Introduction to Data Visualization

Veera Muangsin

References

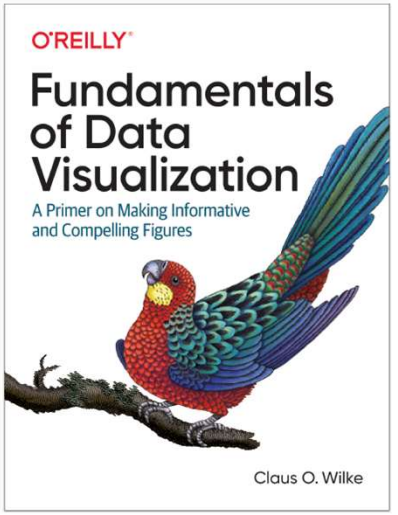
- Book: Fundamentals of Data Visualization, Claus O. Wilke, 2019.
- Book: Visualization Analysis & Design, Tamara Munzner, CRC Press, 2014.

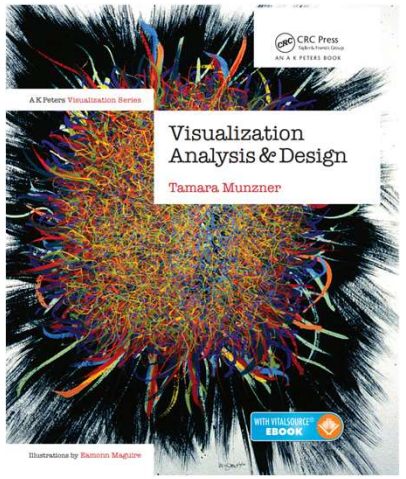
  http://www.cs.ubc.ca/~tmm/talks.html
- A Tour Through the Visualization Zoo, Jeffrey Heer, Michael Bostock and Vadim Ogievetsky, Communications of the ACM, 2010.

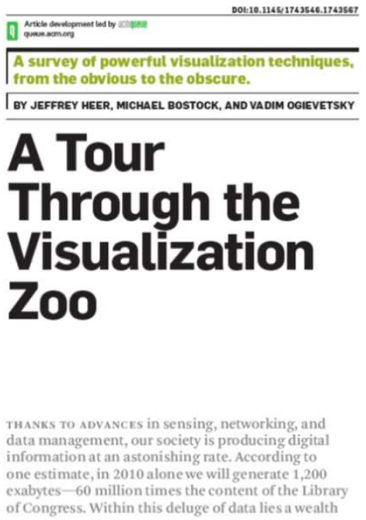
  https://dl.acm.org/citation.cfm?id=1743567
- Book: The Visual Display of Quantitative Information, Edward R. Tufte, 2001.

Examples

- https://public.tableau.com/en-us/s/gallery
- https://community.powerbi.com/t5/Data-Stories-Gallery/bd-p/DataStoriesGallery
- https://www.gapminder.org/tools/
- https://flowingdata.com/
- https://truth-and-beauty.net/
- http://datavis.ca/milestones/





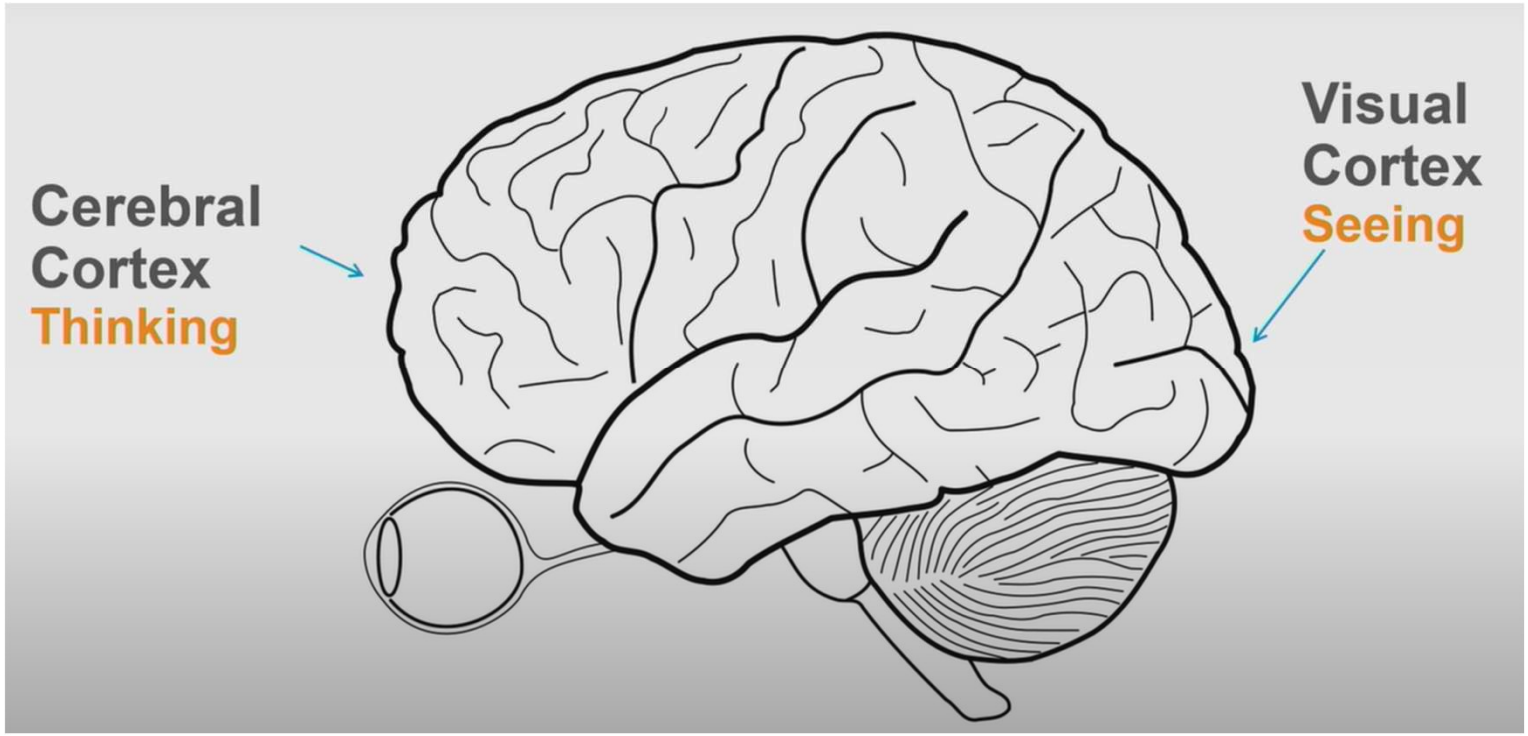


What is Data Visualization?

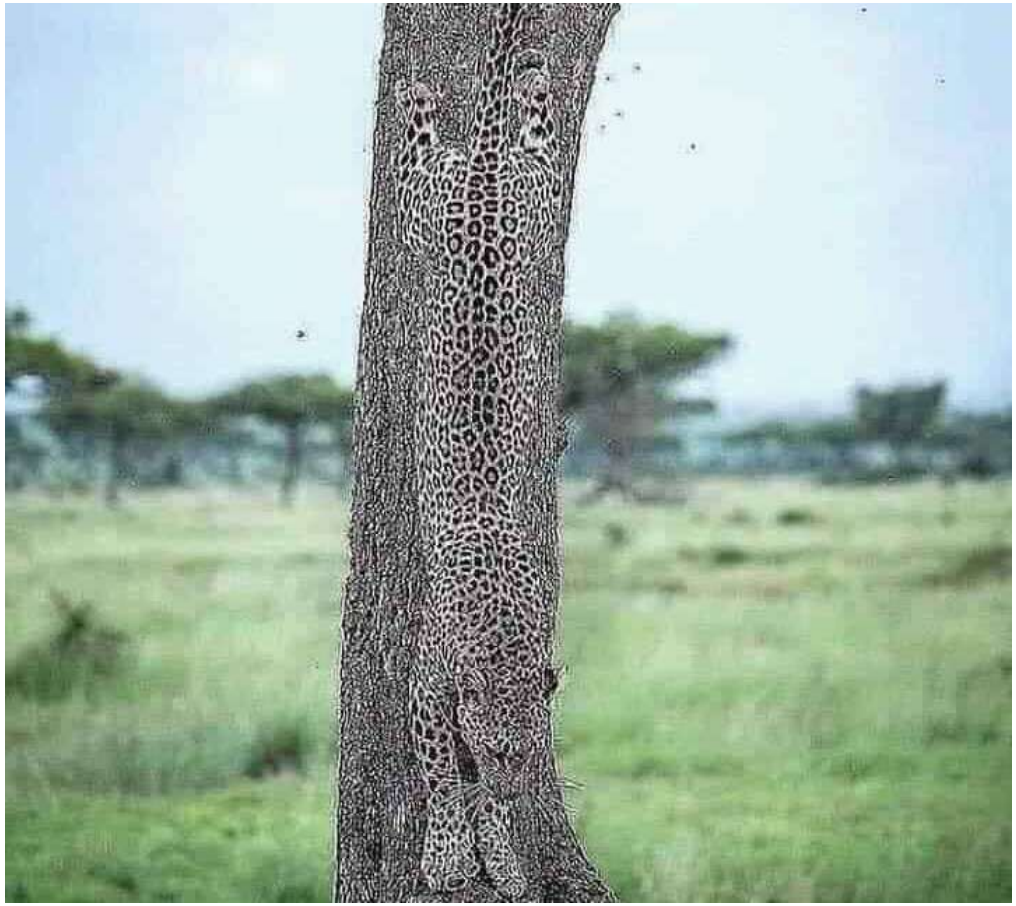
The process of converting raw data
into easily understood visual representation
that enables effective communication
and decision making

Why Visualization?

