EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Mapping

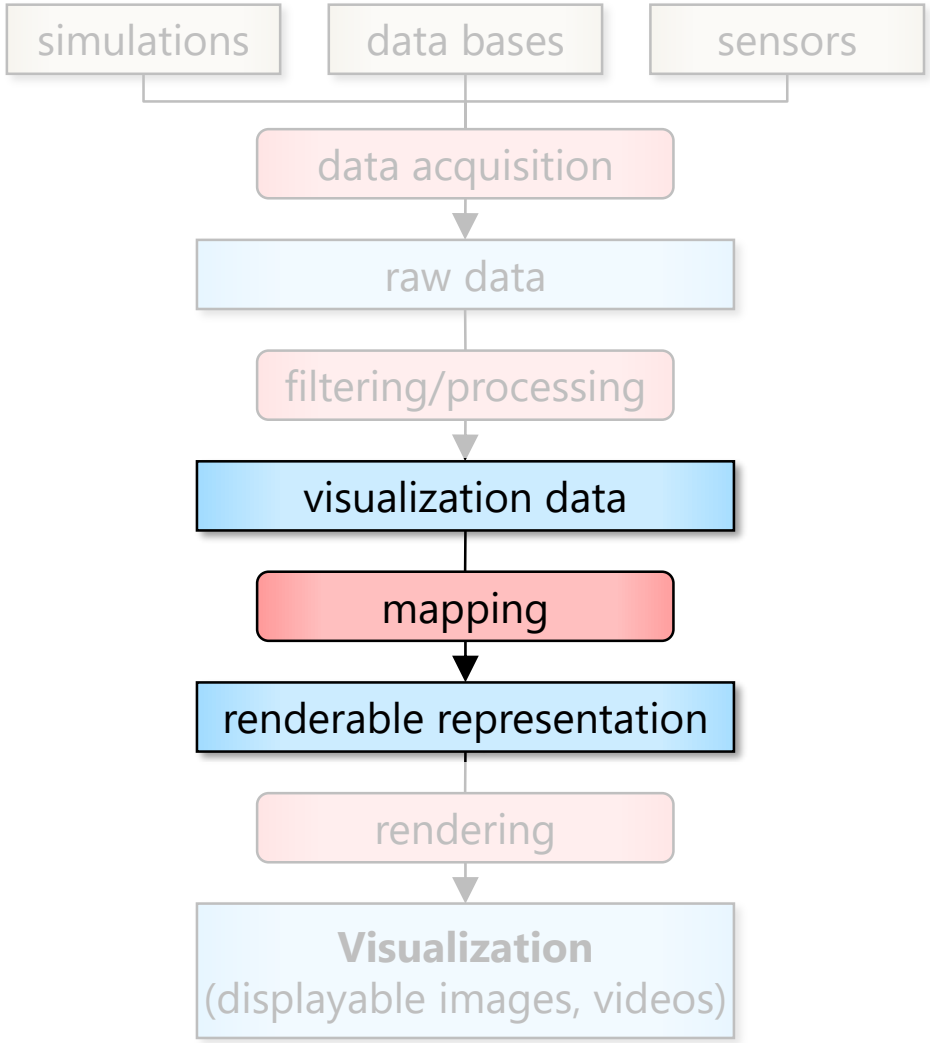
Scientific Visualization – Summer Semester 2021

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

Contents

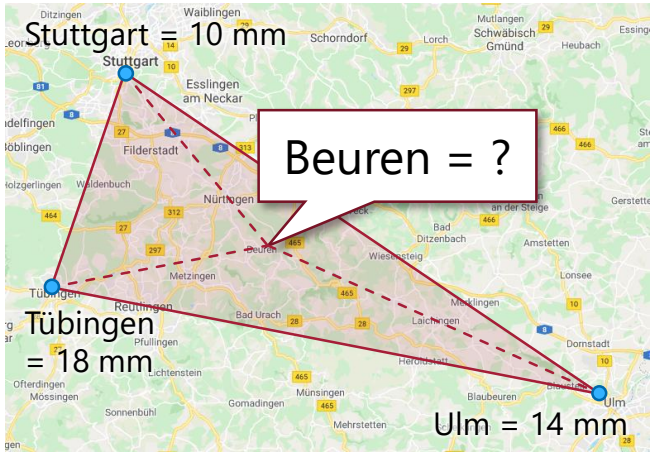
- Effectiveness of mappings
- Mapping to positional quantities
- Mapping to shape
- Mapping to color
- Mapping to texture
- Other mappings
- Glyphs

Focus:
Second step of visualization pipeline



Approaches for Visual Mappings

- Till now just pure numbers
- **Example:** weather report



raw data → *filtering: select values to visualize* → *interpolation: calculate additional values* → visualization data

Location	Temp.	Precip.
Stuttgart	20°C	10 mm
Tübingen	22°C	18 mm
Ulm	17°C	12 mm
…		
…		

Location	Precip.
Stuttgart	10 mm
Tübingen	18 mm
Ulm	14 mm
…	
…	

Location	Precip.
Stuttgart	10 mm
Tübingen	18 mm
Ulm	14 mm
…	
Beuren	***12 mm***
…	

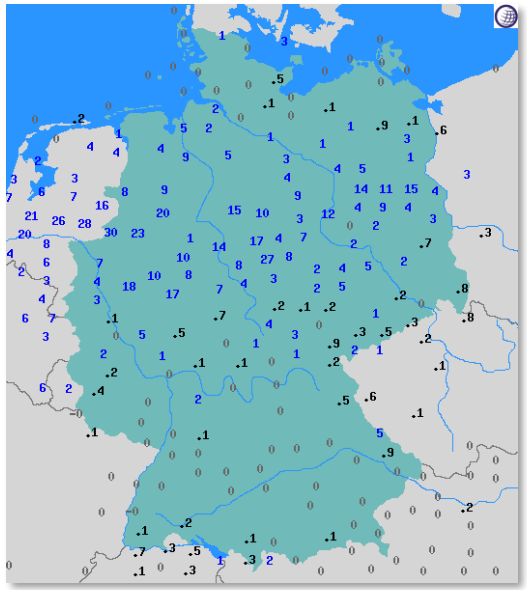
Approaches for Visual Mappings

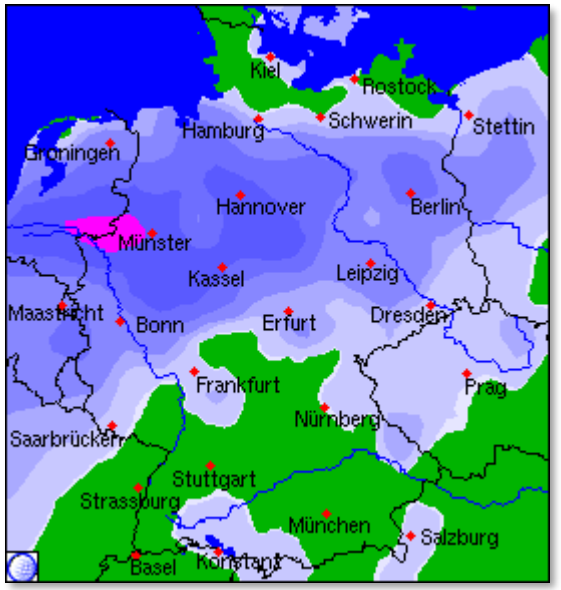
- **Example:** weather report (cont.)

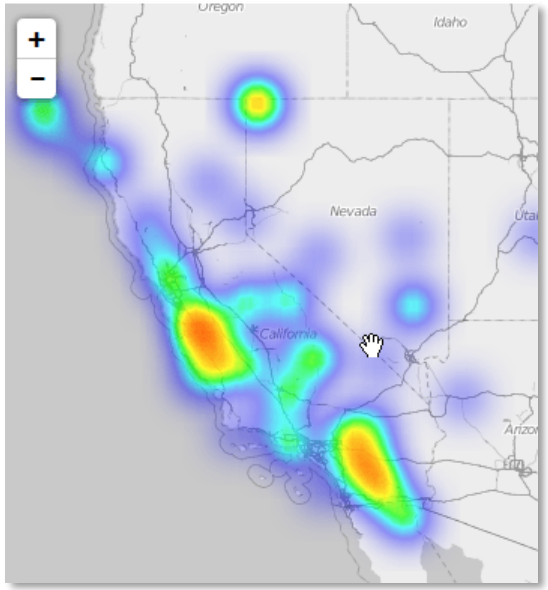
what we have

Location	Precip.
Stuttgart	10 mm
Tübingen	18 mm
Ulm	14 mm
…	
Beuren	***12 mm***
…	

what we would like to have





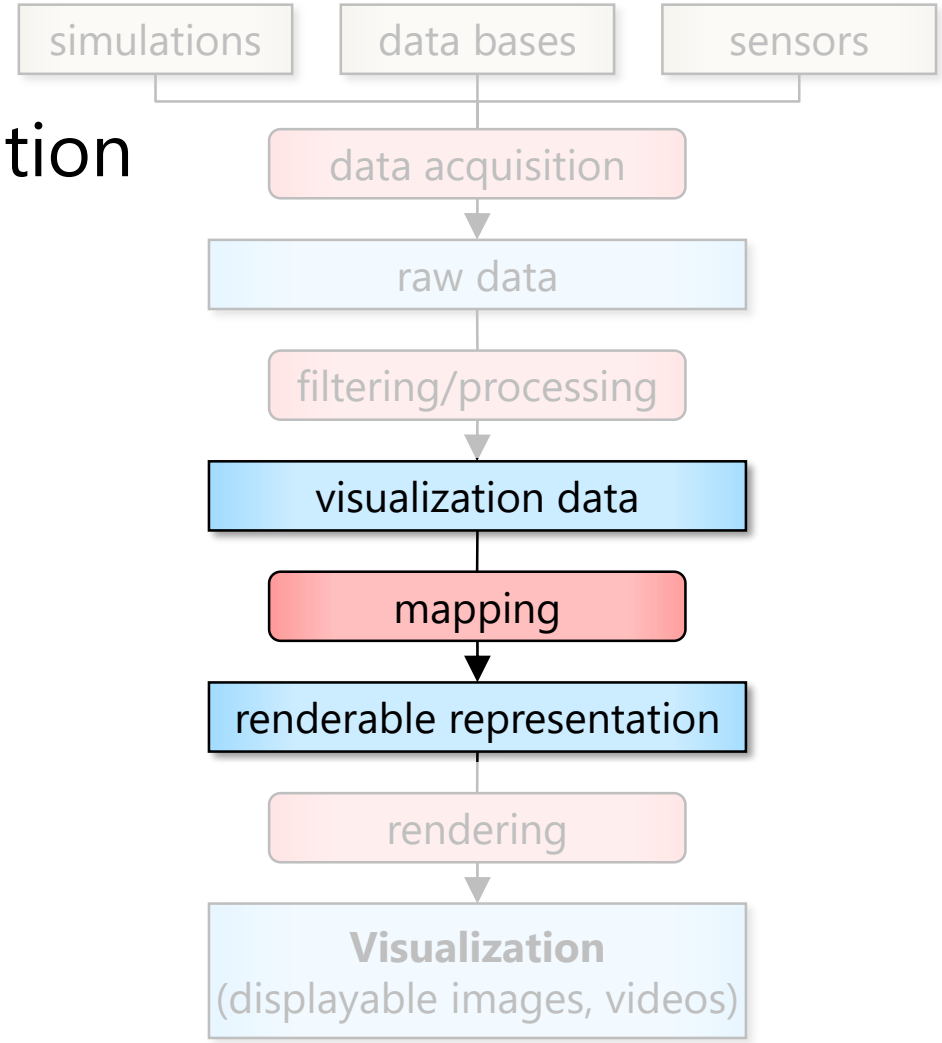


→ **Mapping**
Transferring numerical values into graphical primitives/attributes

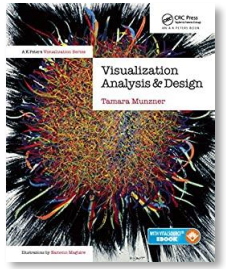
Mapping

- Mapping from (filtered/preprocessed) visualization data to renderable representation
- **Most important part of visualization**
- Possible visual representations
  - Position
  - Size
  - Orientation
  - Shape
  - Brightness
  - Color (hue, saturation)
  - …

Focus:
Second step of visualization pipeline



Mapping – Marks and Channels



- Building Blocks of Visualizations [Munzner, 2014]
  - **Marks** are basic graphical elements, **Channels** control appearance of marks

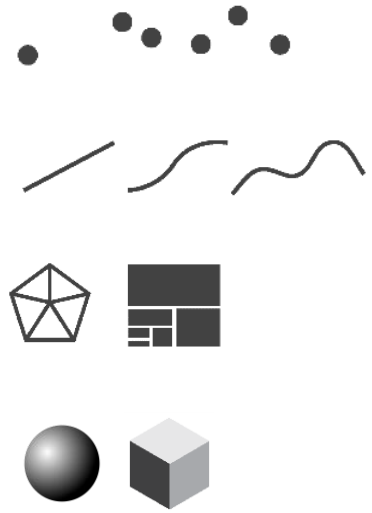
Marks:

0D – point

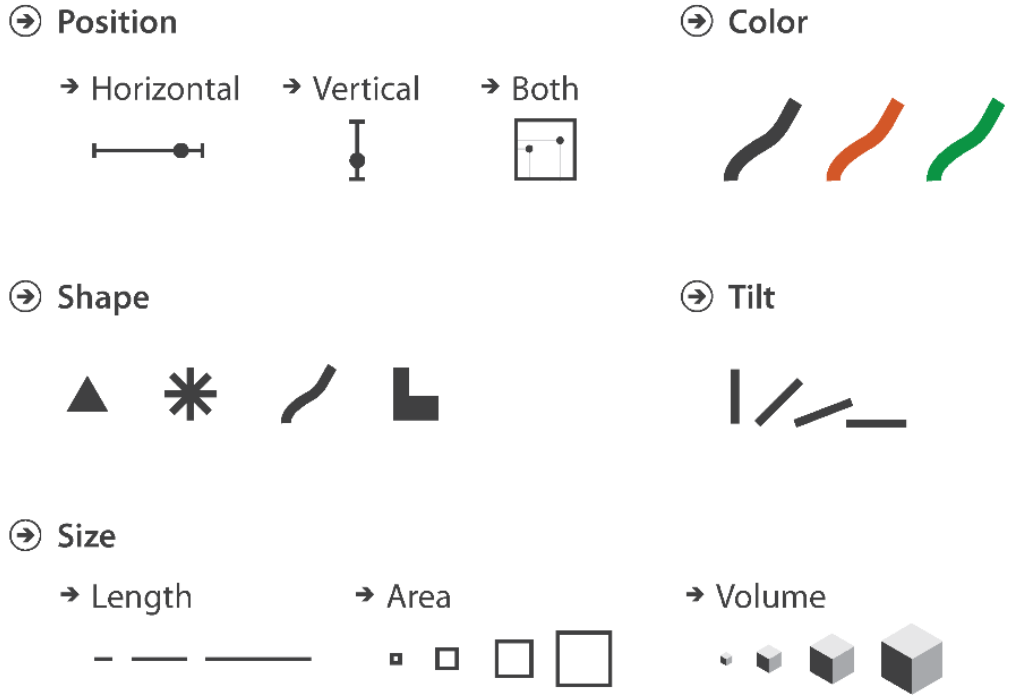
1D – line

2D – area

3D – volume



Channels:



