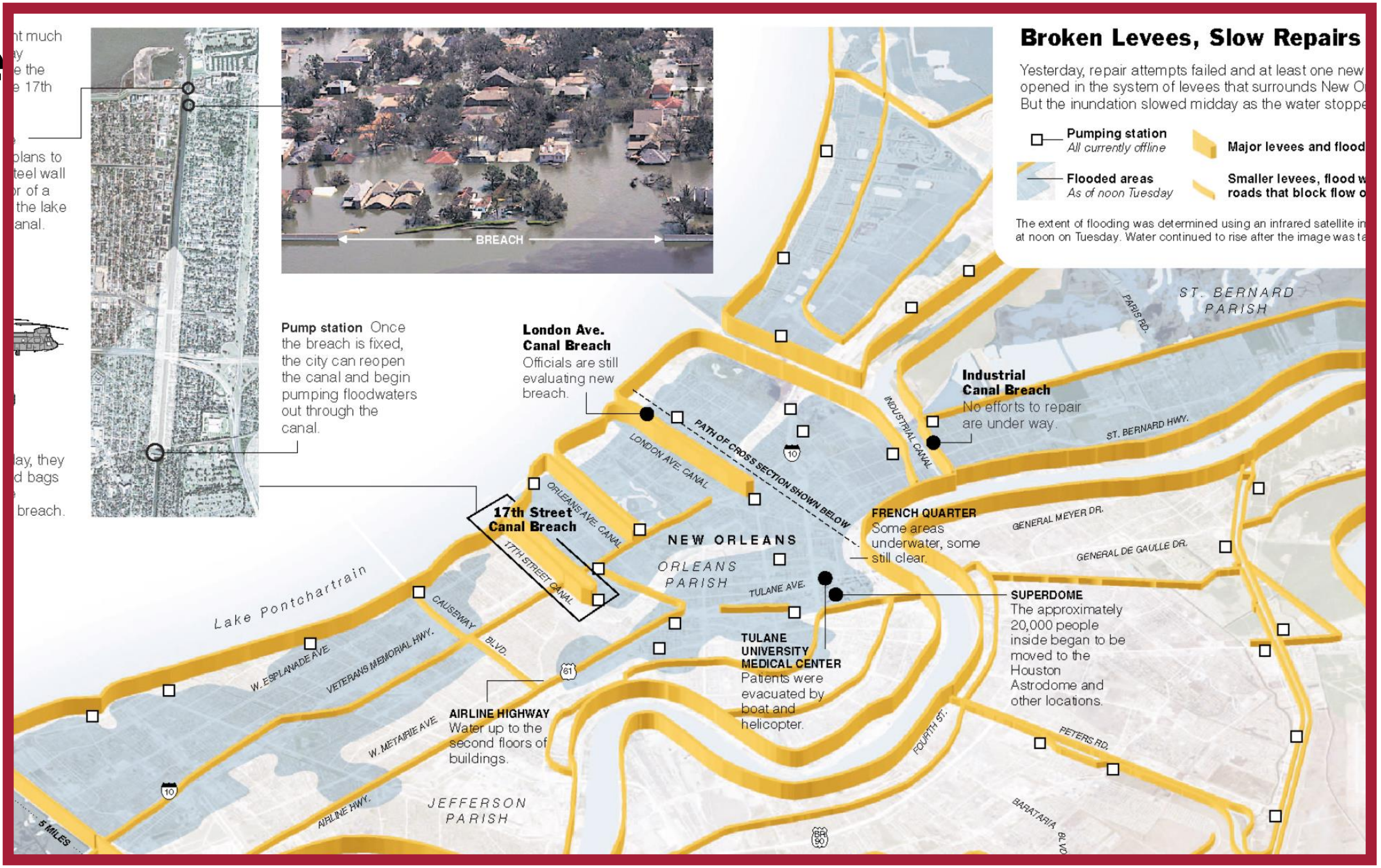
- **Examp**



[M. Ericson: Visualizing Data for the Masses: Information Graphics at The New York Times, IEEE InfoVis 2007]