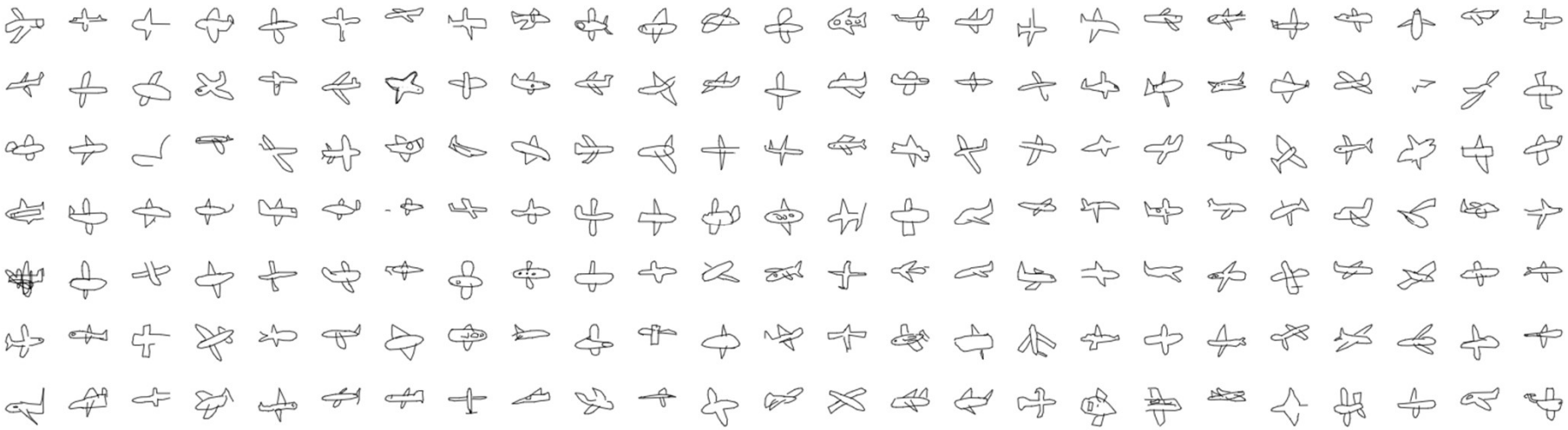
- Of all human senses, visual sense is the most powerful.
  - Smell for dog, sonar for dolphin, etc.
- 90% of all information transmitted to our brains is visual.
- Human is good at finding patterns.



See or Die



Abstraction



https://quickdraw.withgoogle.com/data

Language: Can You Raed Tihs?

We do not raed ervey lteter by itslef but the wrod as a wlohe.

We do not read every letter by itself but the word as a whole.

http://www.mrc-cbu.cam.ac.uk/people/matt.davis/Cmabrigde/

Raw data vs. Visualization

country	region	income per person	life expectancy	population
Afghanistan	asia_west	1840	57.2	30700000
Albania	europe_east	10400	77	2920000
Algeria	africa_north	13200	76.8	37600000
Andorra	europe_west	41900	82.6	82400
Angola	africa_sub_saharan	6000	61.7	25100000
Antigua and Barbuda	america_north	19100	77	96800
Argentina	america_south	19200	76.1	42100000
Armenia	europe_east	7510	74.3	2880000
Australia	east_asia_pacific	42600	82.3	22800000
Austria	europe_west	44400	80.9	8520000
Azerbaijan	europe_east	15900	70.2	9260000
Bahamas	america_north	23000	73.7	372000
Bahrain	asia_west	41500	76.3	1300000
Bangladesh	asia_west	2710	71.3	156000000
Barbados	america_north	15400	76.8	282000
Belarus	europe_east	17500	71.8	9470000
Belgium	europe_west	41000	80.3	11100000
Belize	america_north	7970	71.6	337000
Benin	africa_sub_saharan	1860	62.6	9730000
Bhutan	asia_west	7030	72.9	753000
Thailand	east_asia_pacific	14400	77.2	67800000
Timor-Leste	east_asia_pacific	2030	72	1160000
Togo	africa_sub_saharan	1260	60.4	6860000
Tonga	east_asia_pacific	5130	70	105000
Trinidad and Tobago	america_north	31300	72.8	1340000
Tunisia	africa_north	10400	77.1	10900000
Turkey	europe_east	20300	78.6	74600000
Turkmenistan	asia_west	12200	68.8	5270000
Uganda	africa_sub_saharan	1640	58.6	36300000
Ukraine	europe_east	8320	71.1	45300000
United Arab Emirates	asia_west	59800	76.4	8900000
United Kingdom	europe_west	36700	80.7	64300000
United States	america_north	50500	78.9	313000000
Uruguay	america_south	18500	76.5	3400000
Uzbekistan	asia_west	4770	69.3	29500000
Vanuatu	east_asia_pacific	2900	63.3	247000
Venezuela	america_south	17700	75.3	29900000
Vietnam	east_asia_pacific	4910	73.6	90500000
Yemen	asia_west	3790	67.9	24900000
Zambia	africa_sub_saharan	3510	54.5	14700000
Zimbabwe	africa_sub_saharan	1850	54.1	14700000

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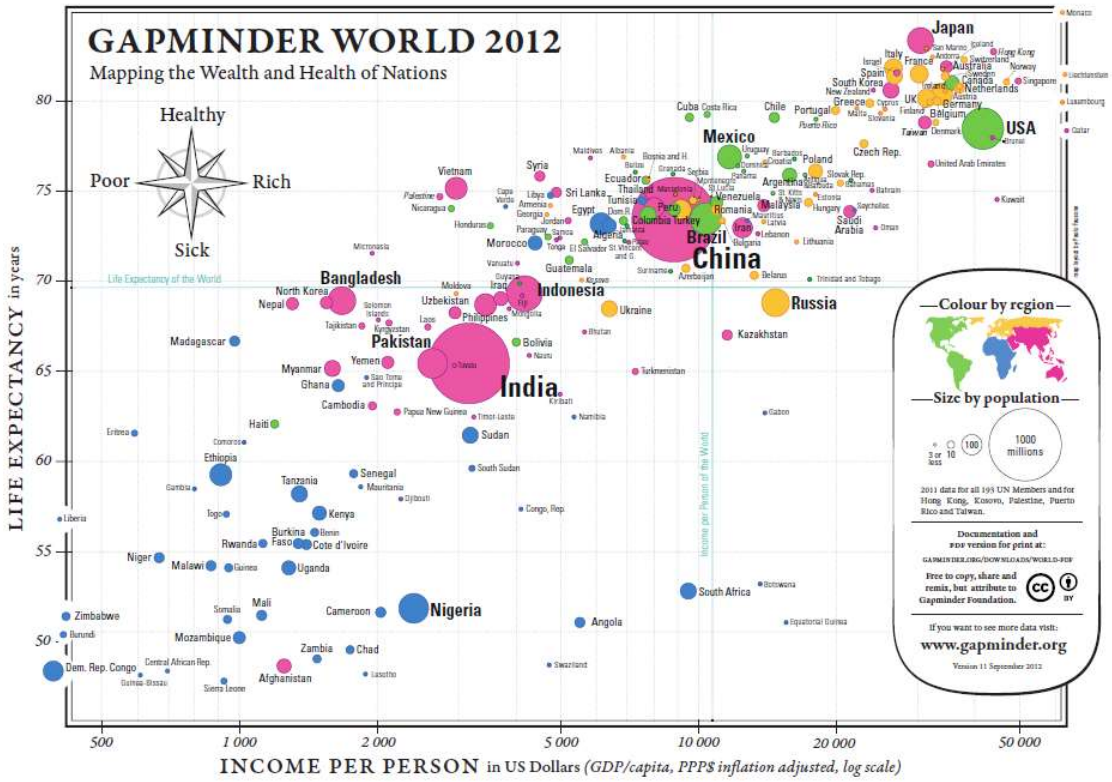
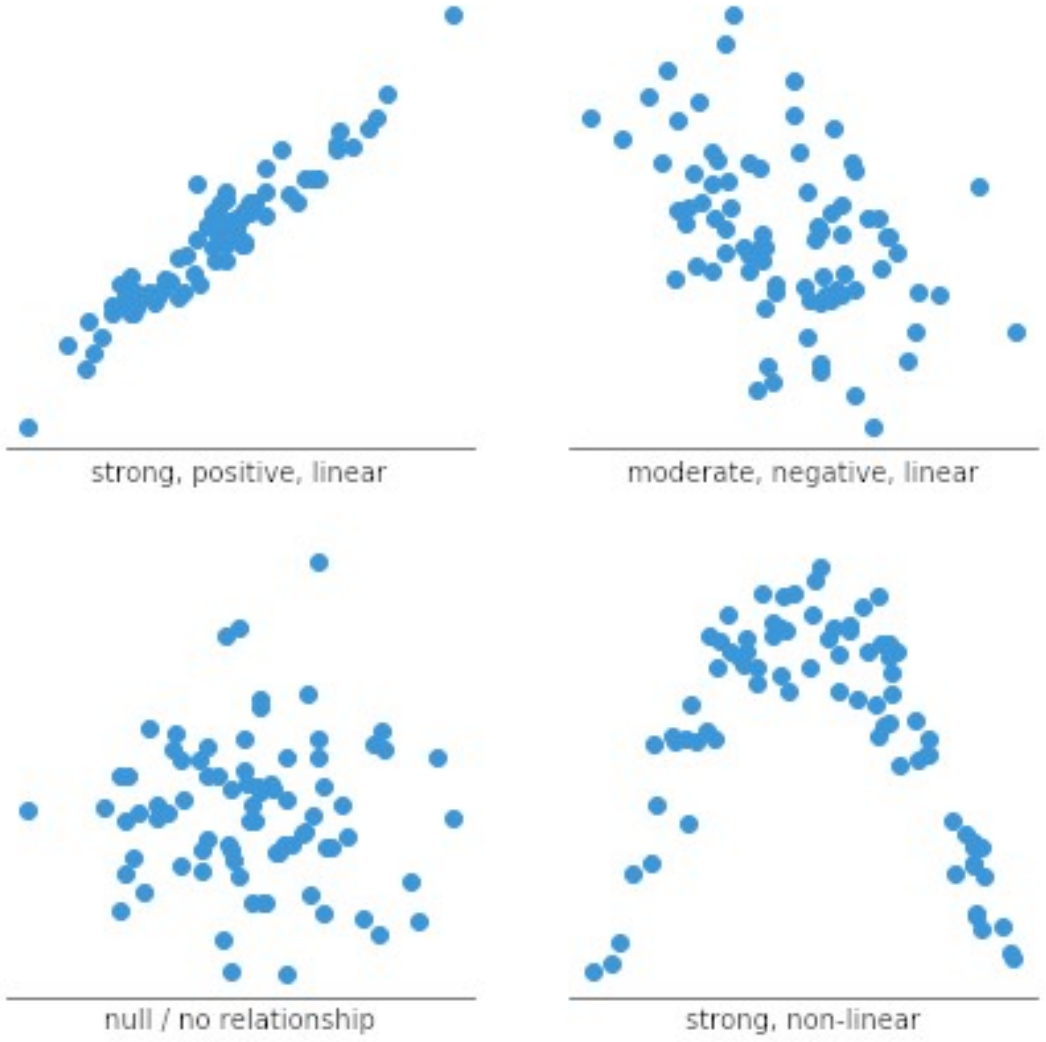
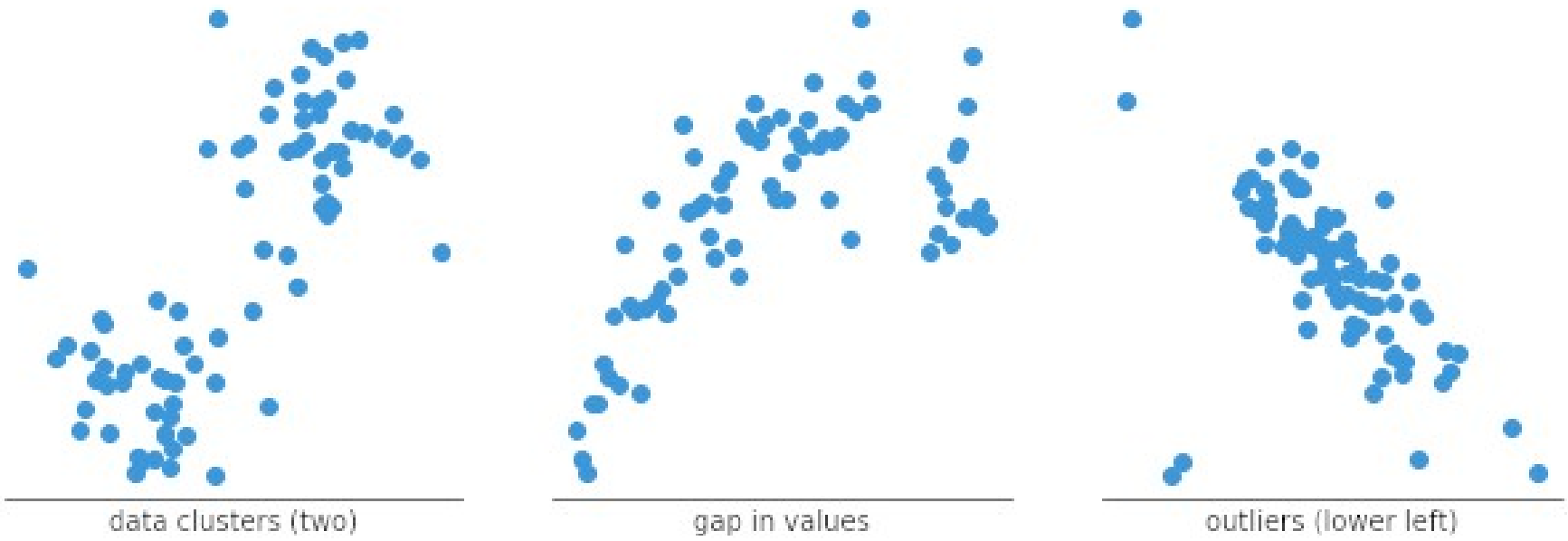
Zambia	africa_sub_saharan	3510	54.5	14700000
Zimbabwe	africa_sub_saharan	1850	54.1	14700000