Effectiveness of Mappings

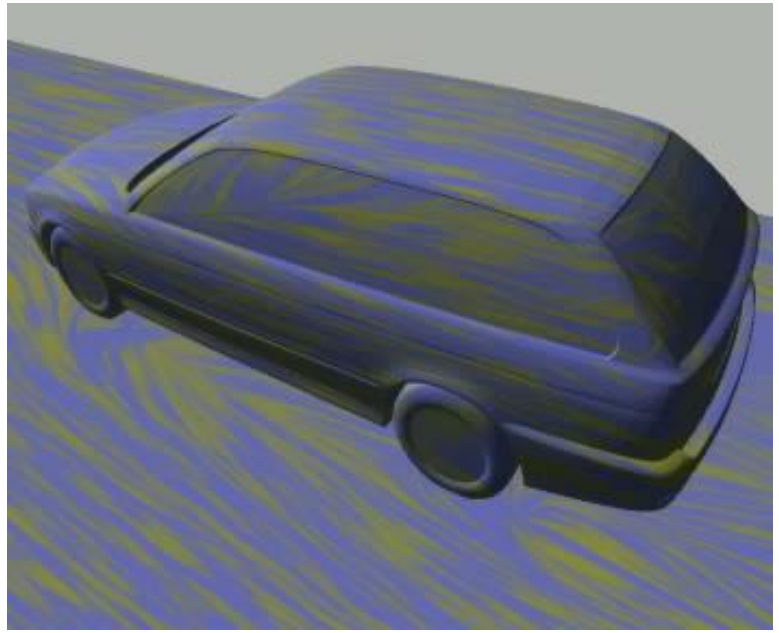
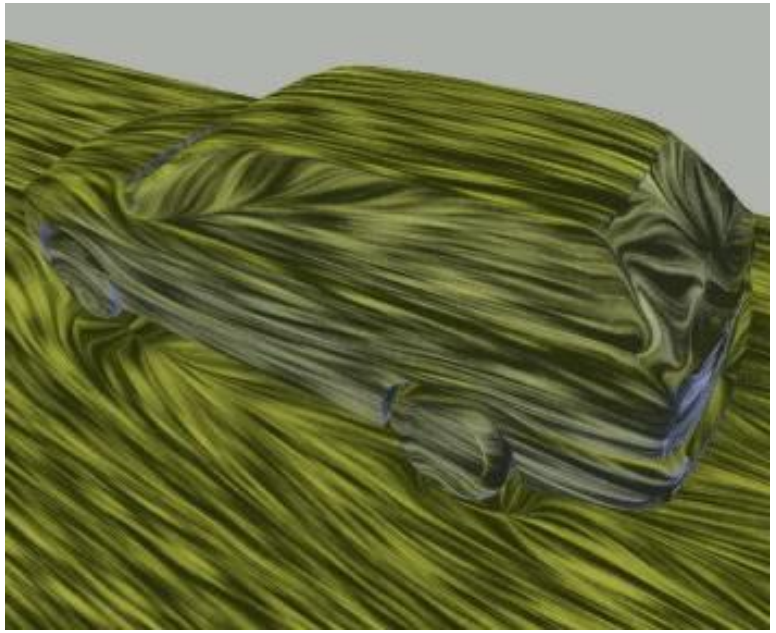
- Efficiency and effectiveness depends on input data
  - Nominal
  - Ordinal
  - Quantitative
- Good visual design
  - Based on psychology and psychophysics
- Psychological investigations to evaluate the appropriateness of mapping approaches

Effectiveness of Mappings

- Many different mapping approaches exist
- Dependent on type of data
- Overview of data attributes (recapitulation):
  - Data domain
    - 0D, 1D, 2D, 3D, …
  - Data type
    - Scalar, vector, tensor, multivariate
  - Range of values
    - Qualitative (non-metric scale)
      - *Ordinal* (order relation exists) or *Nominal* (no order relation exists: pairs are equal or not equal)
    - Quantitative
  - Data structure

Effectiveness of Mappings

- **Example:** Effectiveness of motion perception and color design

Effectiveness of Mappings

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

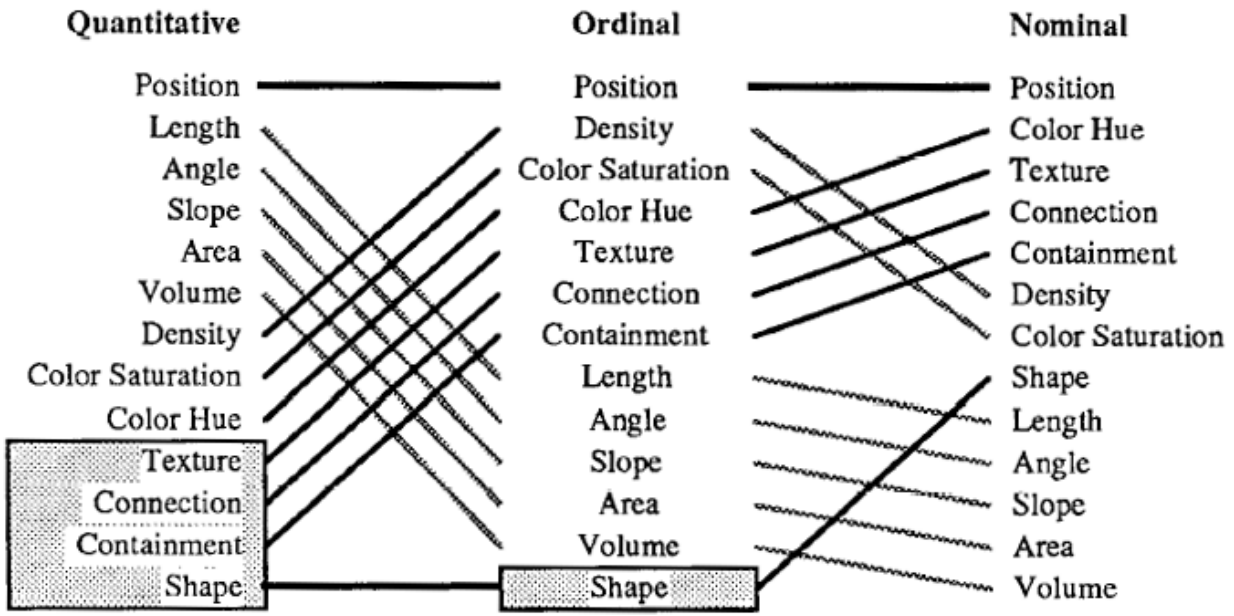
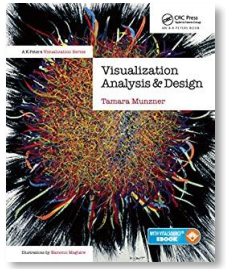


Fig. 15. Ranking of perceptual tasks. The tasks shown in the gray boxes are not relevant to these types of data.

Effectiveness of Mappings [Munzner, 2014]



Magnitude Channels: Ordered Attributes

- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

Same

Same

Most ▲ Effectiveness ▼ Least

Identity Channels: Categorical Attributes

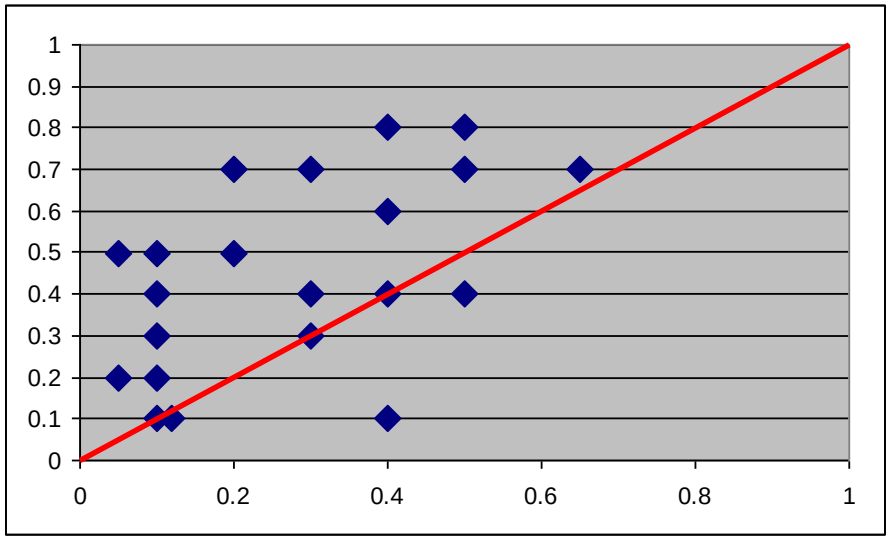
- Spatial region
- Color hue
- Motion
- Shape

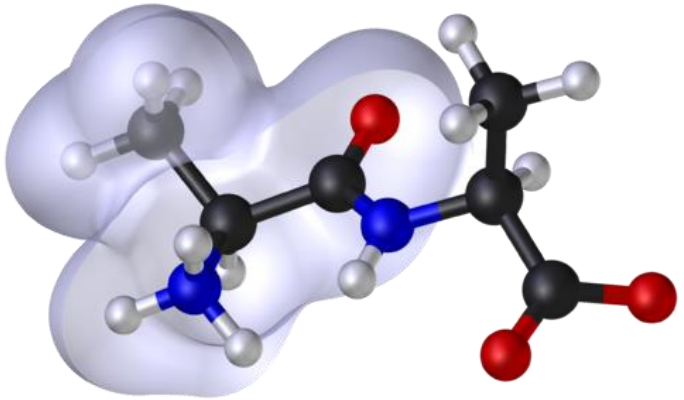
- **Expressiveness principle**
  - match channel and data characteristics
- **Effectiveness principle**
  - encode most important attributes with highest ranked channels

Mapping to Positional Quantities

- Mapping to positional quantities:
  - Position
  - Size
  - Orientation
- Geometric mapping
- Typically, very effective visual parameters
- Generic diagram methods

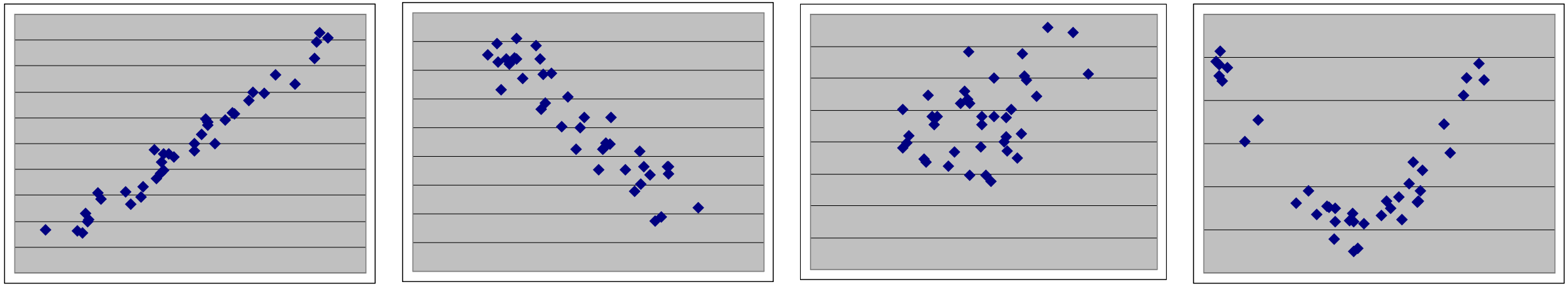
→ Scientific Visualization: "*spatial data*"
i.e., data with inherent spatial reference





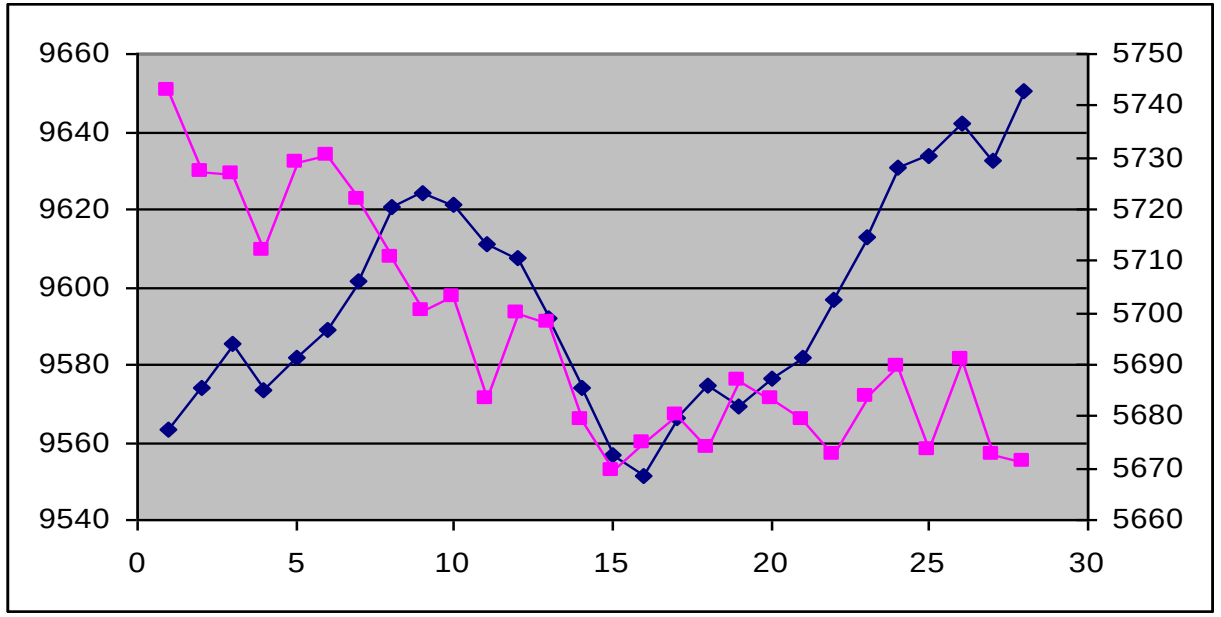
Mapping to Positional Quantities

- Point diagrams
- e.g. *Scatter Plots*: visual recognition of correlations



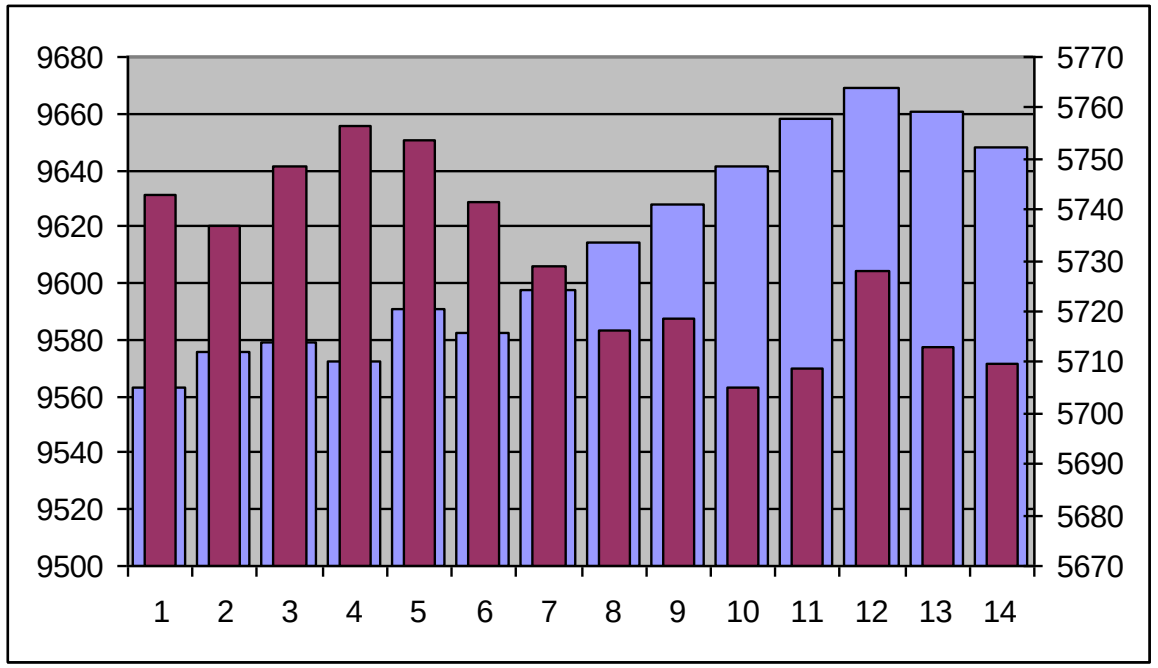
Mapping to Positional Quantities

- Line and curve diagrams:
  - Effective perception of differences in
    - Position and Length