Scenarios – Presentational Visualization

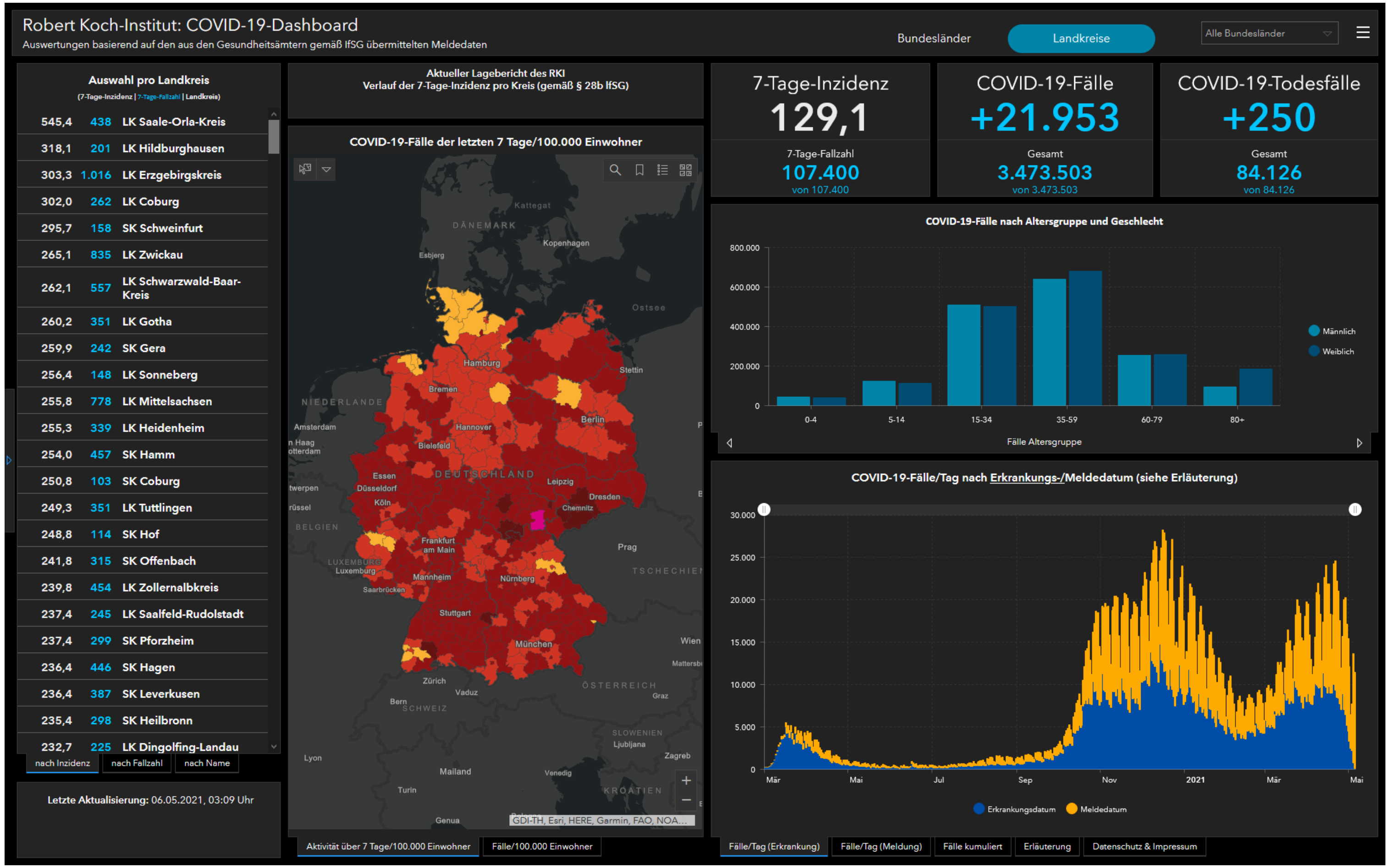
- **Example**



[M. Ericson: Visualizing Data for the Masses: Information Graphics at The New York Times, IEEE InfoVis 2007]

Scenarios – Presentational Visualization

- **Example:** Robert Koch-Institut: COVID-19-Dashboard



Scenarios – Presentational Visualization

- **Example:** Visualization of Molecular Processes (gene transcription)