Identifying Correlational Relationships



Identifying other patterns

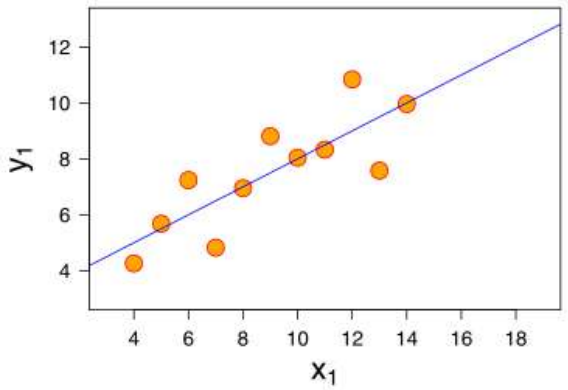


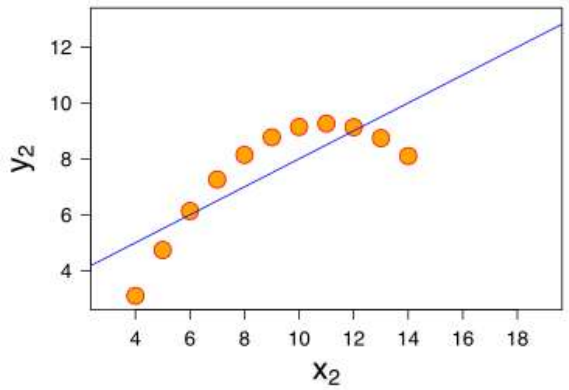
Anscombe's quartet

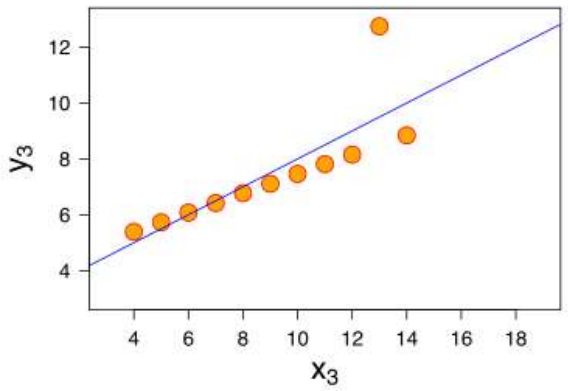
- Demonstrate the importance of visual representation of data
- All four data set have almost identical statistics but different graphs

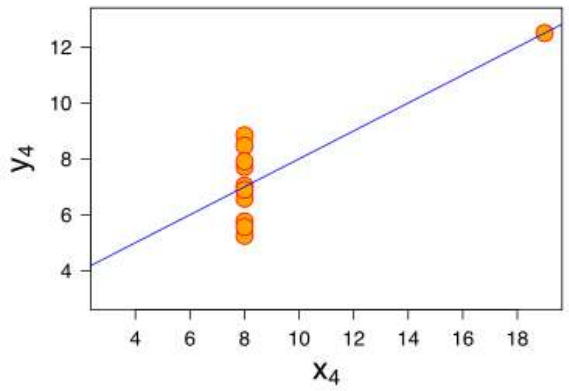
I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	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

Property	Value
Mean of x	9
Sample variance of x	11
Mean of y	7.50
Sample variance of y	4.125
Correlation between x and y	0.816
Linear regression line	$y = 3.00 + 0.500x$
Coefficient of determination of the linear regression	0.67