Mapping to Positional Quantities

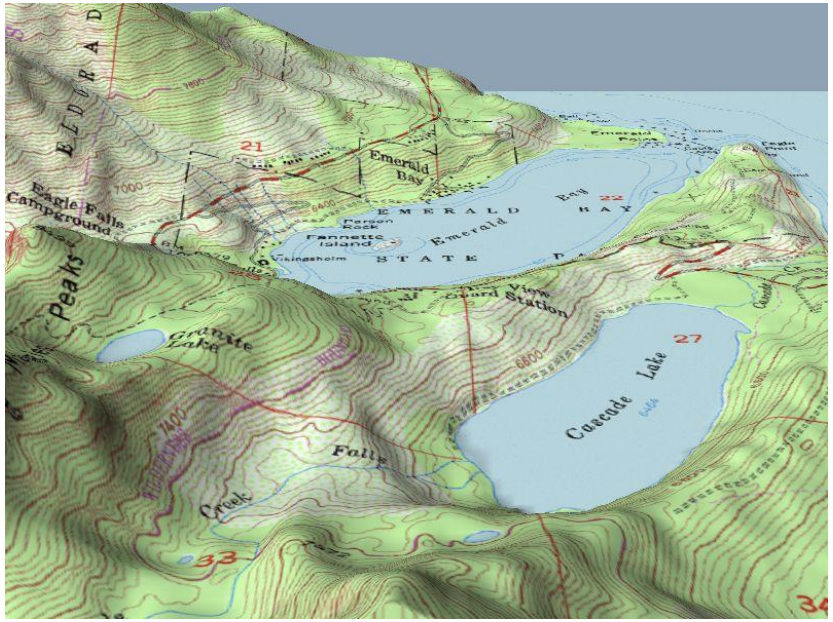
- Bar graph:
  - Discrete independent variable (domain): nominal/ordinal/quantitative
  - Quantitative dependent variable (data)



Mapping to Shape

- Especially useful for data with direct relationship to locations
  - Convey spatial structures
- **Examples**
  - Isolines (contour lines)
  - Function graphs (function plots)
  - Height fields

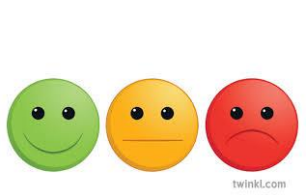
  →See chapter "*Scalar field visualization*"

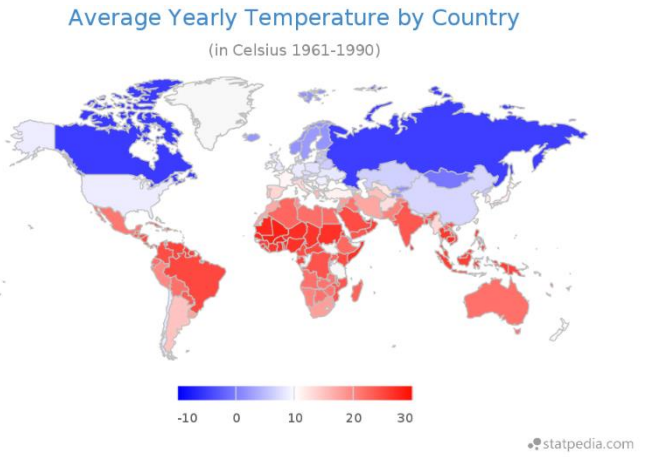


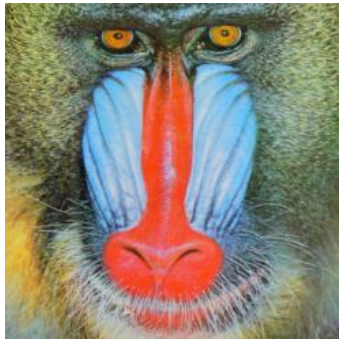
- Direct encoding of qualitative data
  - Typically in the form of glyphs (see later)

Mapping to Color

- Color = a retinal variable
  - Can be combined with other mapping techniques
- Very important mapping technique
  - Very strong visual channel → *People love color!*
  - People are used to various color codings, e.g.:
    - warm = red, cold = blue
    - ok = green, not ok = red
    - Traffic lights





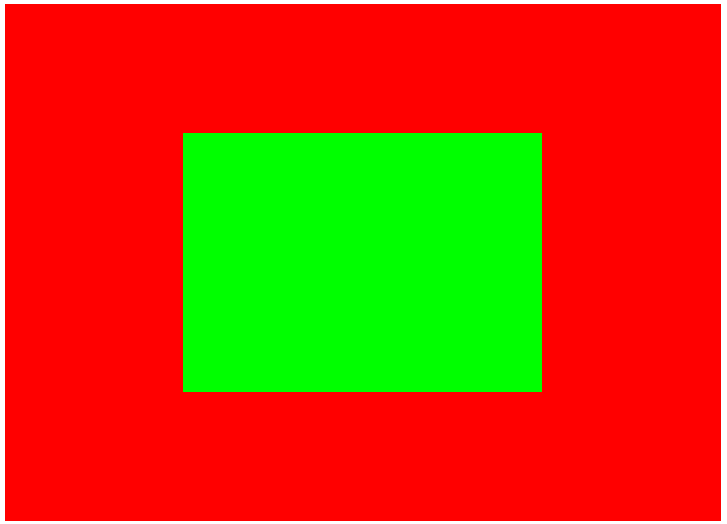


Mapping to Color

- Issues:
  - What kind of data can be color-coded?
  - What kind of information can be efficiently visualized using color?
- Areas of application
  - Provide information coding
  - Designate or emphasize a specific target in a crowded display
  - Provide a sense of realism or virtual realism
  - Provide warning signals or signify low probability events
  - Group, categorize, and chunk information
  - Convey emotional content
  - Provide an aesthetically pleasing display

Mapping to Color

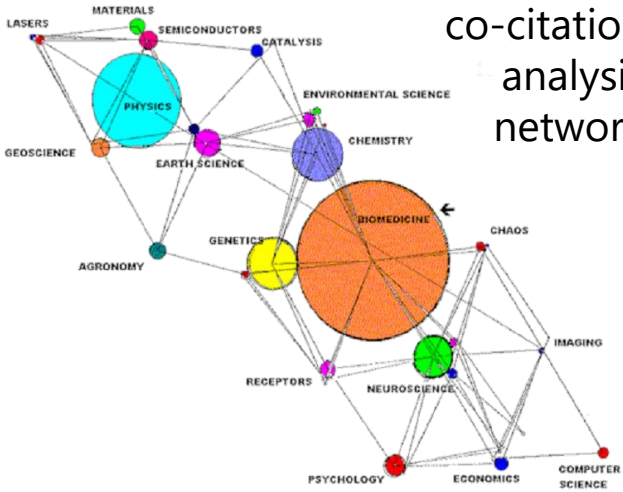
- Possible problems:
  - Distracts the user when inadequately used
  - Dependent on viewing and stimulus conditions
  - Ineffective for color deficient individuals (use redundancy)
  - Results in information overload
  - Unintentional conflict with cultural conventions
  - Causes unintended visual effects and discomfort



Mapping to Color

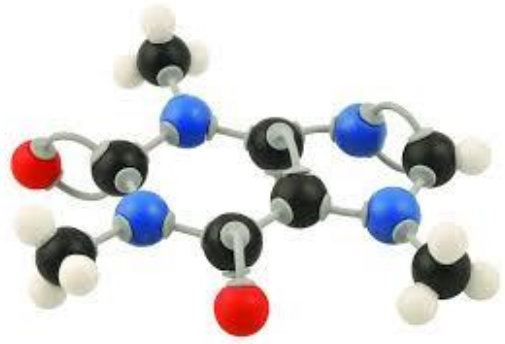
- Nominal data
  - Colors need to be distinguished
  - Localization of data
  - Around 8 different basis colors

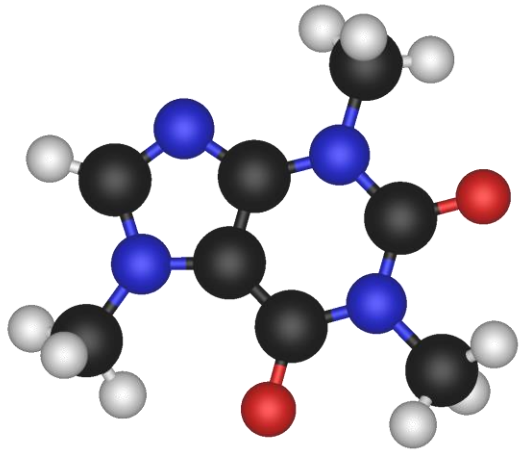
→ *Colors and perception covered in more detail in "Visualization of Biological Data"*



co-citation analysis network

https://www.everypixel.com/image-277790899799948627

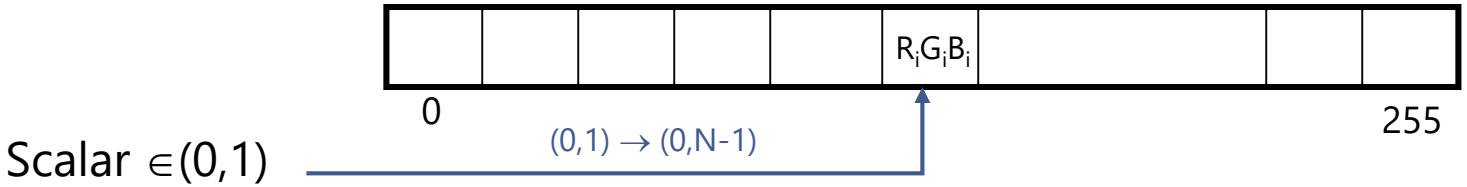




Mapping to Color

- Ordinal and quantitative data
  - Ordering of data should be represented by ordering of colors
  - Psychological aspects
  - $x_1 < x_2 < \cdots < x_n \rightarrow E(c_1) < E(c_2) < \cdots < E(c_n)$

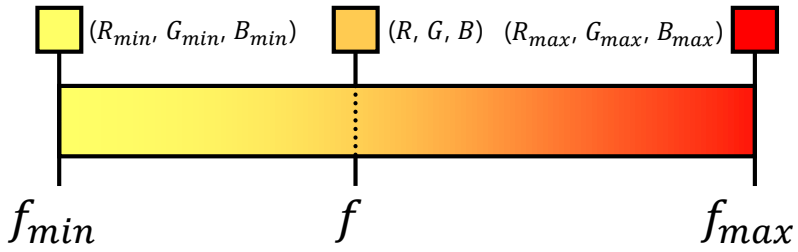
- Color coding for scalar data
  - Assign to each scalar value a different color value
  - Assignment via **transfer function** T
    - $T : scalar\ value \rightarrow color\ value$
  - Code color values into a color lookup table



Mapping to Color

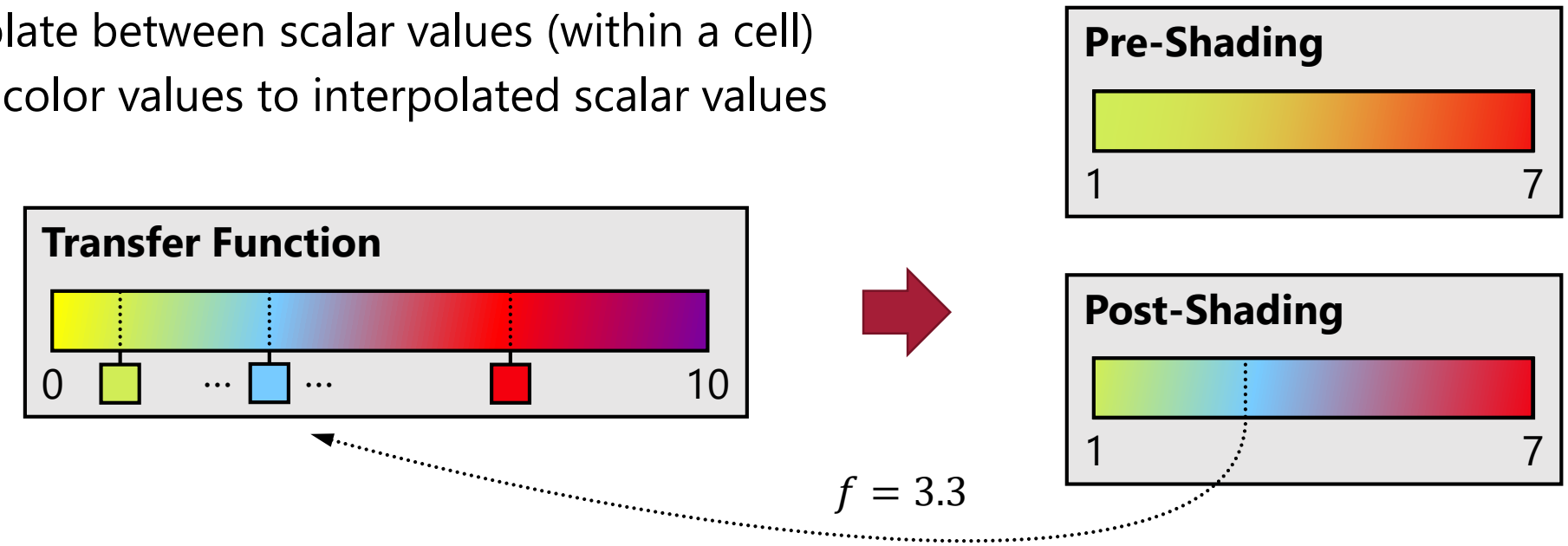
- Linear transfer function for color coding
  - Specify colors for f_{min} and $f_{max} \rightarrow (R_{min}, G_{min}, B_{min})$ and $(R_{max}, G_{max}, B_{max})$
  - Linearly interpolate between them

$$f \rightarrow \frac{f_{max} - f}{f_{max} - f_{min}}(R_{min}, G_{min}, B_{min}) + \frac{f - f_{min}}{f_{max} - f_{min}}(R_{max}, G_{max}, B_{max})$$