Drew Berry

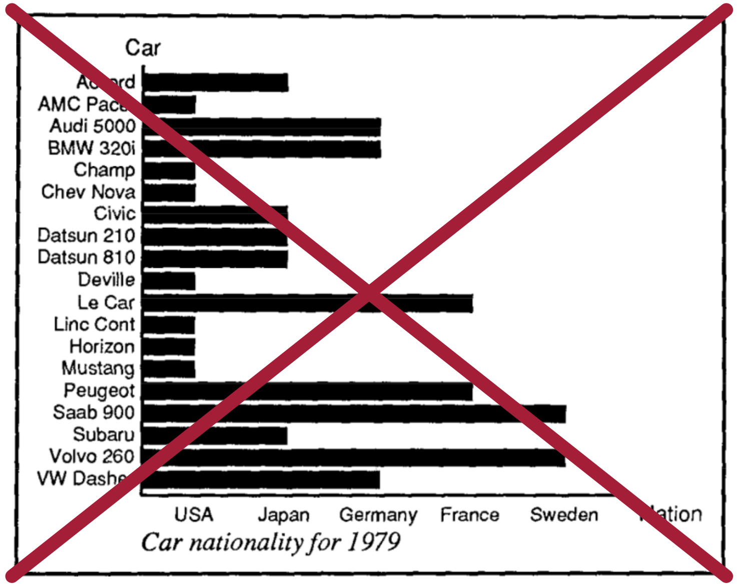
Data Types

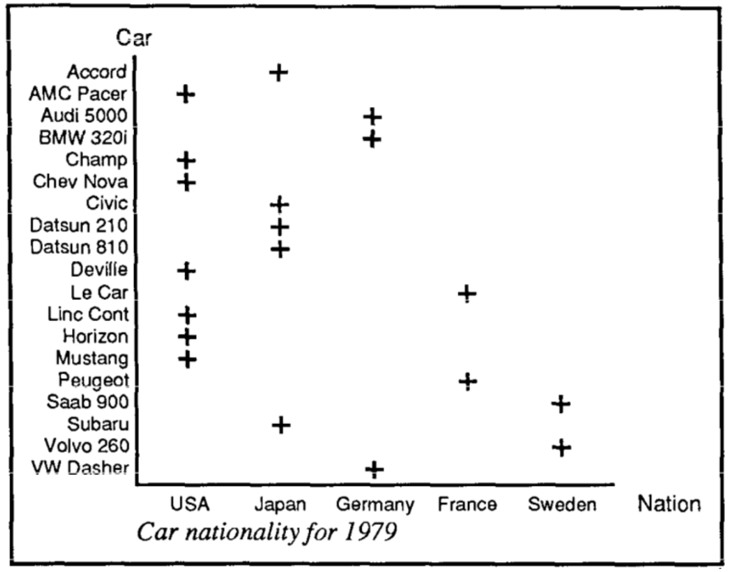
- Levels of measurement
  - Measurements (in science) performed using 4 different types of scales
- Types of scales (in ascending order)
  - **Nominal** (categorical; attributes only named)
  - **Ordinal** (rank order of data attributes)
  - **Interval** (distances defined, but no absolute zero point)
  - **Ratio** (distances defined and absolute zero)
- Interval & ratio: also subsumed as quantitative data
- Attribute dimensions
  - Scalar, vector, tensor, multivariate
- Data domain
  - 0D, 1D, 2D, 3D, ..., time dependency

[S. S. Stevens: On the Theory of Scales of Measurement, *Science* 103 (2684):677–680, 1946]

Data Types

- Data type has effect on appropriate visualization
- **Example** for nominal data

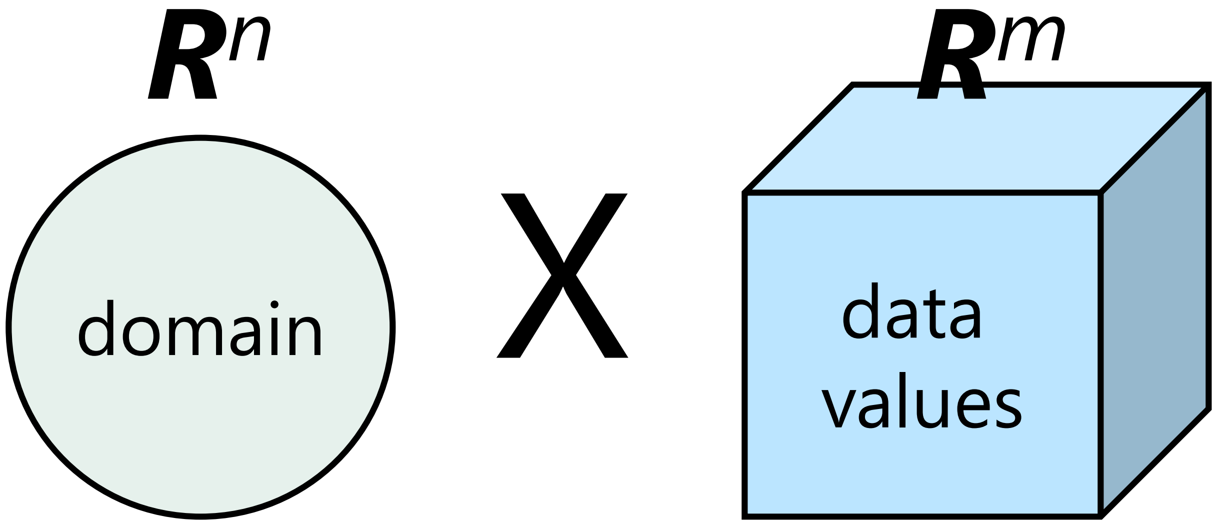




[J. Mackinlay: *Automating the design of graphical presentations of relational information*. ACM TOG 5(2):110-141, 1986]