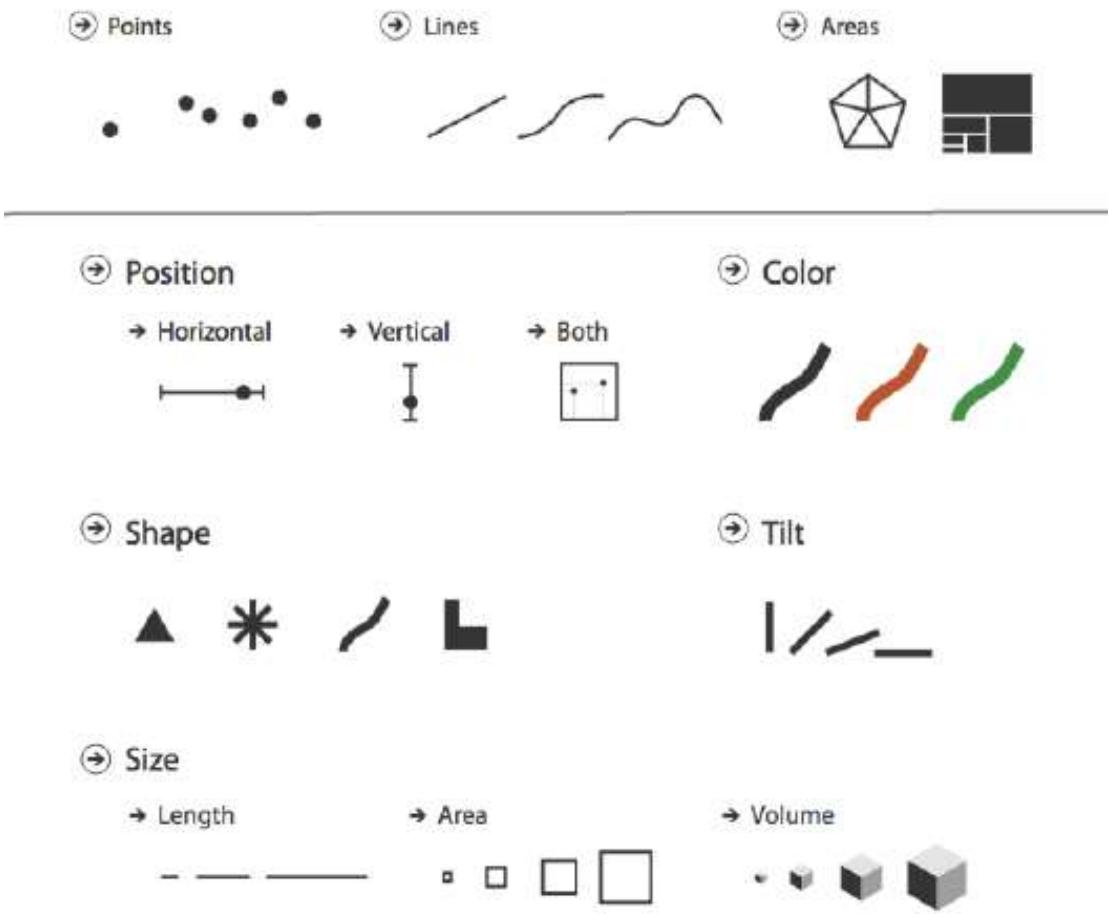




https://en.wikipedia.org/wiki/Anscombe%27s_quartet

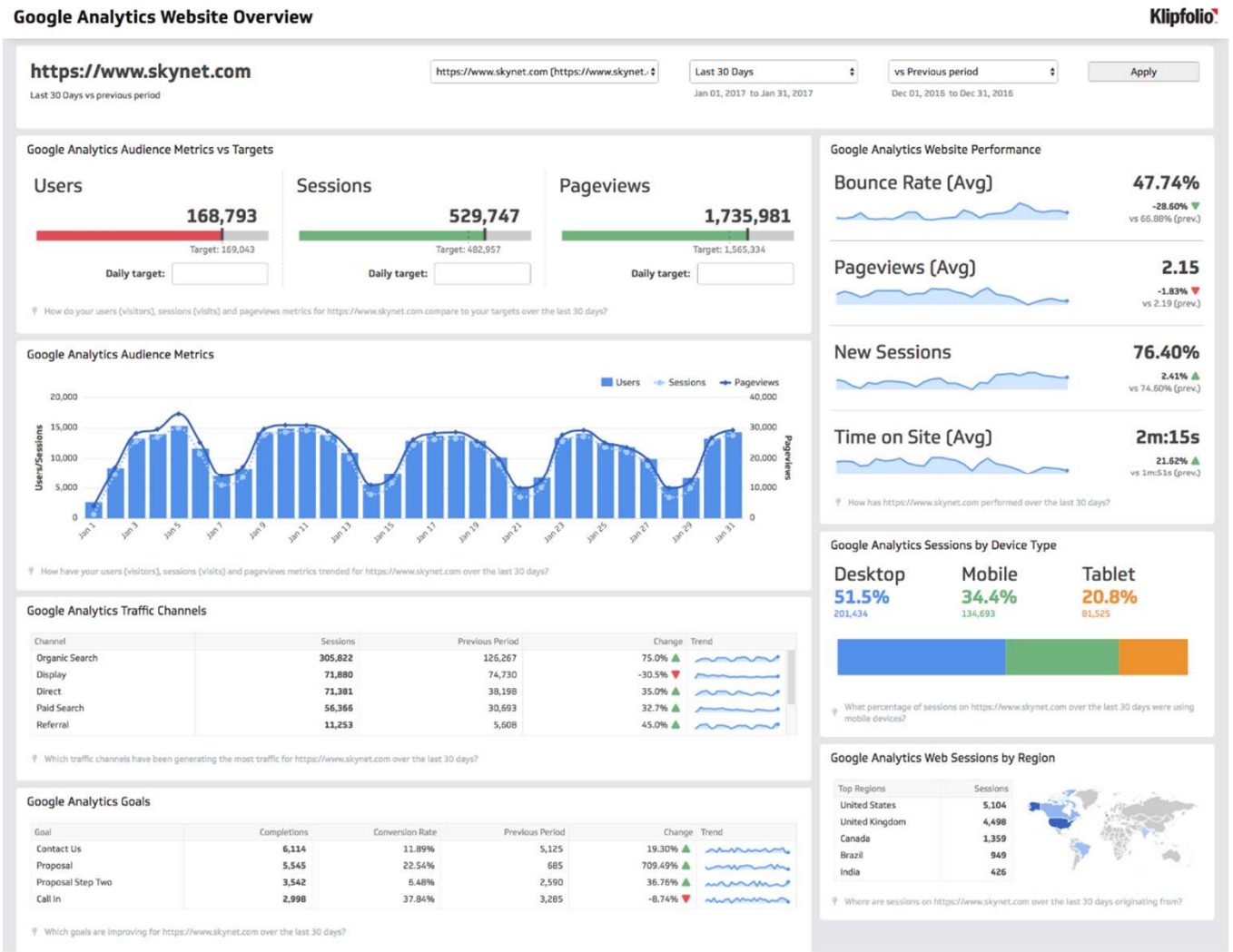
Visual Representation

Data visualization displays measured quantities using a combination of visual variables.



Dashboard

Display many measures or key performance indicators (KPIs) on different charts.

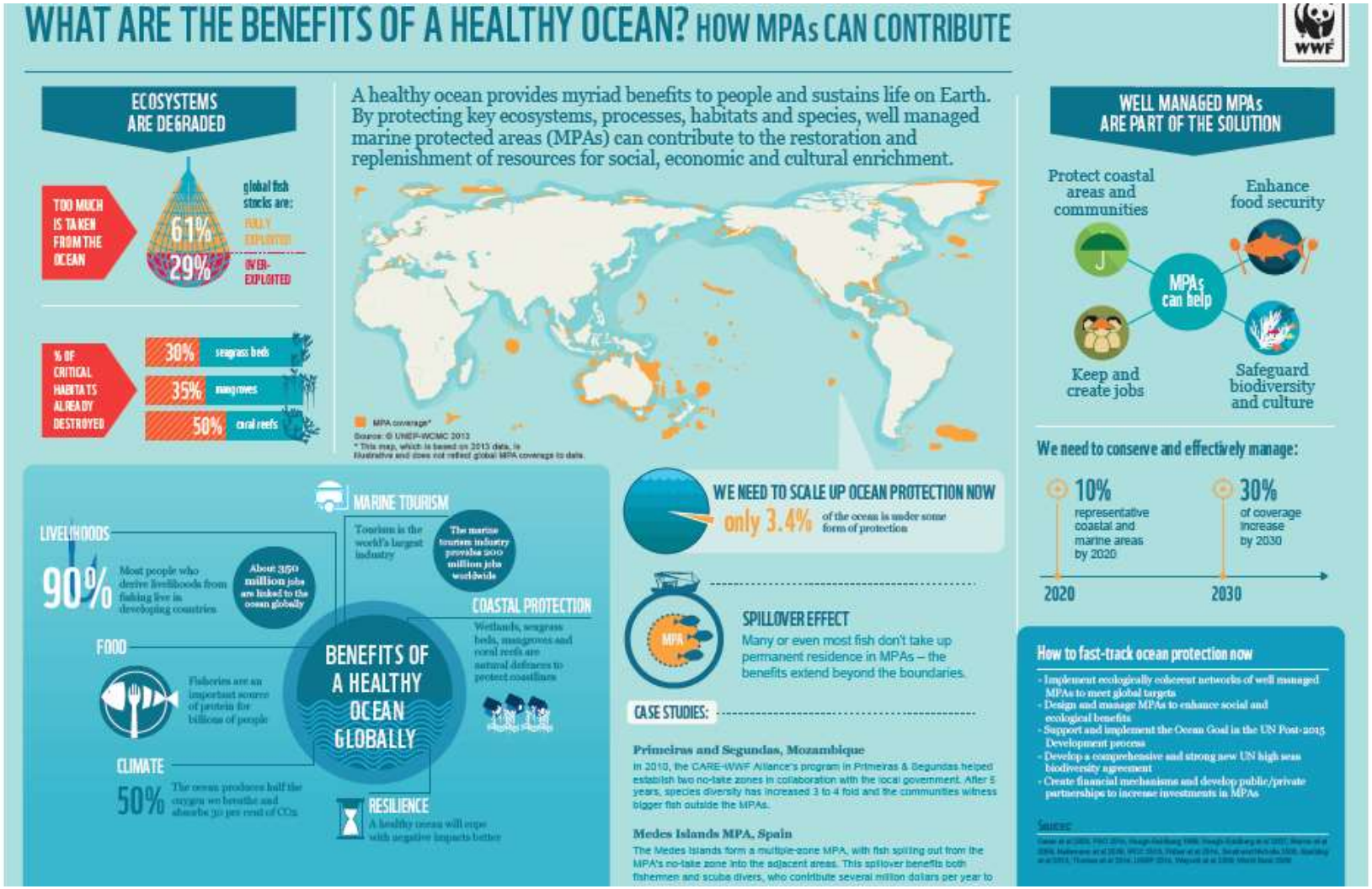


Stock Market Technical Chart

Infographics

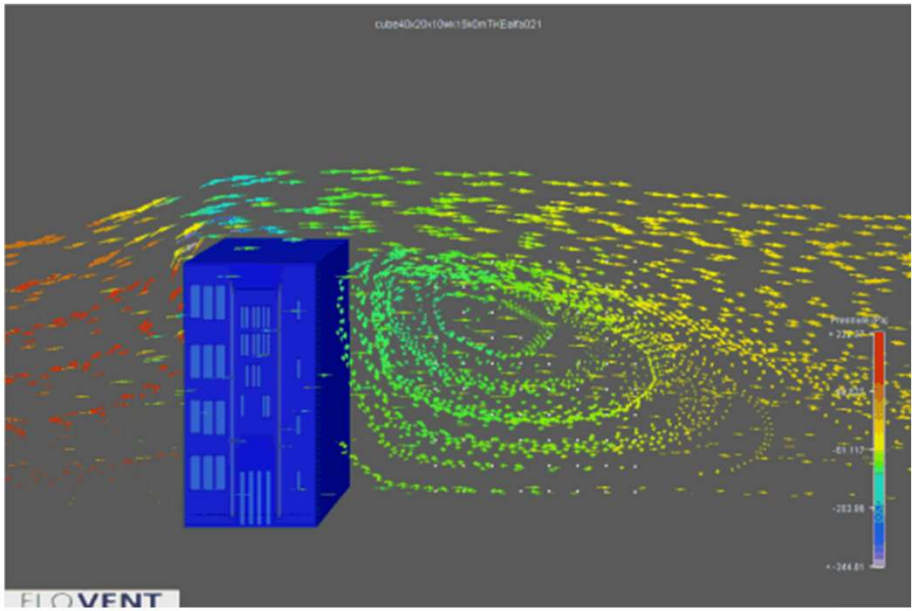
Storytelling via graphical data representation.