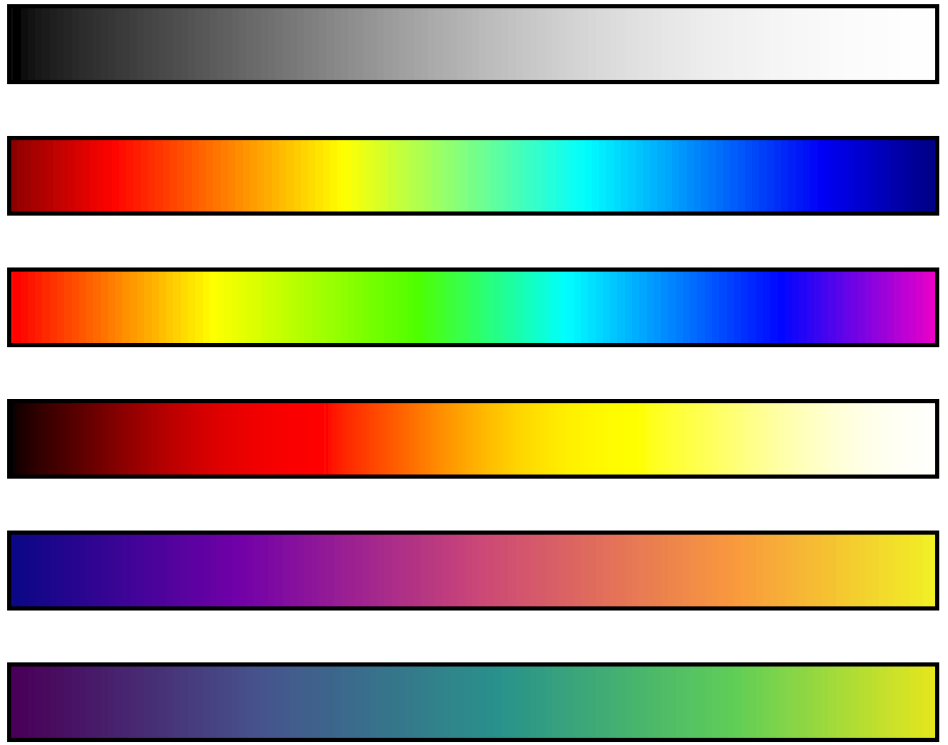
Mapping to Color

- Pre-shading vs. post-shading
  - Pre-shading
    - Assign color values to original function values (e.g., at nodes of a cell)
    - Interpolate between color values (within a cell)
  - Post-shading
    - Interpolate between scalar values (within a cell)
    - Assign color values to interpolated scalar values

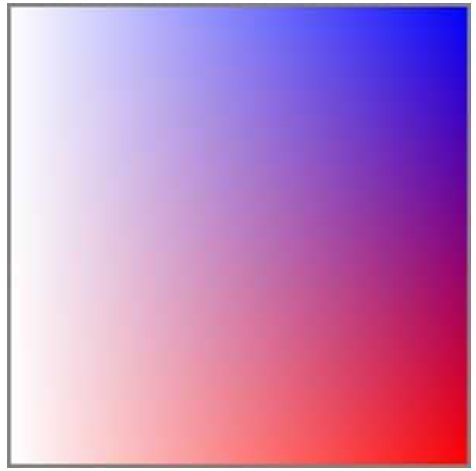


Mapping to Color

- Different color spaces lead to different interpolation functions
- In order to visualize (enhance/suppress) specific details, non-linear color lookup tables are needed
- Gray scale color table
  - Intuitive ordering
- Rainbow color table
  - Less intuitive, perceptual issues
- Other color tables
  - Temperature (“black body radiation”/inferno)
  - Plasma
  - Viridis → Perceptually uniform sequential color maps



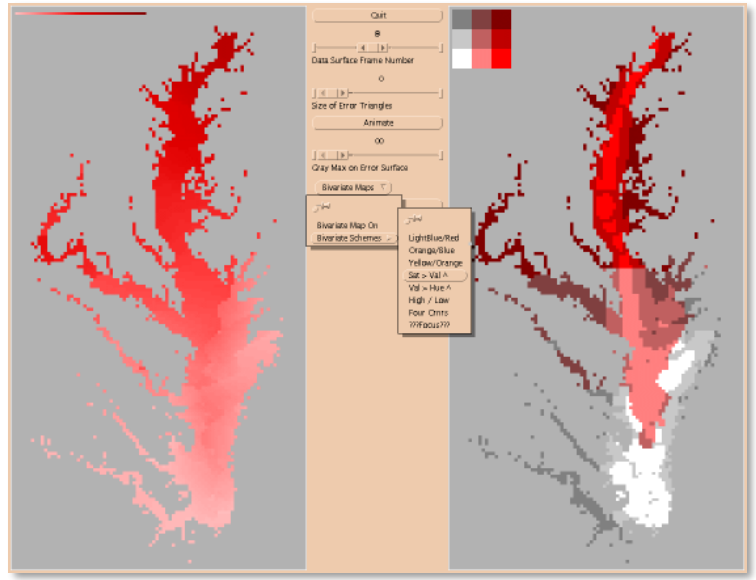
Mapping to Color



- Bivariate and trivariate color tables are problematic:
  - No intuitive ordering
  - Colors hard to distinguish

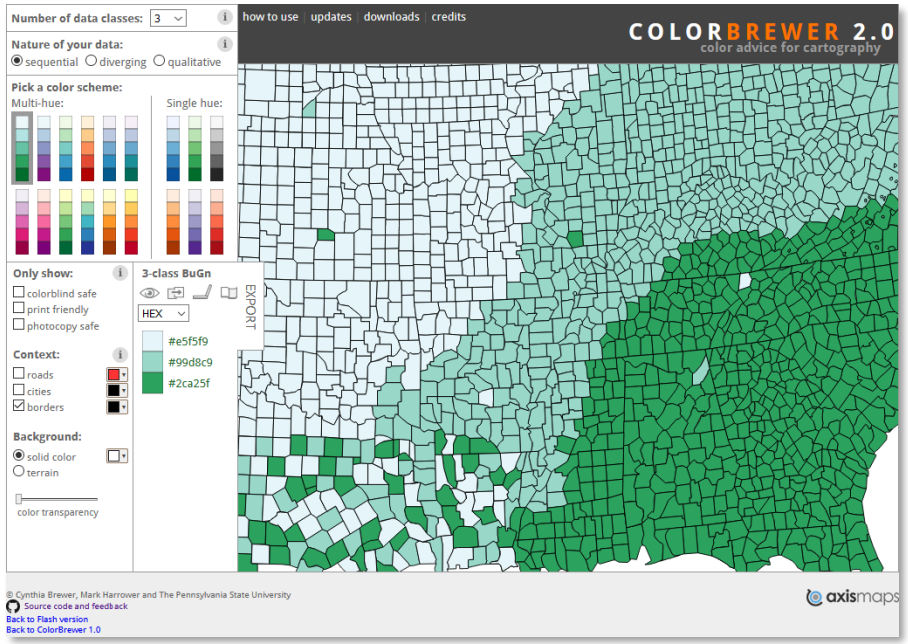
- Many more color tables for specific applications
- Design of good color tables depends on psychological / perceptual issues

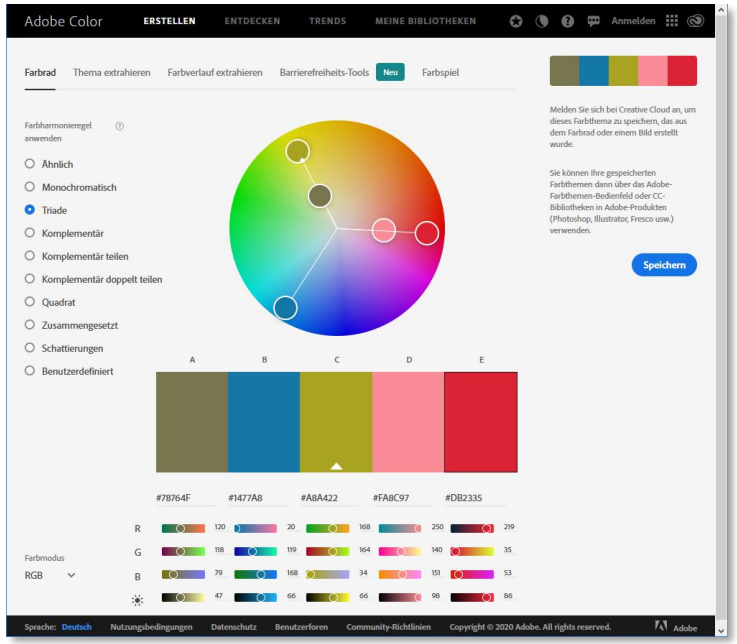
- Often interactive specification of transfer functions to extract important features

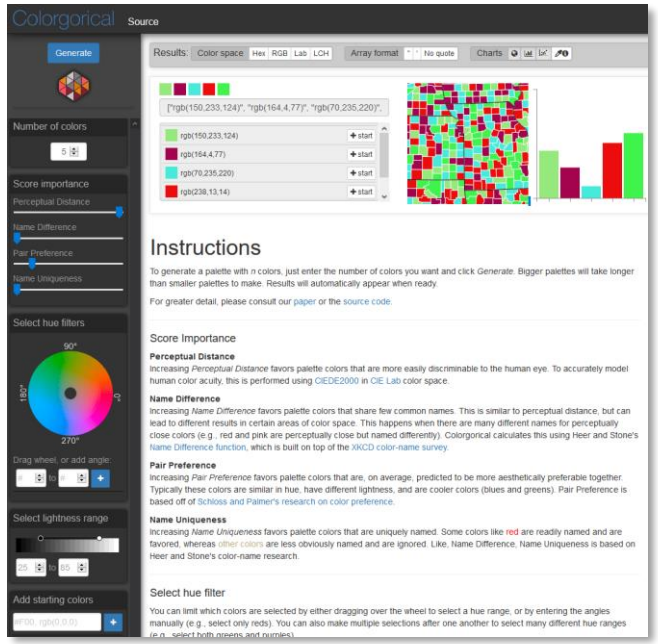


Mapping to Color: How to Choose Colors

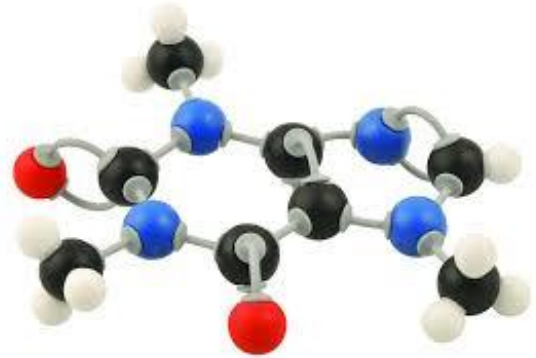
- Recommended Web tools:
  - Color Brewer (http://colorbrewer2.org/)
  - Adobe Color Wheel (https://color.adobe.com/de/create/color-wheel)
  - Colorgorical (http://vrl.cs.brown.edu/color)





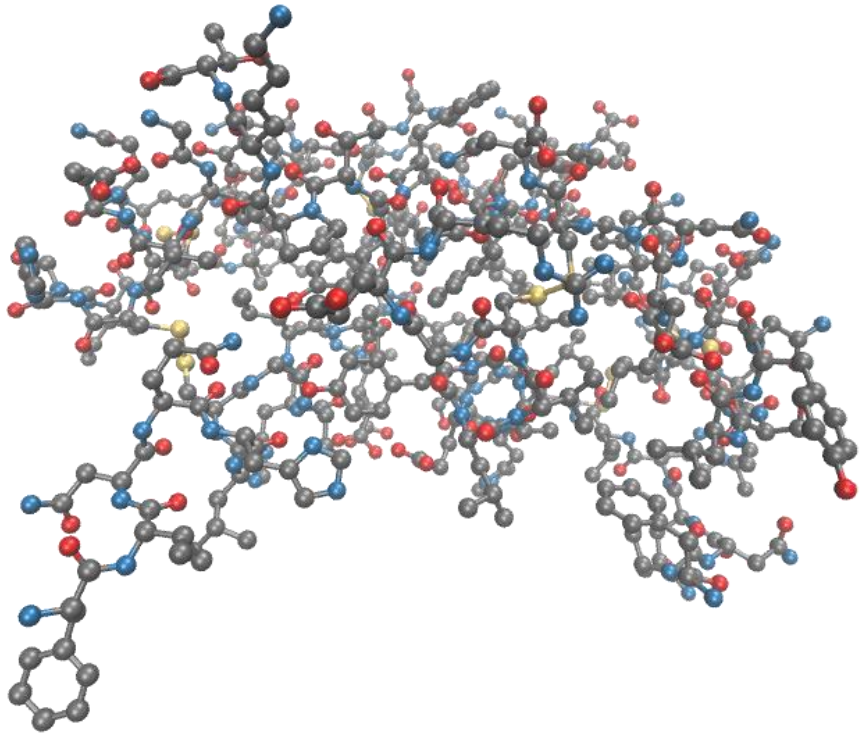


Example: Molecular Visualization



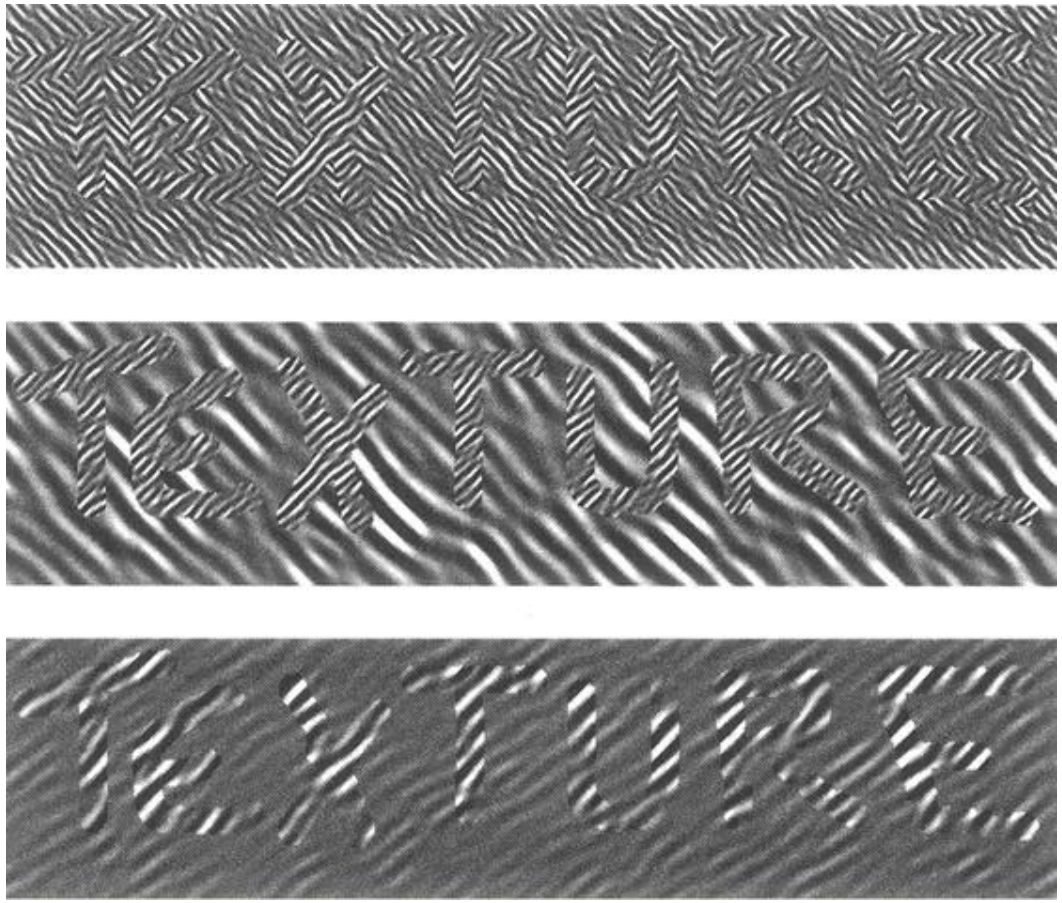
- Input Data:
  - Atom positions: $p_i = (x, y, z) \in \mathbb{R}^3$
  - Element → also determines atomic radius: $r_i \in \mathbb{R}$
  - Atomic (covalent) bonds: $b_{ij} = (i, j) \in \mathbb{N}^2$
    → Bond between atom i and atom j
- Visualization / Mapping:
  - Depict atoms as spheres s_i at position p_i
    - Radius $r_{s_i} = r_i \cdot k$; $k \in [0,1]$ or fixed radius $r_{s_i} \ll r_i$
  - Bonds depicted by lines or thin cylinders
  - Coloring by element (CPK color table)