→APT (A Presentation Tool): using Artificial Intelligence to chose a visualization

Data Representation in Scientific Visualization



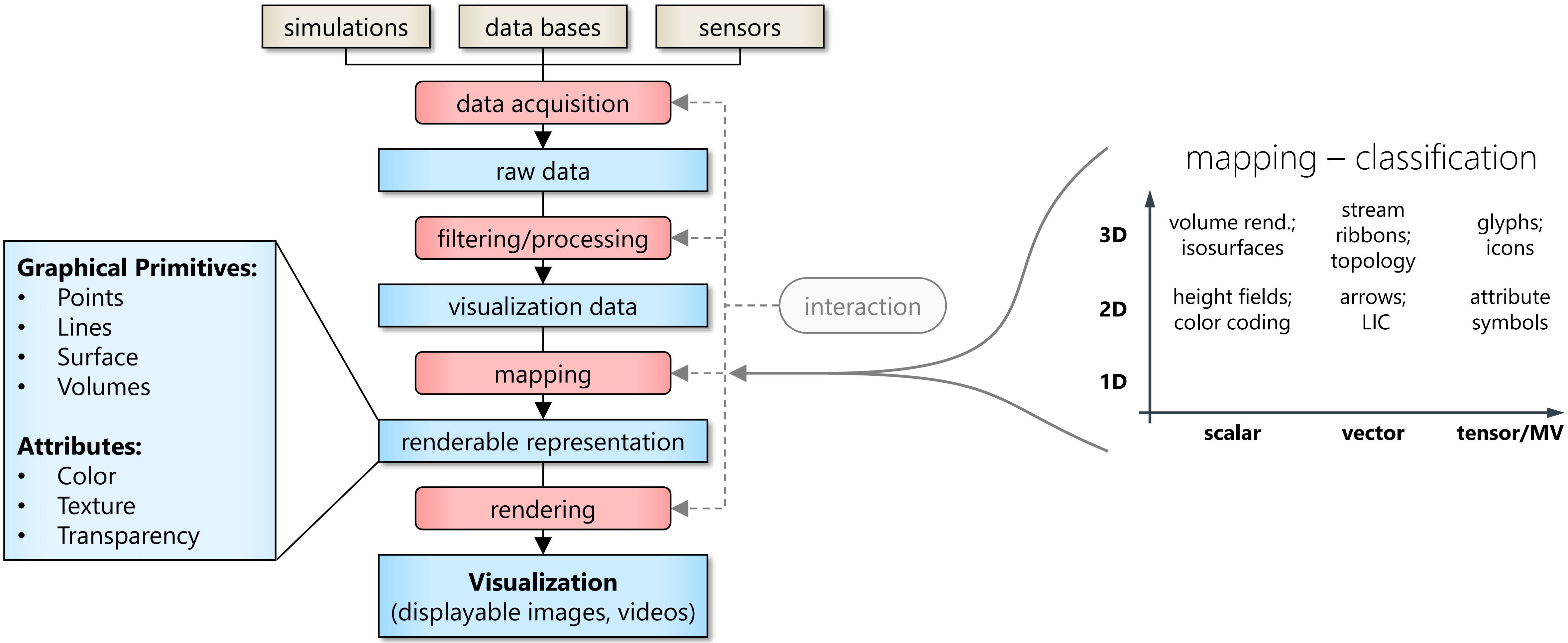
independent variables

dependent variables

scientific data $\subseteq \boldsymbol{R}^{n+m}$

Classification of Visualization Methods

The Visualization Pipeline



Classification of Visualization Methods

Visualization

Continuous Model

# Independent Variables	# Dep. Variables	1			Many
	Data Type	**Scalar**	**Vector**	**Tensor**	**Multi-variate**
	1D	- Line graph			Combine scalar, vector, & tensor methods
	2D	- Colour map - Isolines	- LIC - Particle traces - Glyphs		
	3D	- Volume rendering - Isosurfaces		- Tensor ellipsoids	
	nD	Multiple 1D, 2D, or 3D views			

Discrete Model

Connected

Graph & Tree Visualizations:
- Node - link diagrams (2D and 3D)
- Space-filling mosaics
- Hierarchical graphs

Unconnected

# Variables	
2D	- Scatter plot - Bar chart
3D	- 3D scatter plot - 3D bar chart
nD	- Multiple views - Aggregation - Glyphs - Dense pixel displays - Parallel coordinates

Image adapted from [Tory and Möller, 2002]