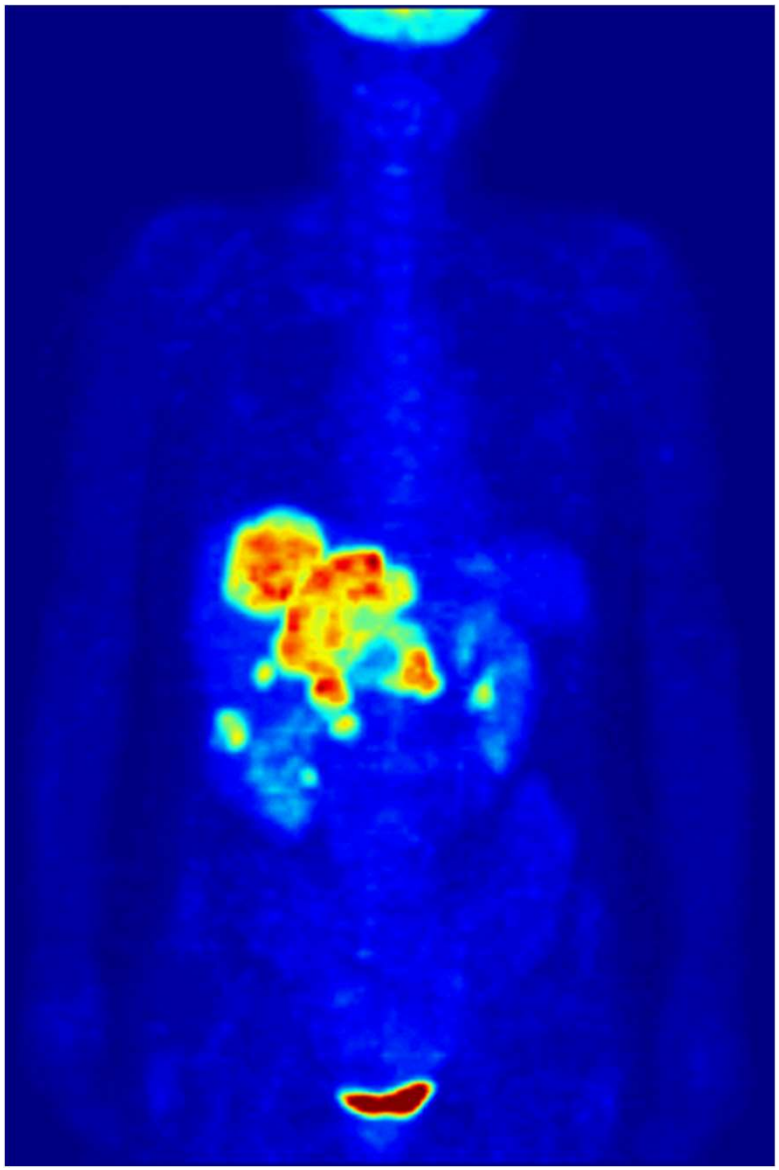
Aesthetic is more important than accuracy.



Scientific Visualization

Visualize data from scientific instruments and simulation.





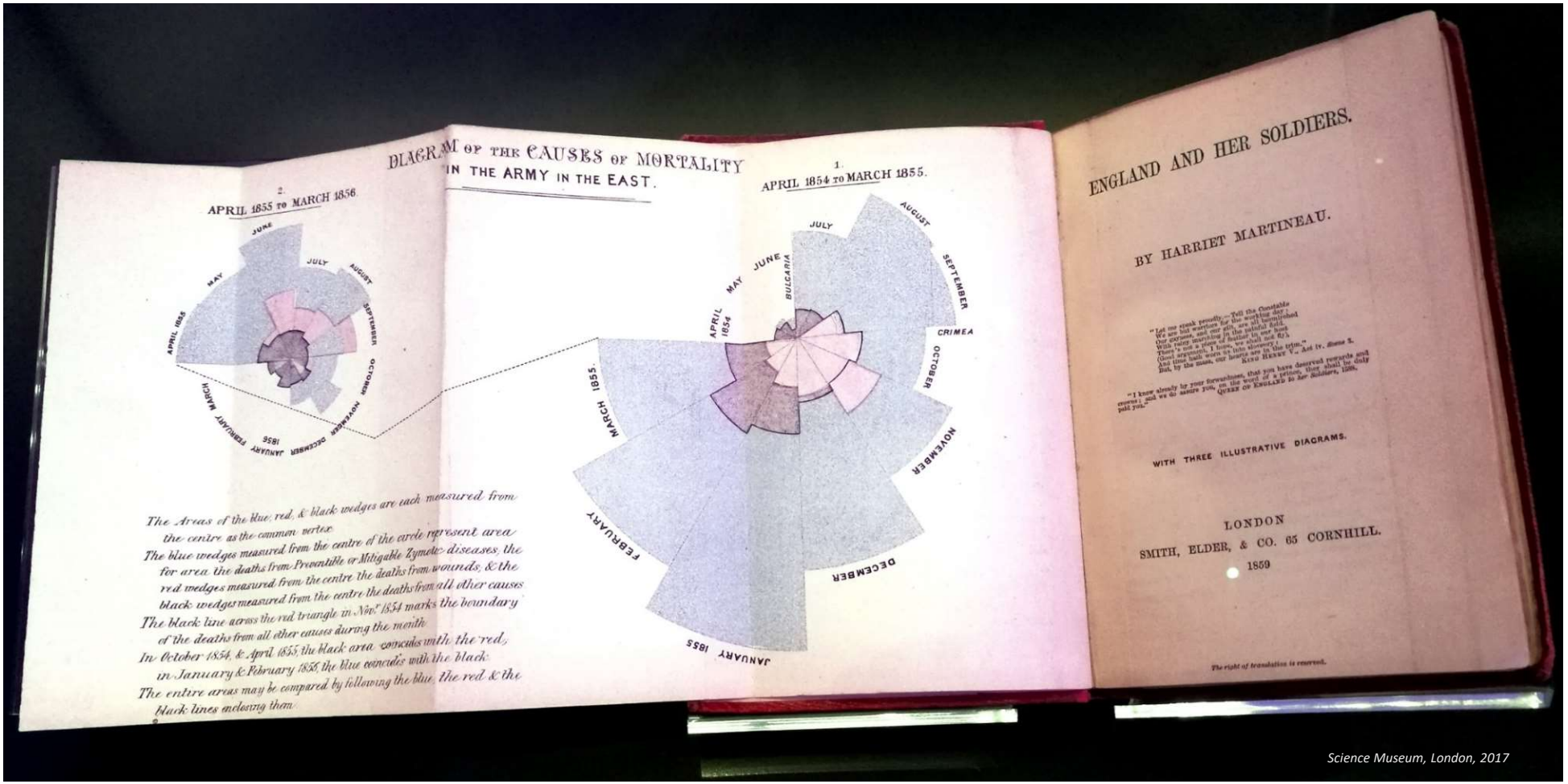
Examples

Classic Example: Dr.John Snow's Cholera Map (1855)

To stop the outbreak of cholera in London in 1854, **Dr. John Snow marked the cholera deaths on a map**. This map visualization indicated that the water from a pump on **Broad Street** was to blame as a large number of deaths were marked close to that pump. Snow's visualization is one of the most important early examples of epidemiology, that **clearly linked cholera's spread to water and not air**.