  → ***Ball-and-stick model***



Mapping to Texture

- Main parameters for texture
  - Orientation
  - Size
  - Contrast
- Alternatively [Tamura 78]:
  - Coarseness
  - Roughness
  - Contrast
  - Directionality
  - Line-likeness
  - Regularity



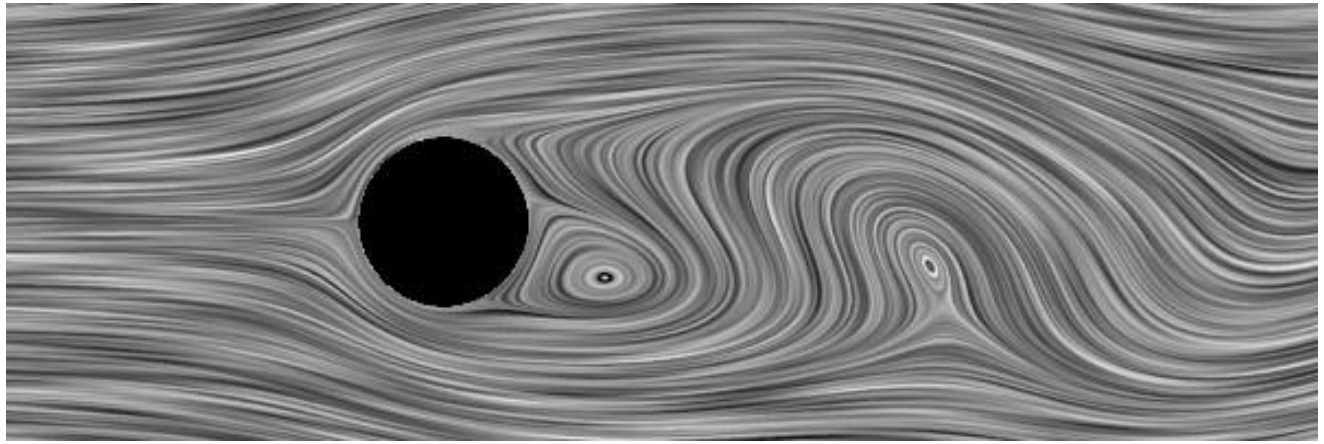
[C. Ware, Information Visualization]

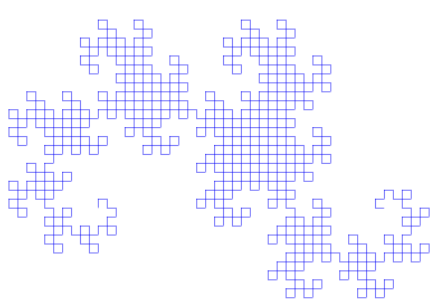
Mapping to Texture

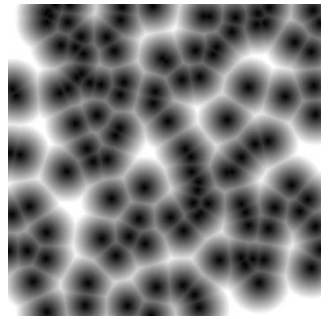
- Goal:
  - Avoid visual “crosstalk” (visual mixup of independent variables)
  - “Orthogonal” perceptual channels
- Restricts range of parameters
  - e.g., approximately 30° difference in orientation needed to distinguish textures
- Main application for textures: nominal data
- Some applications for direct visualization of orientations

Mapping to Texture

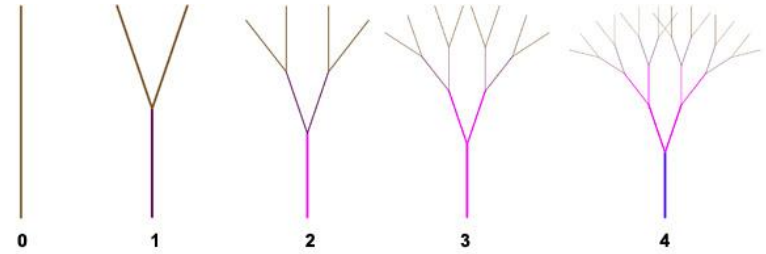
- Stochastic texture models:
  - LIC (Line Integral Convolution) for vector field visualization (*see later*)





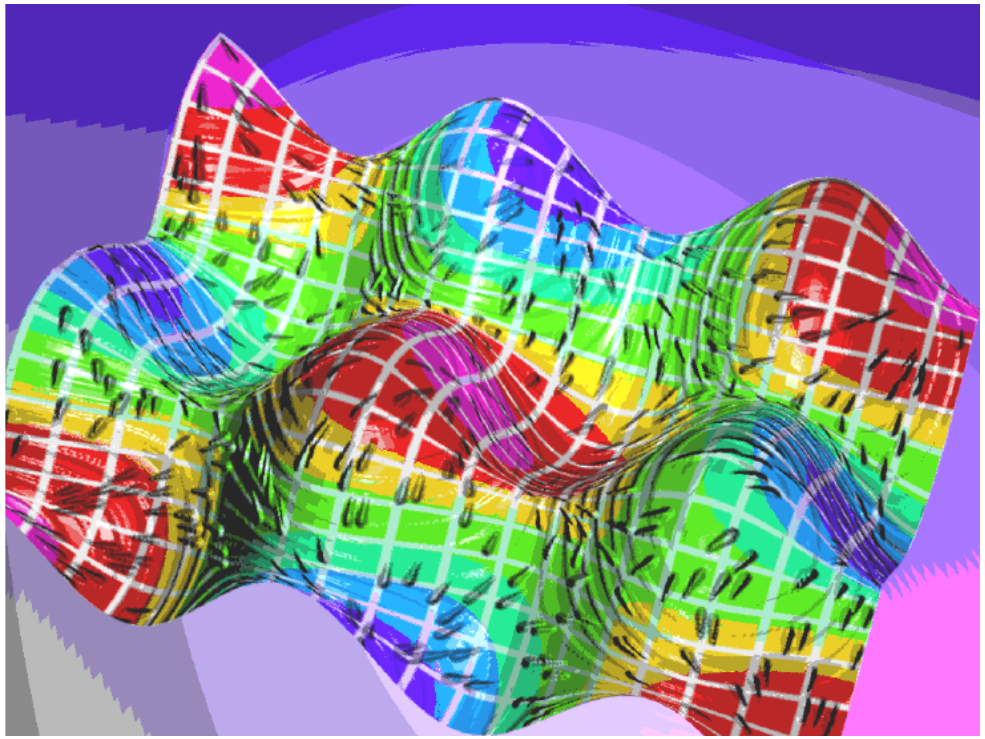


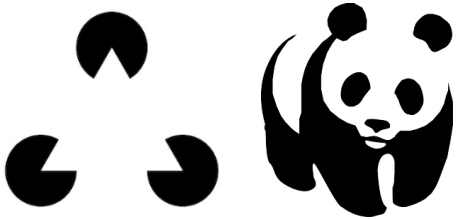
- Structural models
  - Procedural description of texture generation
  - e.g., Lindenmayer systems (L-systems)



Other Mappings

- More advanced mappings possible
  - Examples for other visual variables
    - Motion
    - Blink coding
    - Explicit use of 3D
- Multiple attributes
  - Typical combination of attributes:
    - Geometric position, e.g. height field
    - Color: saturation, intensity, tone
    - Texture
- Perceptional issues, e.g., color perception, Gestalt laws,…
- **Issue:** Interference?

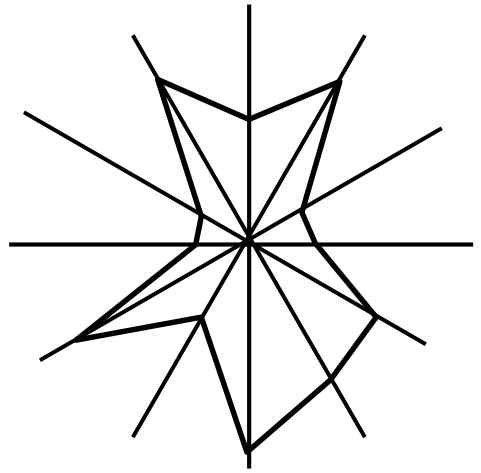


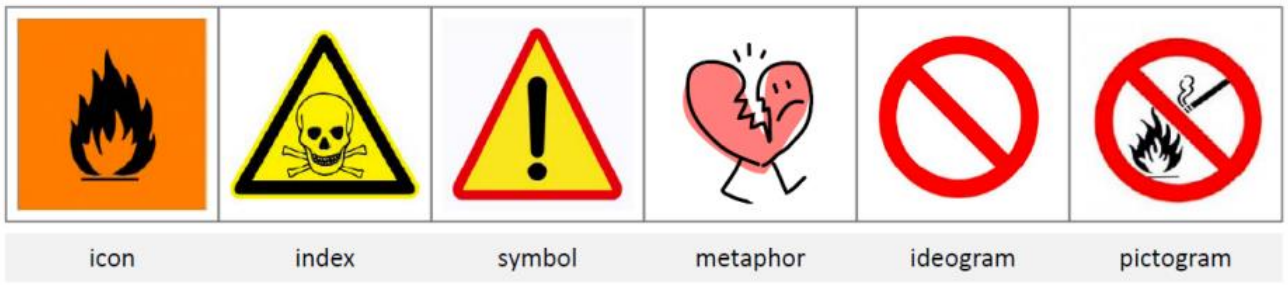


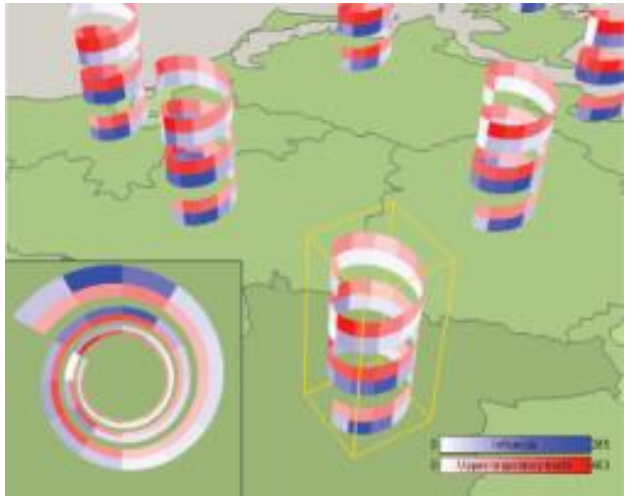
Gestalt laws: Closure

Mapping to Glyphs

- Glyphs and icons
  - Small independent visual object
  - Consist of several components
  - Encodes data values
- Features should be easy to distinguish and combine
- Icons should be separated from each other
- Mainly used for multivariate discrete data



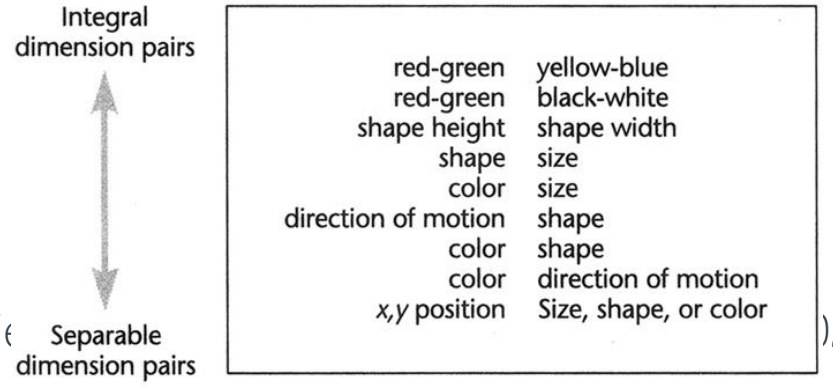




Glyphs

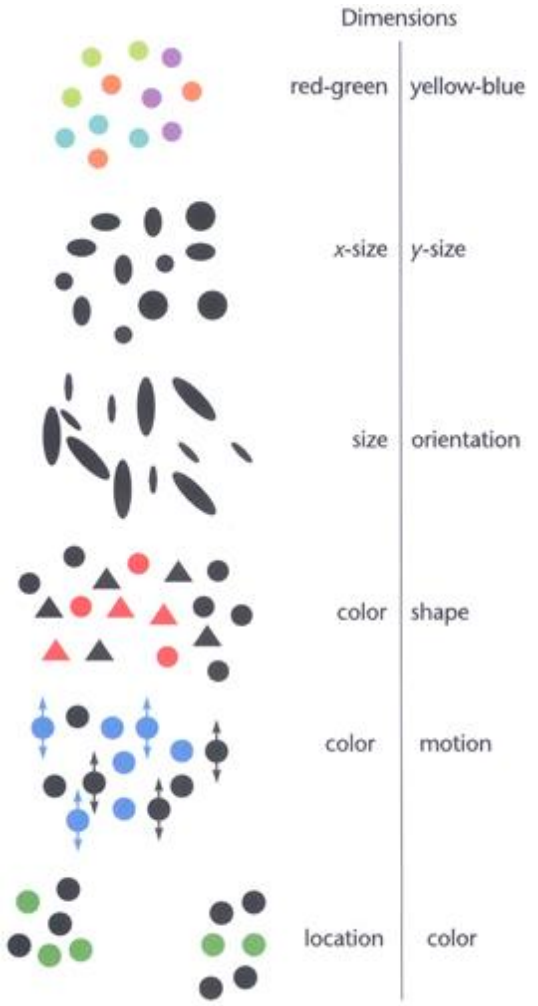
- Multi-dimensional coding
  - Perceptual independence?
- ***Integral*** display dimensions
  - Two or more attributes perceived holistically
- ***Separable*** dimensions
  - Separate judgments about each graphical dimension

→ *Simplistic classification, with a large number of exceptions and asymmetries*



Sci)21)

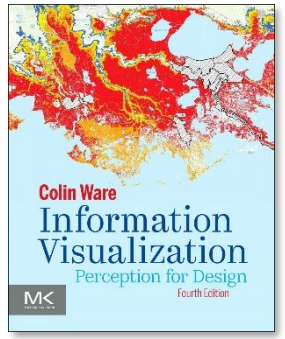
More integral coding pairs



[C. Ware, Information Visualization]

More separable coding pairs

Glyphs



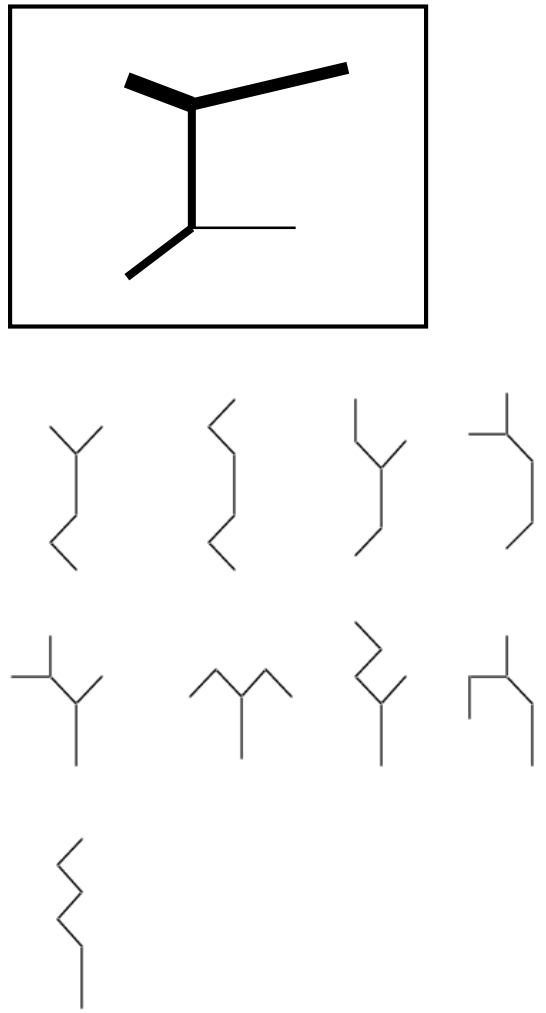
- Interesting graphical attributes for basic glyph design
  [according to C. Ware, Information Visualization]

Visual variable	***Dimensionality***
Spatial position of glyph	3 dimensions: X, Y, Z
Color of glyph	3 dimensions: defined by color opponent theory
Shape	2–3? dimensions unknown
Orientation	3 dimensions: corresponding to orientation about each of the primary axes
Surface texture	3 dimensions: orientation, size, and contrast
Motion coding	2–3? Dimensions largely unknown, but phase may be useful
Blink coding: The glyph blinks on and off at some rate	1 dimension

Glyphs

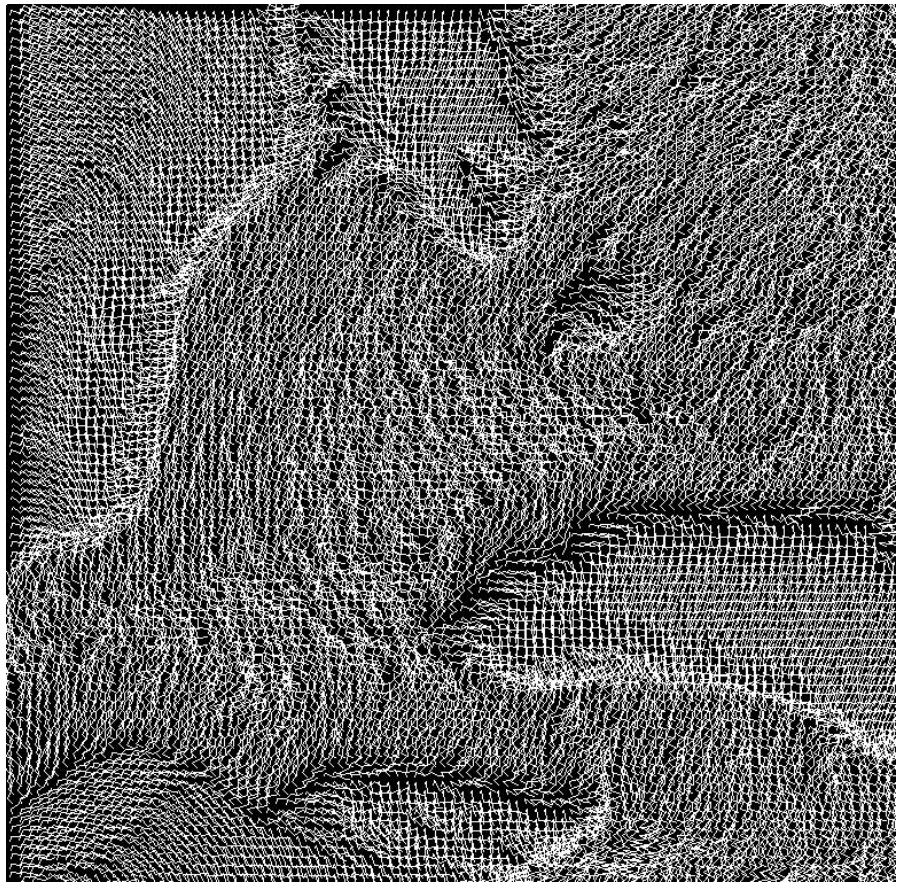
Stick-figure icon [Picket & Grinstein 88]

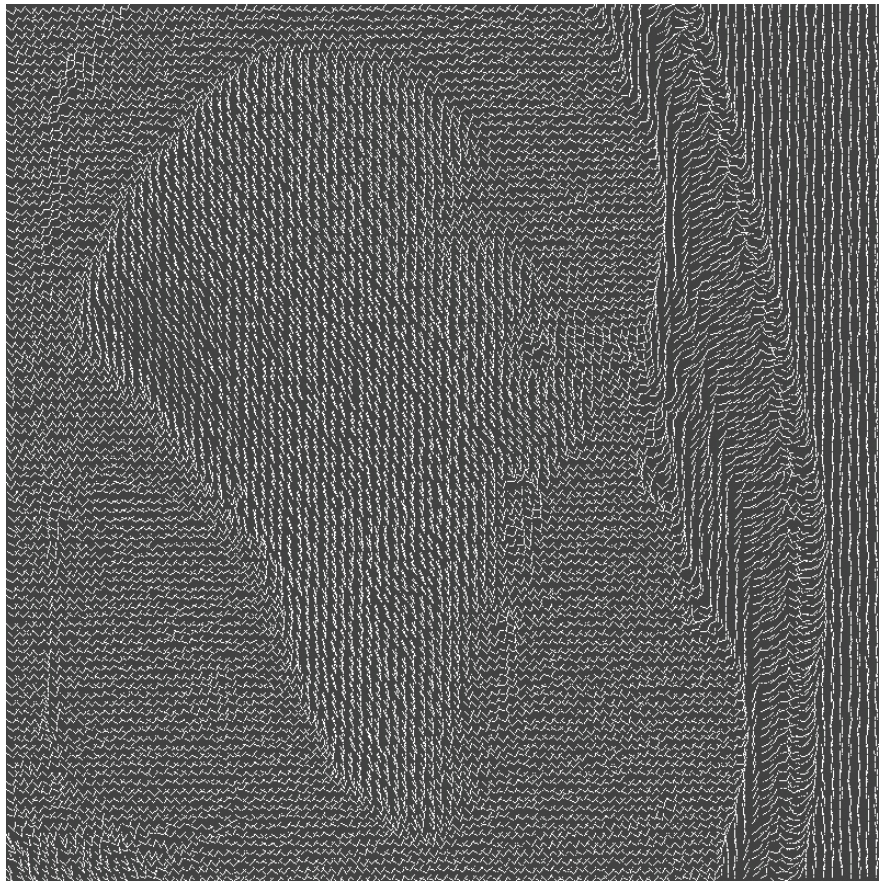
- 2D figure with 4 limbs
- Coding of data via
  - Length
  - Thickness
  - Angle with vertical axis
- 12 attributes
- Exploits the human capability to recognize patterns/textures



Glyphs

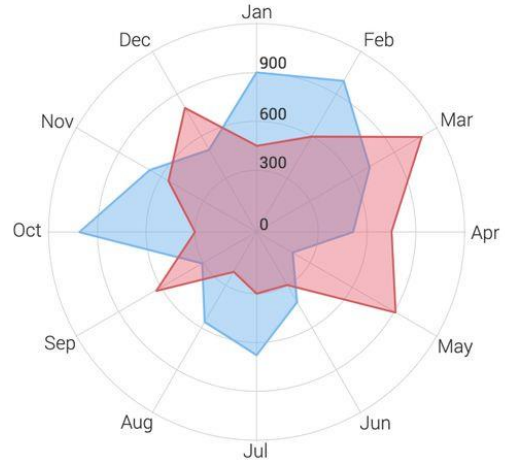
Stick-figure icon [Picket & Grinstein 88]





Glyphs

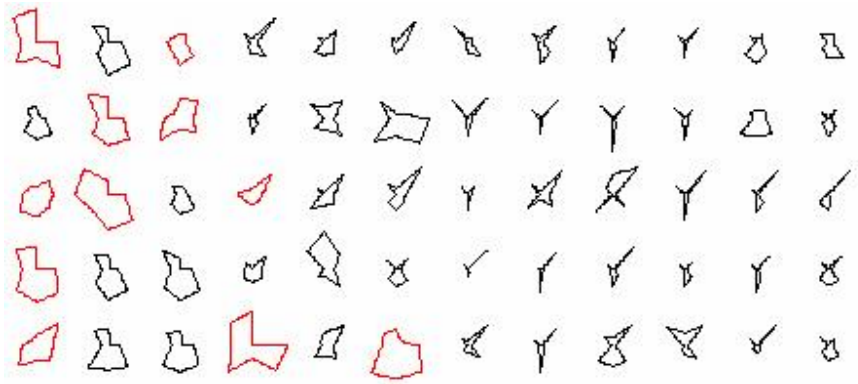
- Circular icon plots:
  - Star plots
  - Sun ray plots
  - etc…
- Follow a “spoked wheel” format
- Values of variables are represented by distances between the center (“hub”) of the icon and its edges

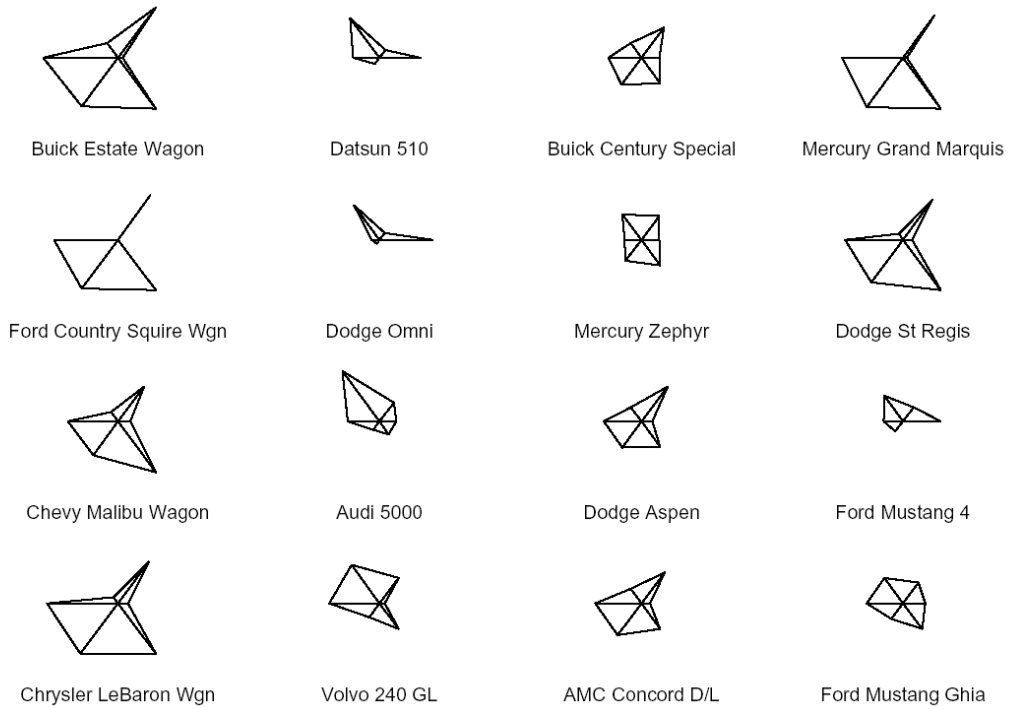


https://www.americanscientist.org/article/circular-visualizations

Glyphs

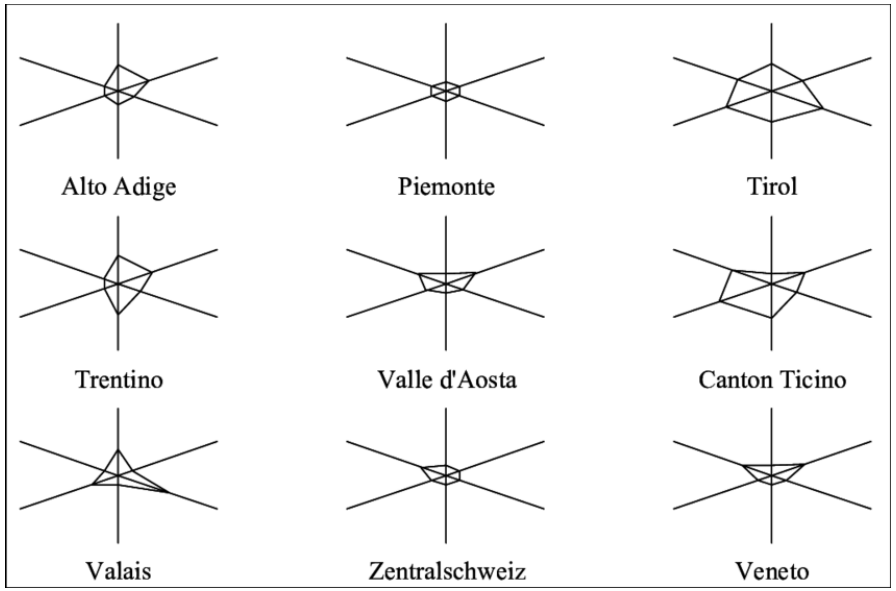
- Star glyphs [Fienberg: *Graphical methods in statistics*. Am. Stat., 33, 1979]
  - A star is composed of equally spaced radii, stemming from the center
  - The length of the spike is proportional to the value of the respective attribute
  - The first spike/attribute is to the right
  - Subsequent spikes are counter-clockwise
  - Ends of rays are connected by a line

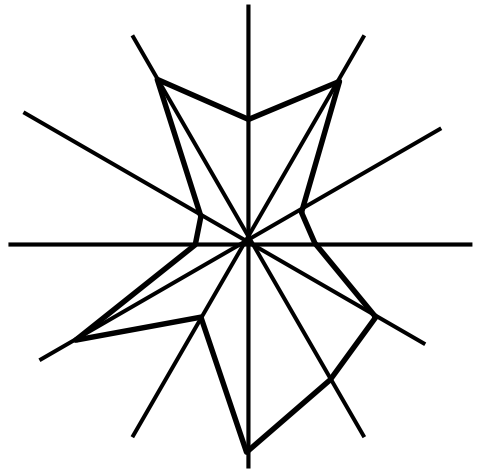


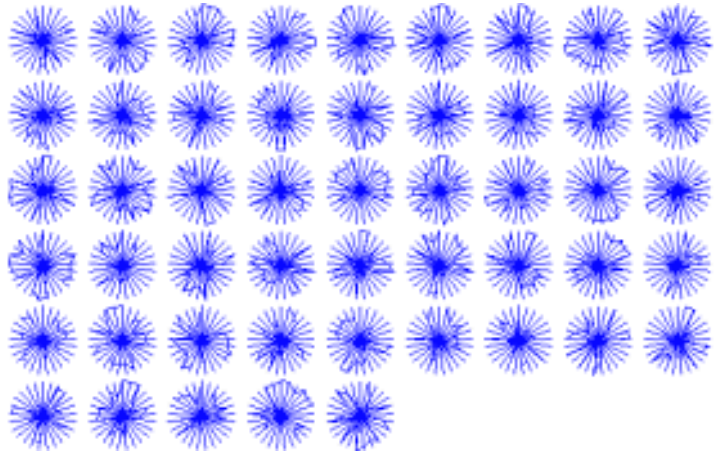


Glyphs

- Sun ray plots
  - Similar to star glyphs/plots
  - Underlying star-shaped structure