Snow, 1855 in
On the Mode of Communication of Cholera

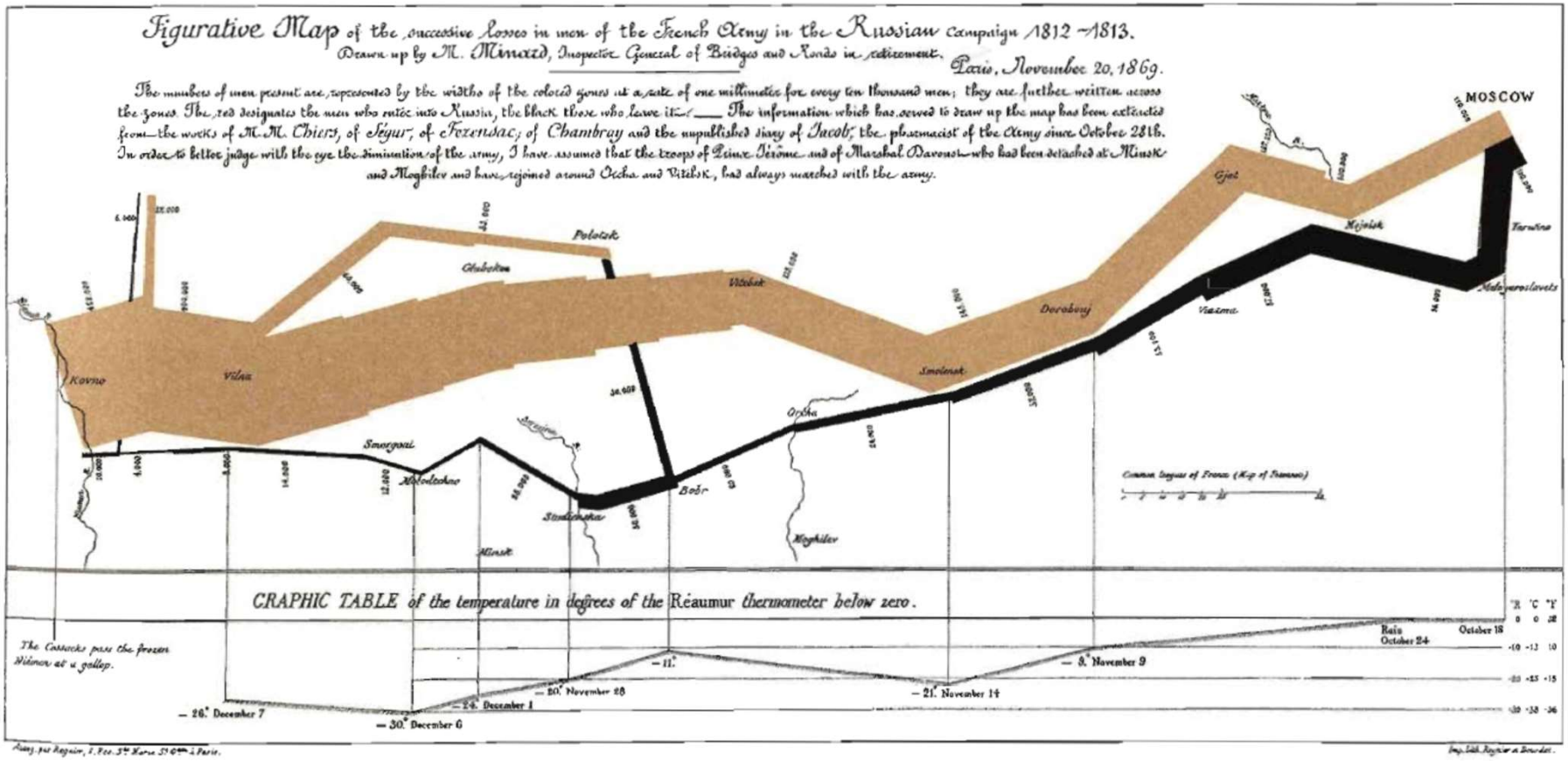
Classic Example: Florence Nightingale's Diagram (1859)



- Polar area diagrams (or coxcomb diagram) showed the causes of soldiers' deaths in each month.
- The right diagram showed the data of the first year when she arrived the hospital.
- Blue area showed deaths from preventable diseases due to bad conditions in hospital. Red area showed deaths from battlefield wounds. Black represented other causes.
- The left diagram showed the data of the second year after she implemented hygiene practices.

https://beta.sciencemuseum.org.uk/stories/2016/11/4/florence-nightingalethe-pioneer-statistician

Classic Example: Napoleon's army in Russia (1869)



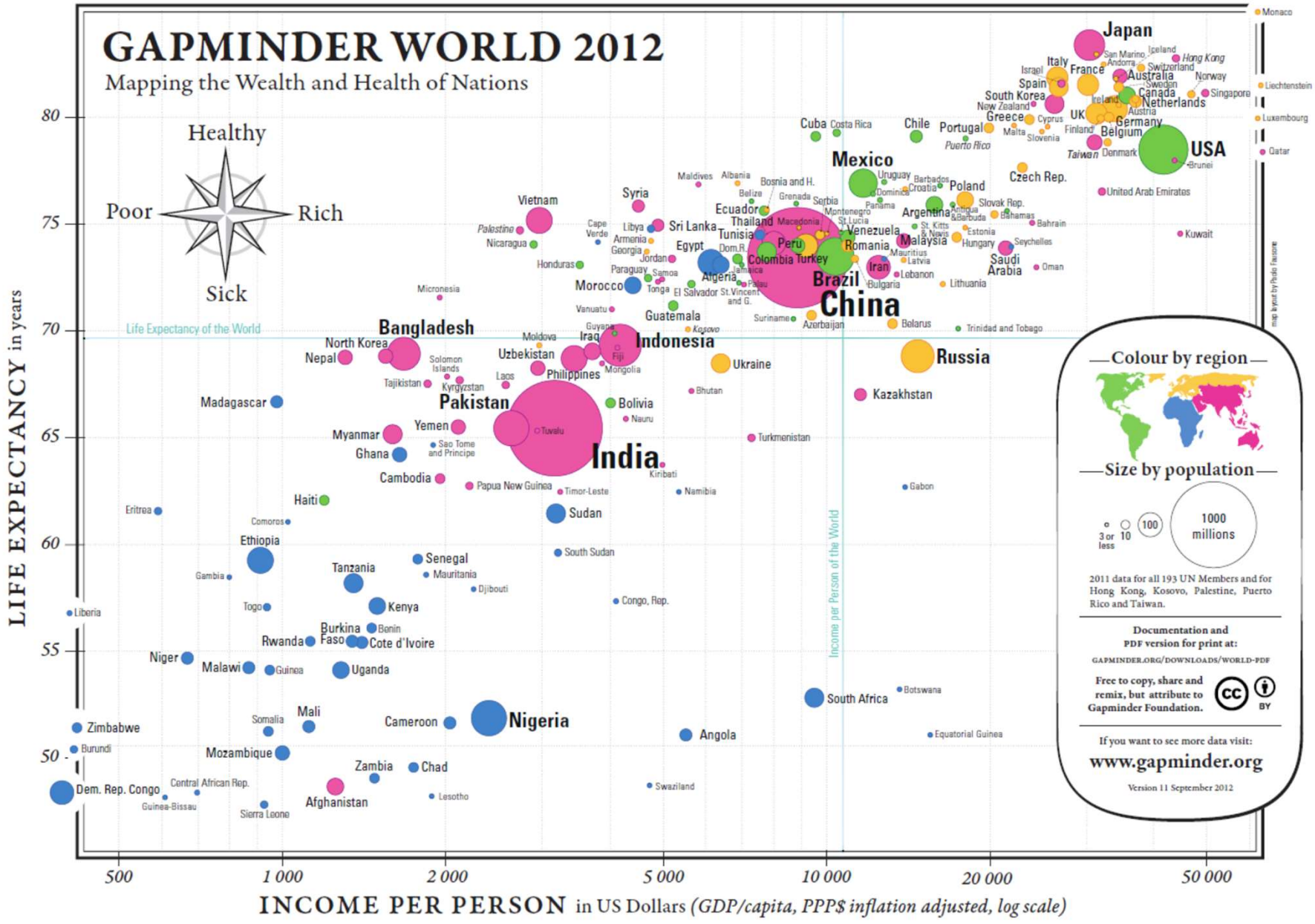
- Charles Joseph Minard (1869)
- Napolean led the army of 422,000 men from Poland border to Moscow (north-east direction) and then retreated. Only 10,000 men came back.
- Combined data map and time-series
- Thickness of flow line represents size of army at each place on the map. The different colors represent the directions.
- The time-series chart show temperature and date.
- 6 variables are plotted: size of army, its location on two-dimensional map, direction of army's movement, temperature, and date.

JHU COVID-19 Dashboard (2019)