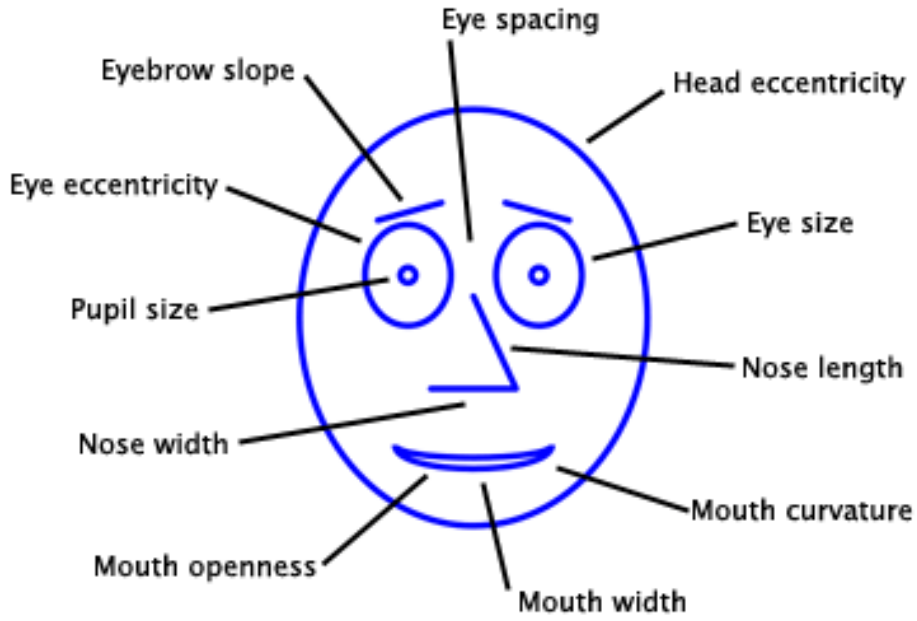




Glyphs

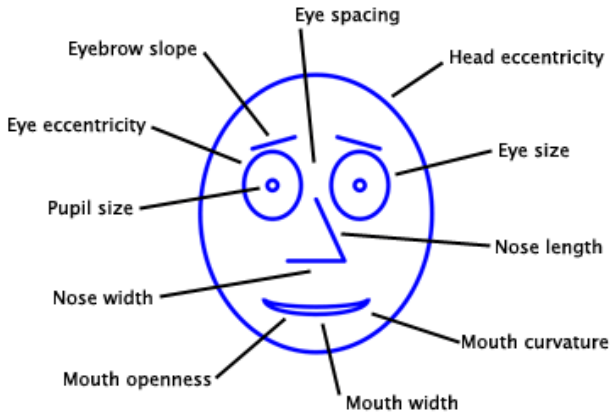
- Chernoff faces/icons [Chernoff: The use of faces to represent points in k-dimensional space graphically. J. Am. Stat. Assoc., 68, 1973]

- Each facial feature represents one variable
- Human ability to distinguish small features in faces



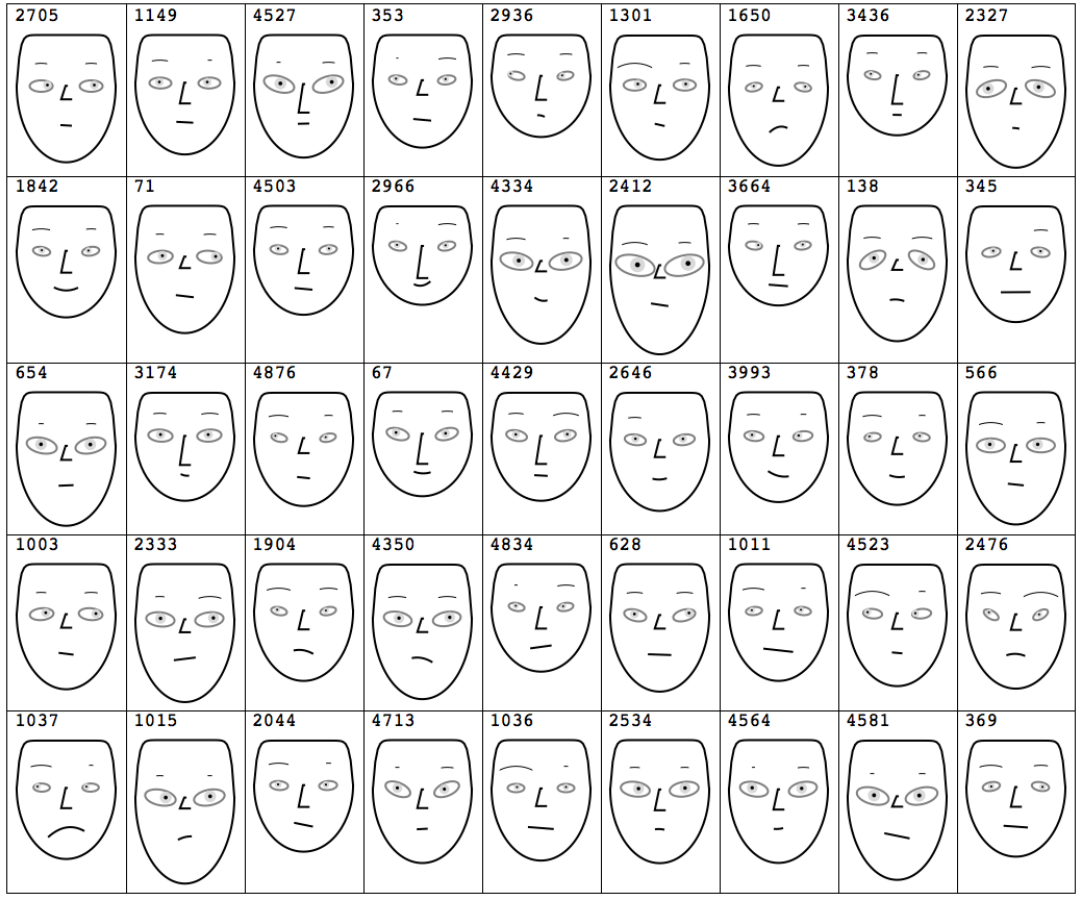
Glyphs

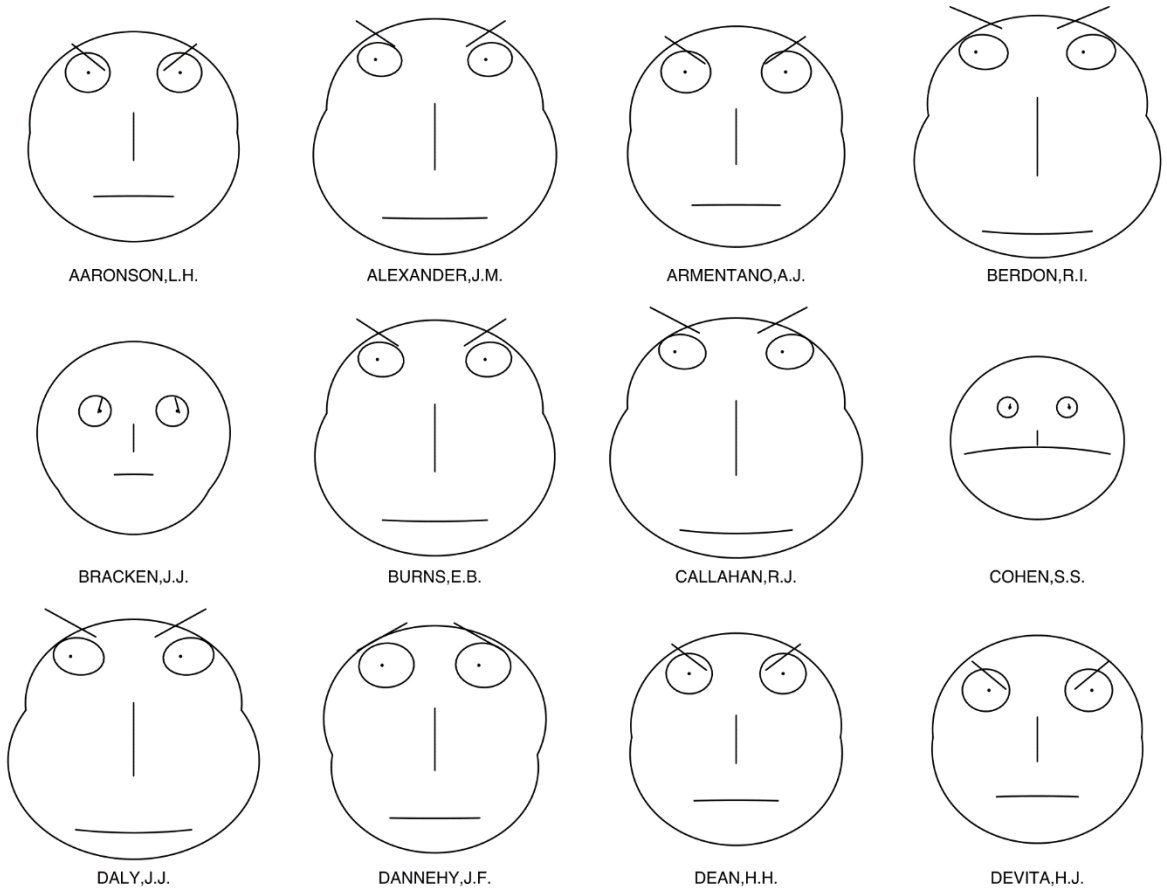
- Chernoff faces/icons
- Possible assignment in the decreasing order of importance:
  - Area of the face
  - Shape of the face
  - Length of the nose
  - Location of the mouth
  - Curve of the smile
  - Width of the mouth
  - Location, separation, angle, shape, and width of the eyes
  - Location of the pupil
  - Location, angle, and width of the eyebrows
- Coding of 15 attributes
- Additional variables could be encoded by making faces asymmetric



Glyphs

- Chernoff faces/icons (Examples)



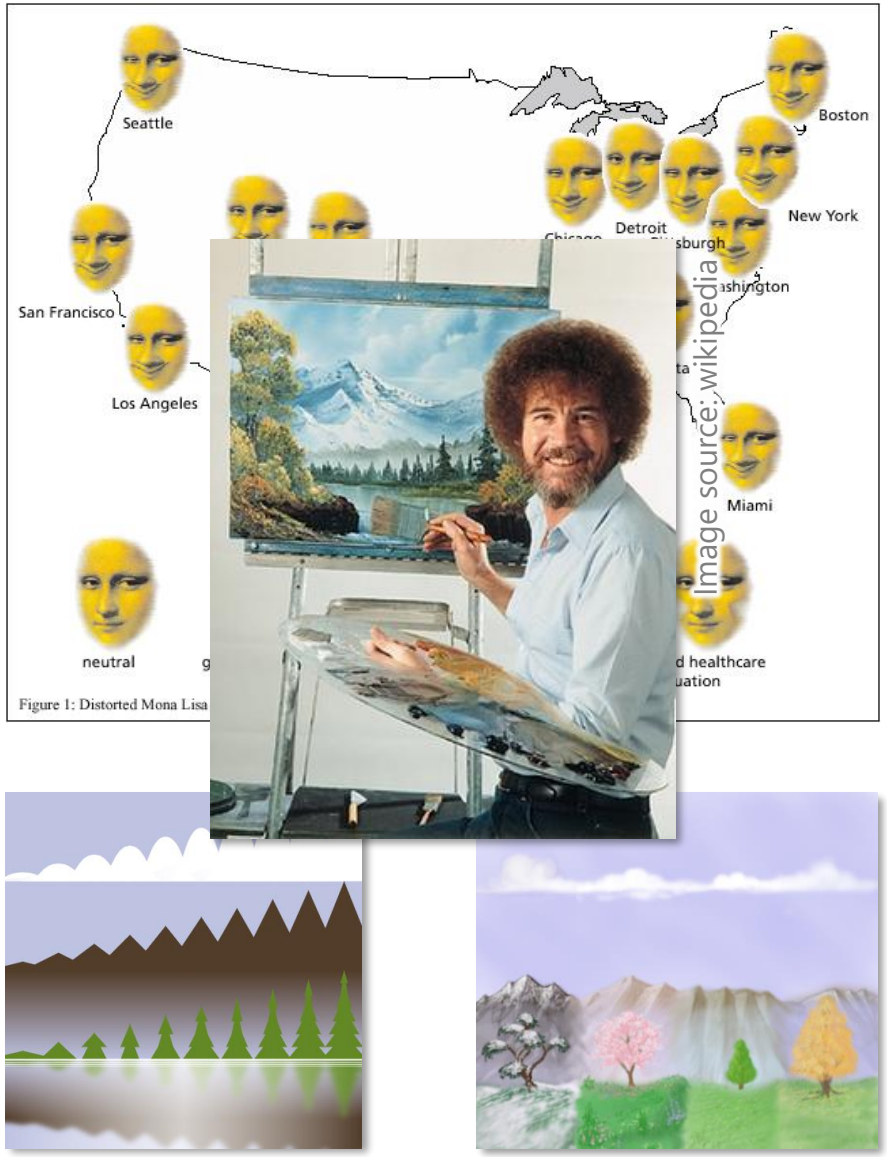


Glyphs

- Face morphing
  [Alexa, Müller: *Visualization by Metamorphosis*, Visualization, 1998]
- Ross-Chernoff Glyphs
  [Correll: *Ross-Chernoff Glyphs Or: How Do We Kill Bad Ideas in Visualization?*, CHI, 2018]
  - "[…] extend and improve Chernoff faces by merging them with the work of landscape painter Bob Ross […]"

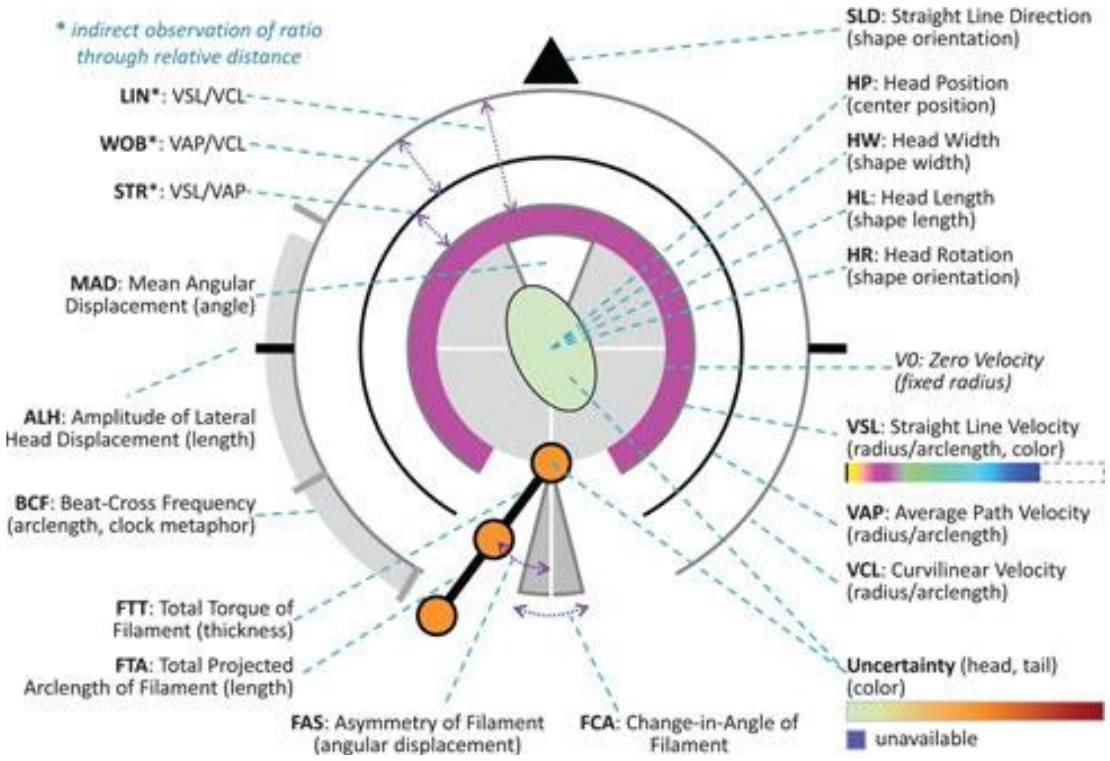
  → **Provocative Joke:** "[…] obviously a bad idea, yet it is difficult to precisely articulate why […]"

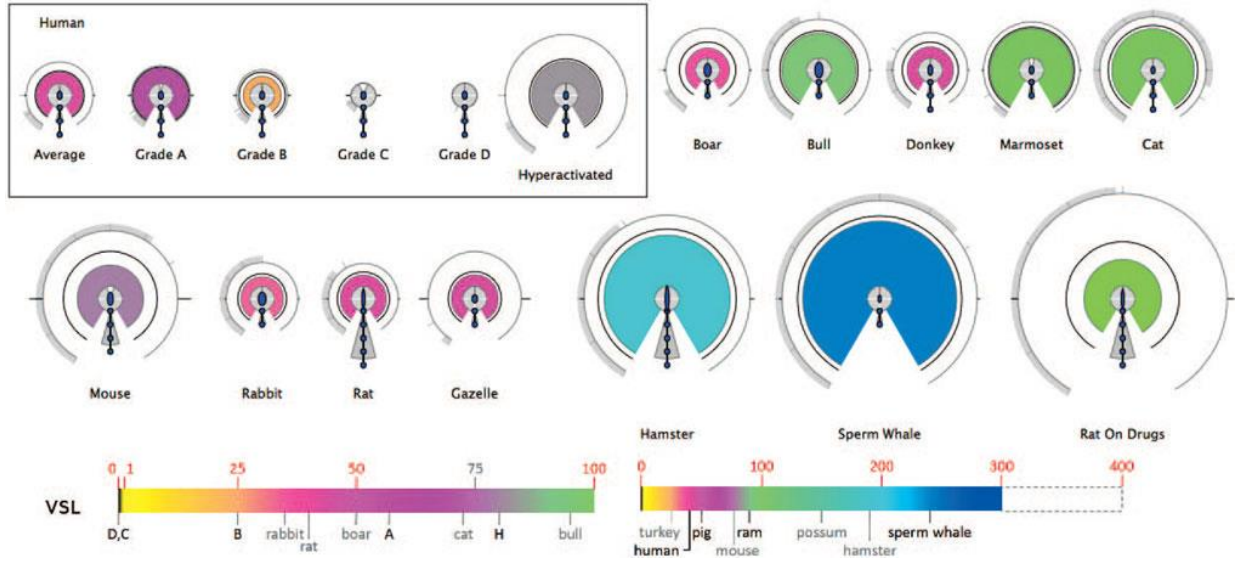
  → *Adding complexity is not always helpful*



Example: Glyph Design & Scalability

- Design of a glyph encoding 20 parameters

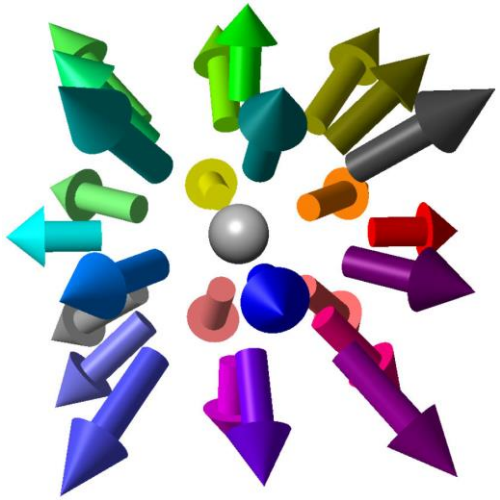


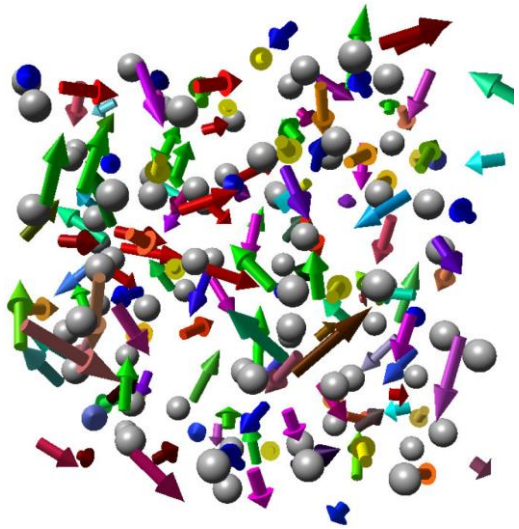


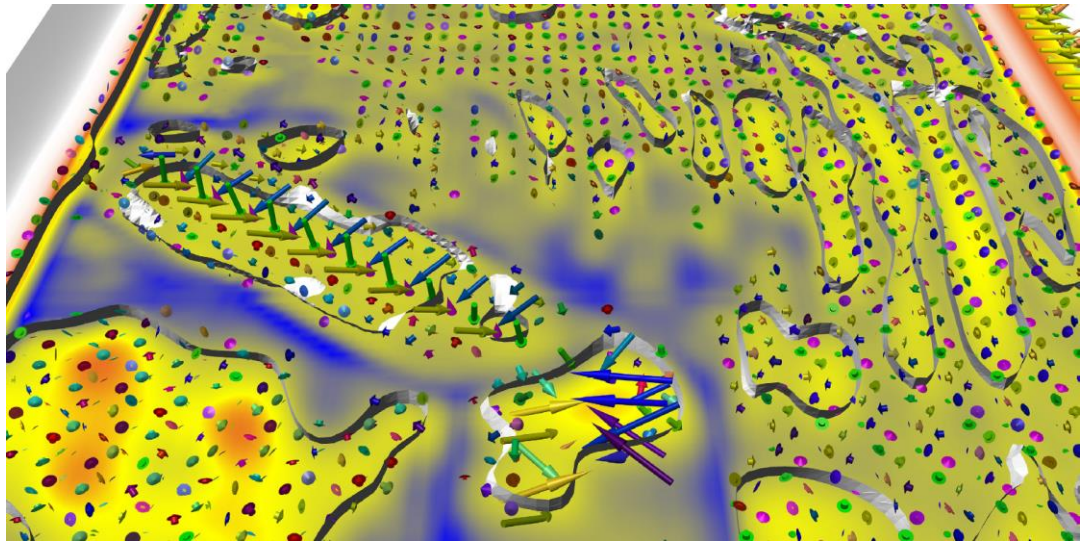
Duffy, Thiyagalingam, Walton, Smith, Trefethen, Kirkman-Brown, Gaffney, Chen, "Glyph-Based Video Visualization for Semen Analysis," *IEEE Trans. Vis. Comput. Graphics* 21(8), 2015.

Example: Dipole Glyphs

- Molecular Simulation of cracks on the atomic scale
  - Mechanical forces lead to cracks in the simulated material
  - Cracks lead dipole moments and fractional anisotropy
  - **Arrow glyphs**: orientation + length of dipole moment (color shows direction)

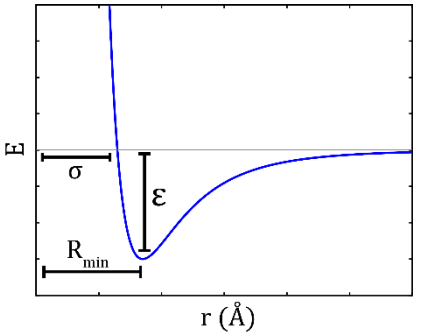




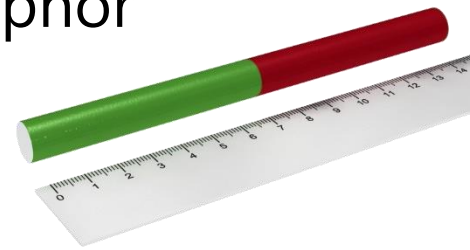


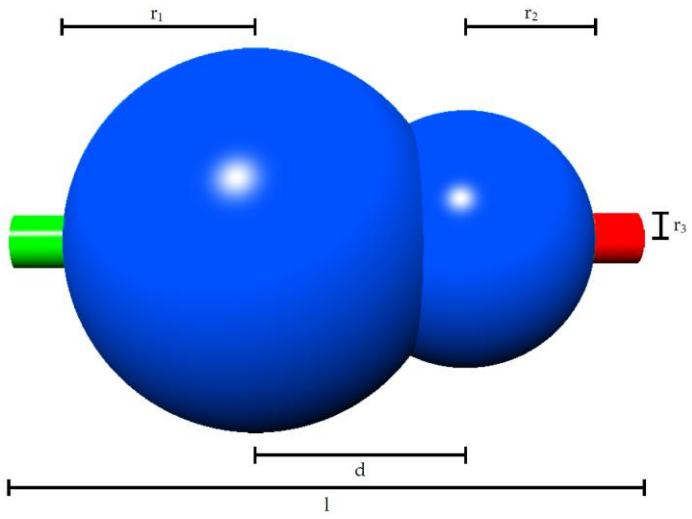
Grottel, Beck, Müller, Reina, Roth, Trebin, Ertl, "Visualization of Electrostatic Dipoles in Molecular Dynamics of Metal Oxides," *IEEE Trans. Vis. Comput. Graphics* 18(12), 2012

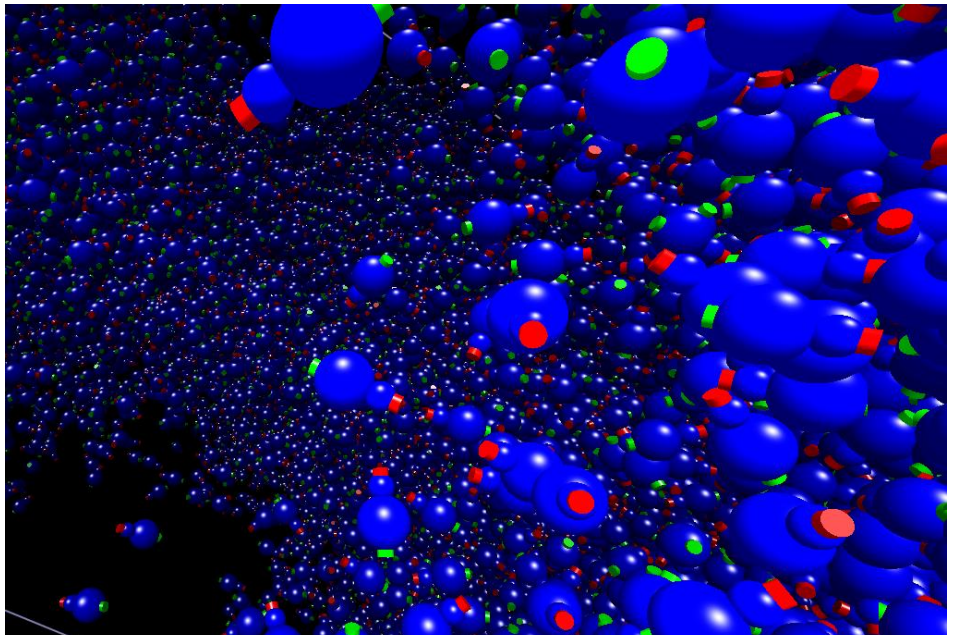
Example: Dipole Glyphs



- Molecular Simulation of Lennard-Jones potentials
  - Two Lennard-Jones centers → pair of spheres with radii of respective atoms
  - Mapping of charges (red and green cylinder) → rod magnet metaphor
  - Distance between Lennard-Jones centers
  - Length of cylinder: charge







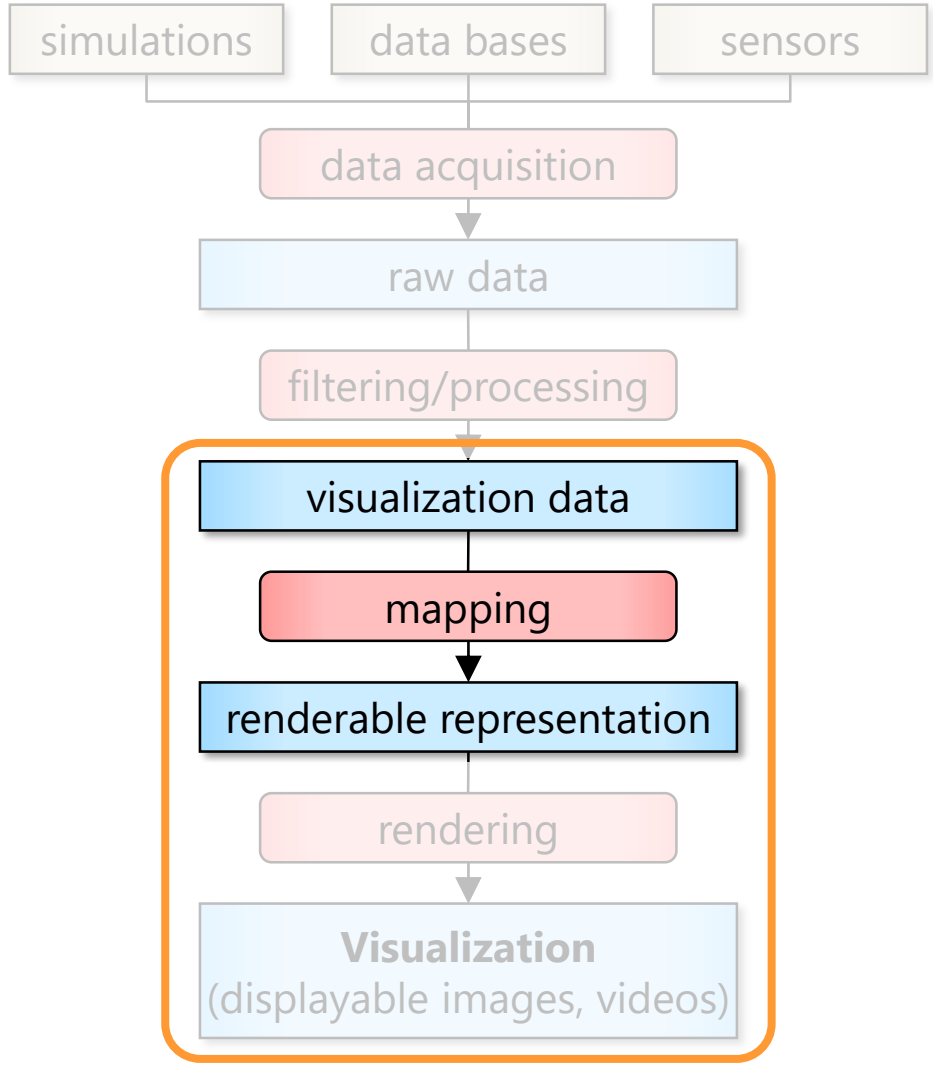
Reina, T. Ertl, "Hardware-Accelerated Glyphs for Mono- and Dipoles in Molecular Dynamics Visualization," IEEE Visualization, 2005.

Summary

- Mapping of data to visual attributes
  - Most important step of the vis pipeline:
    → how to express data visually?
  - Marks and channels
  - Effectiveness of mappings
  - Examples: Mapping to position, shape, color, texture,…
- Glyphs

→ **Rest of this lecture:** different types of mappings and corresponding rendering techniques

Focus:
Second step of visualization pipeline



Next Chapter:

Visualization of Scalar Fields