https://coronavirus.jhu.edu/map.html

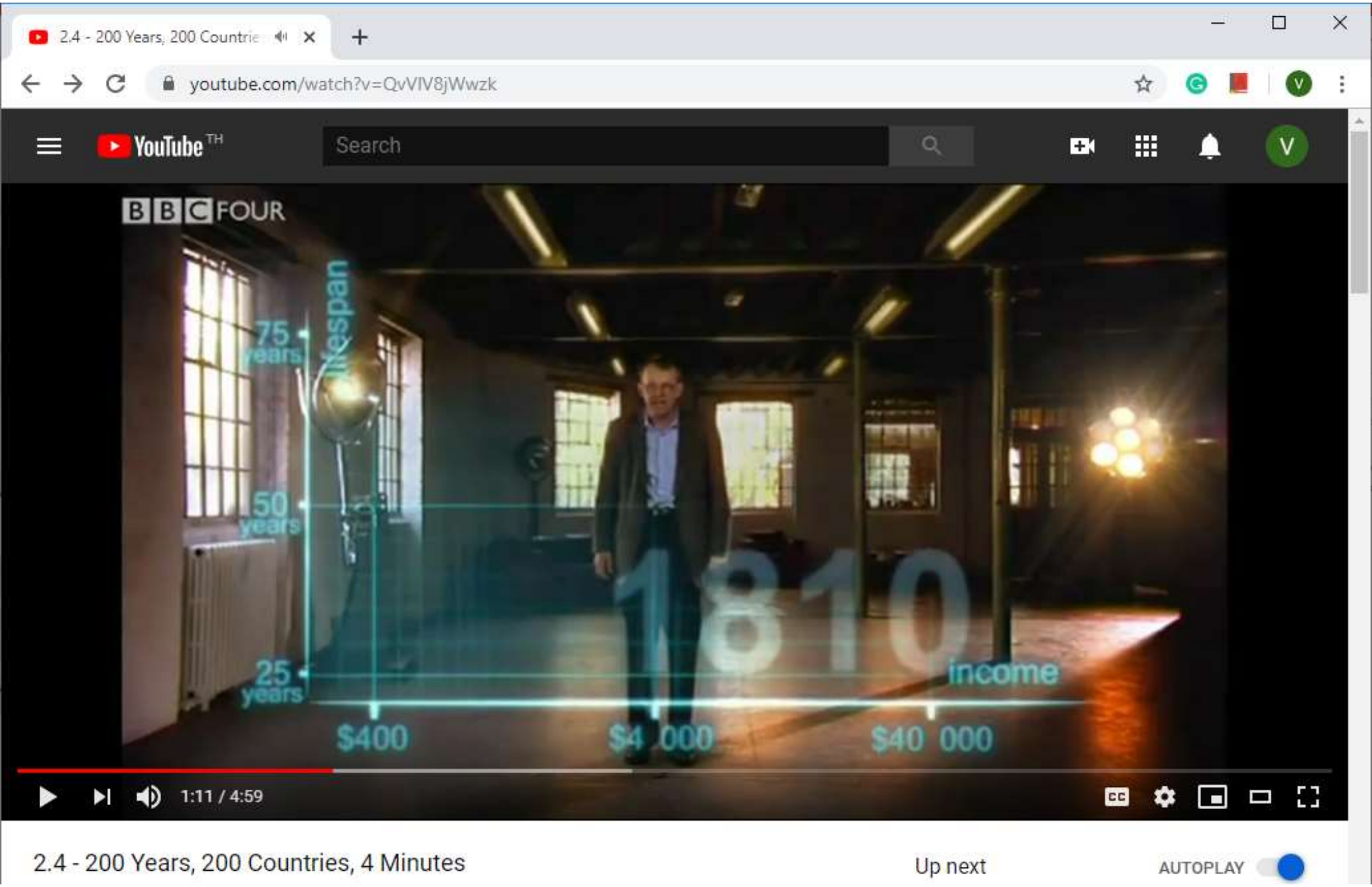
Gap Minder

https://www.gapminder.org/tools/



Hans Rosling's Visualization Demo

https://www.youtube.com/watch?v=QvVlV8jWwzk



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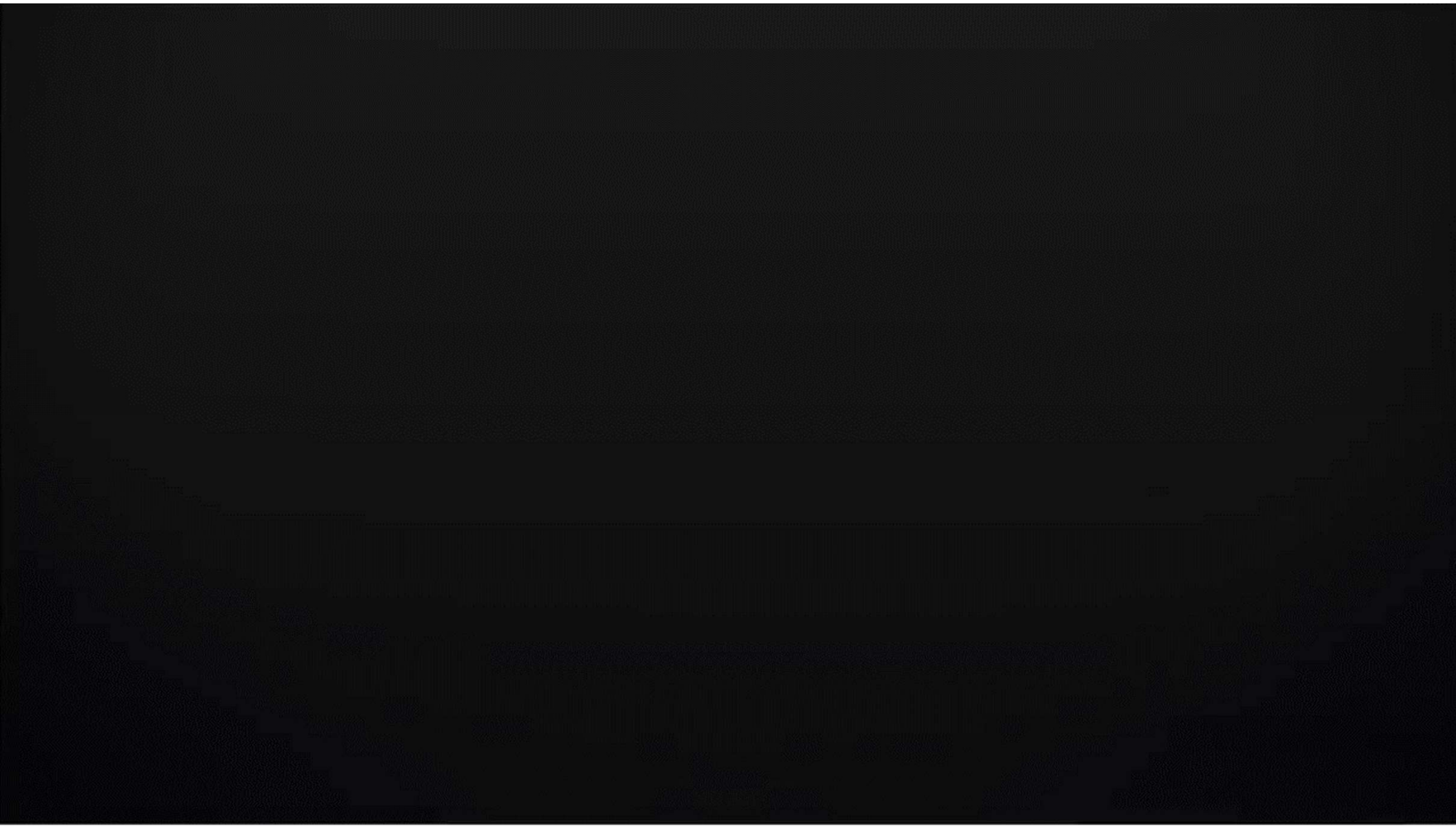
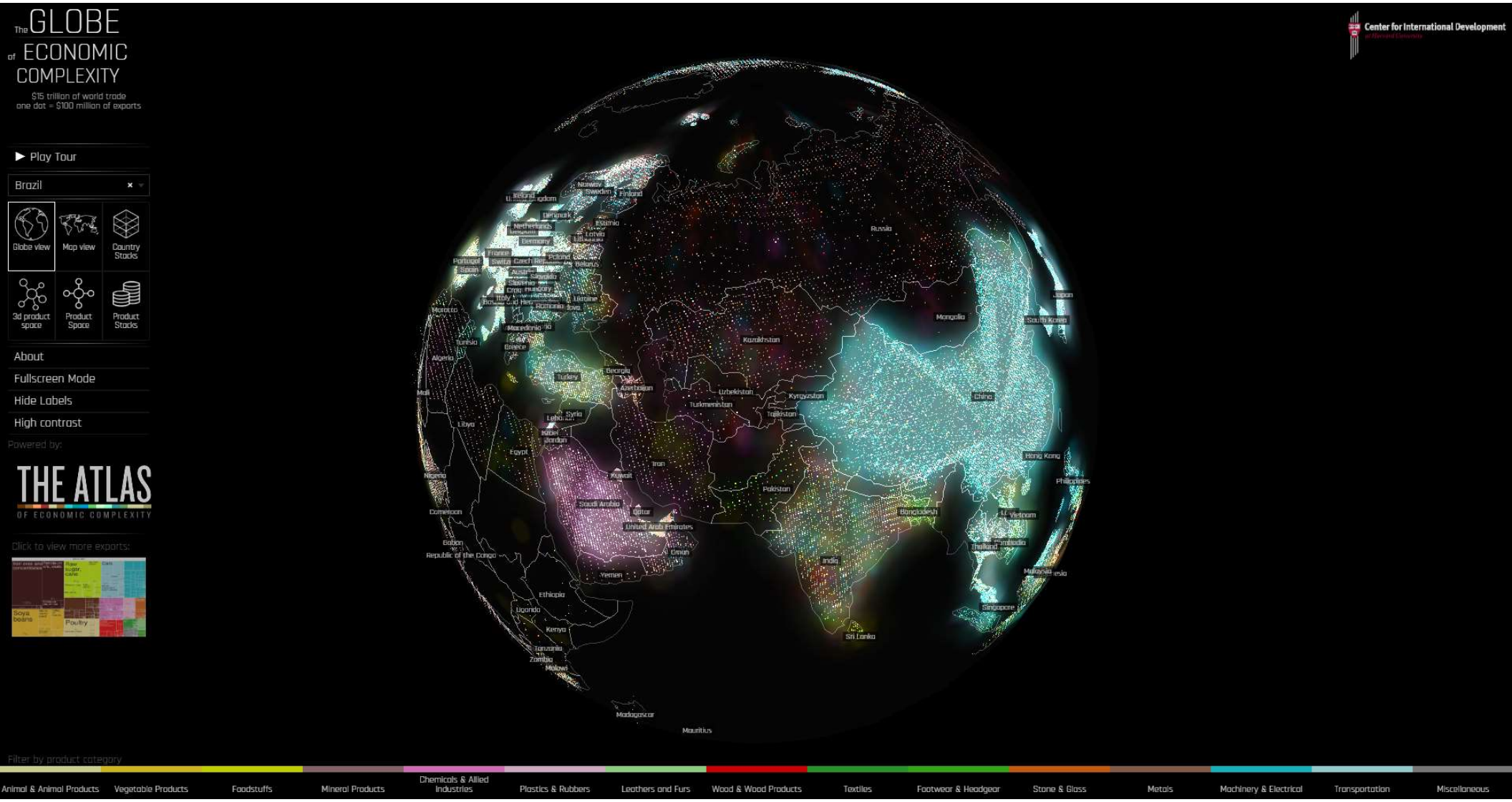


The Globe of Economic Complexity

http://globe.cid.harvard.edu/?mode=gridSphere&id=BA



The Globe of Economic Complexity

https://youtu.be/Obuq_L2U4VU

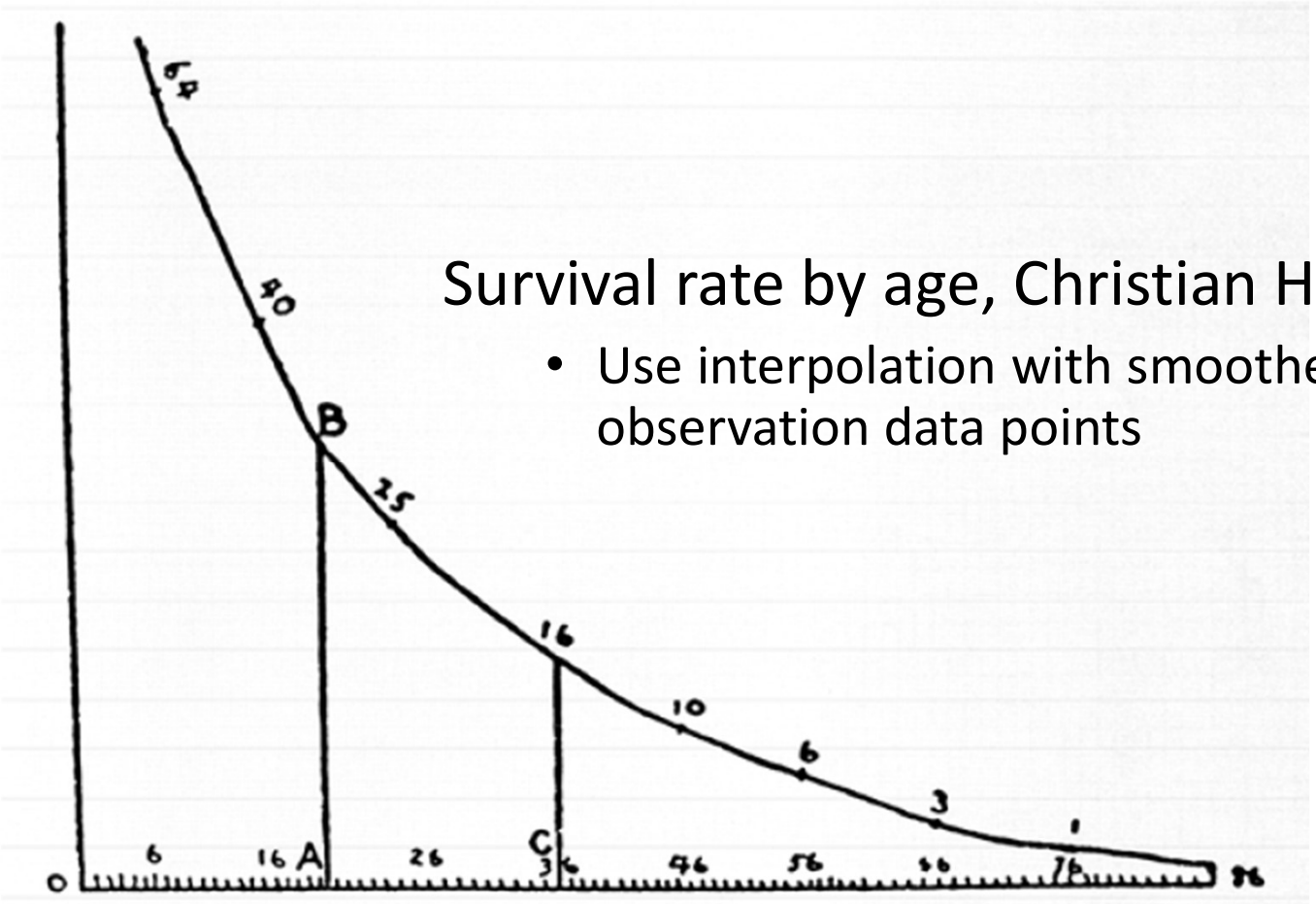
Types of Visualization

Main types of data visualization

- Relational graphics
- Time-series
- Spatial data map
- Network graph

Relational Graphics

Show quantitative relationships between variables



Survival rate by age, Christian Huygens, 1669

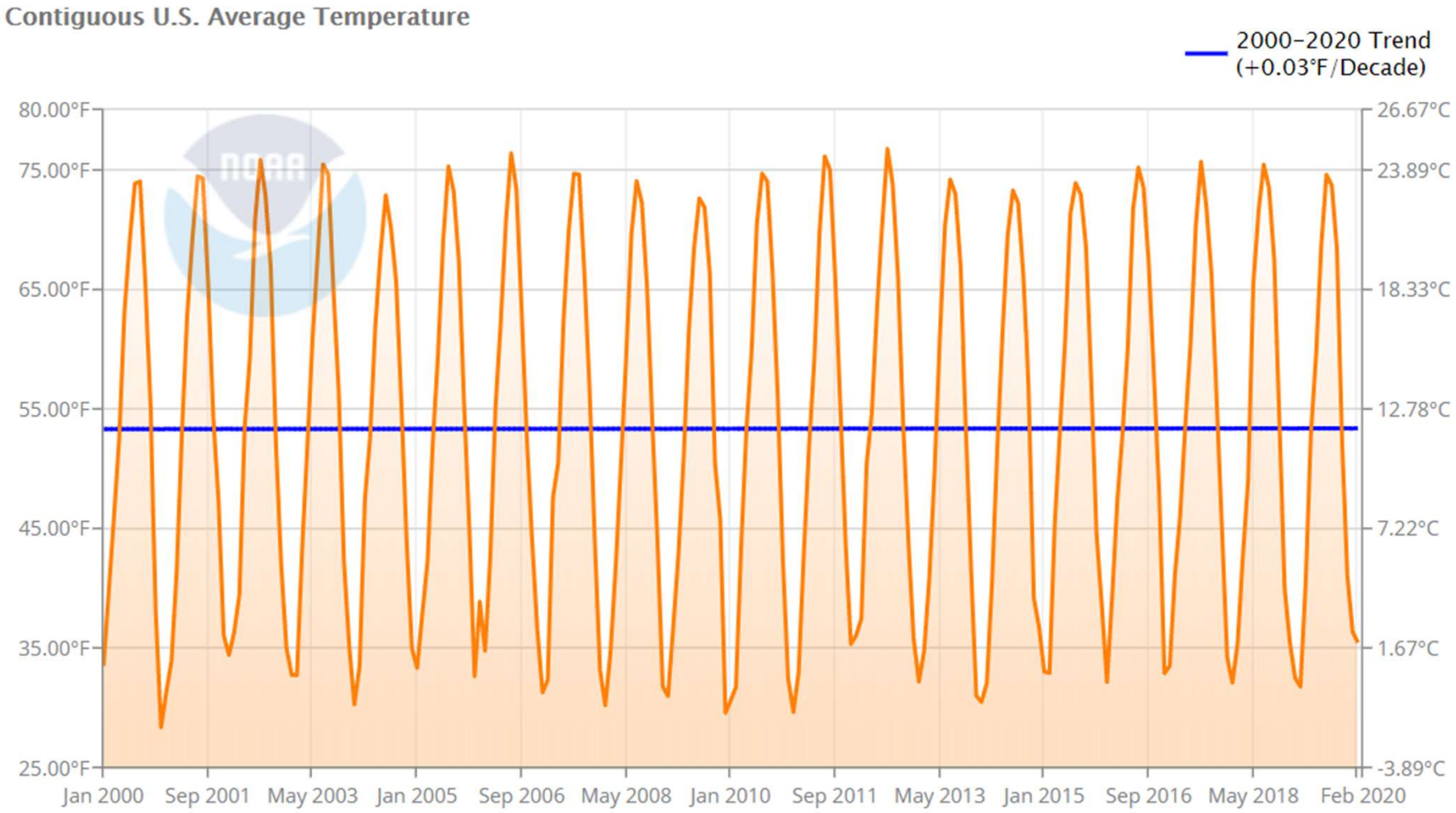
- Use interpolation with smoothed curve from observation data points

Time series

Show change over time and repeating patterns

Daily barometric pressure in Oxford, Robert Plot, 1685

Time series



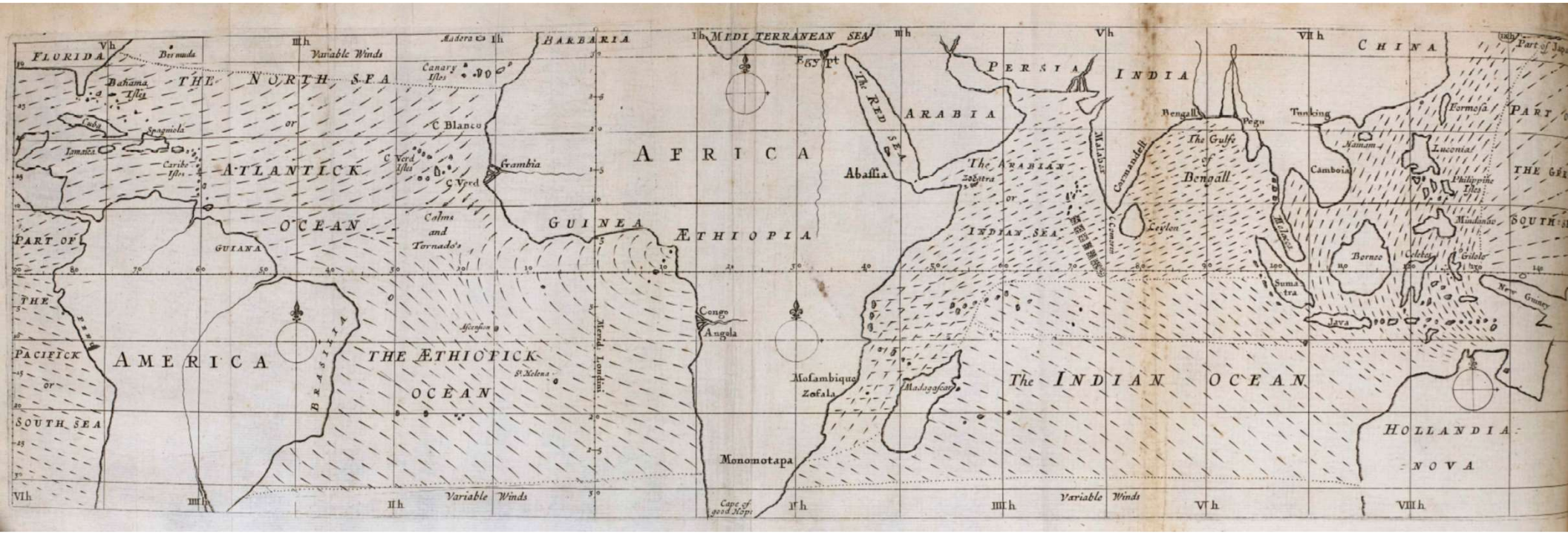
https://www.ncdc.noaa.gov/cag/national/time-series/

Spatial data map

Show relationships between data and geolocation on map

Map of Trade Winds and Monsoons, Edmond Halley, 1686

- Use line symbols to represent direction



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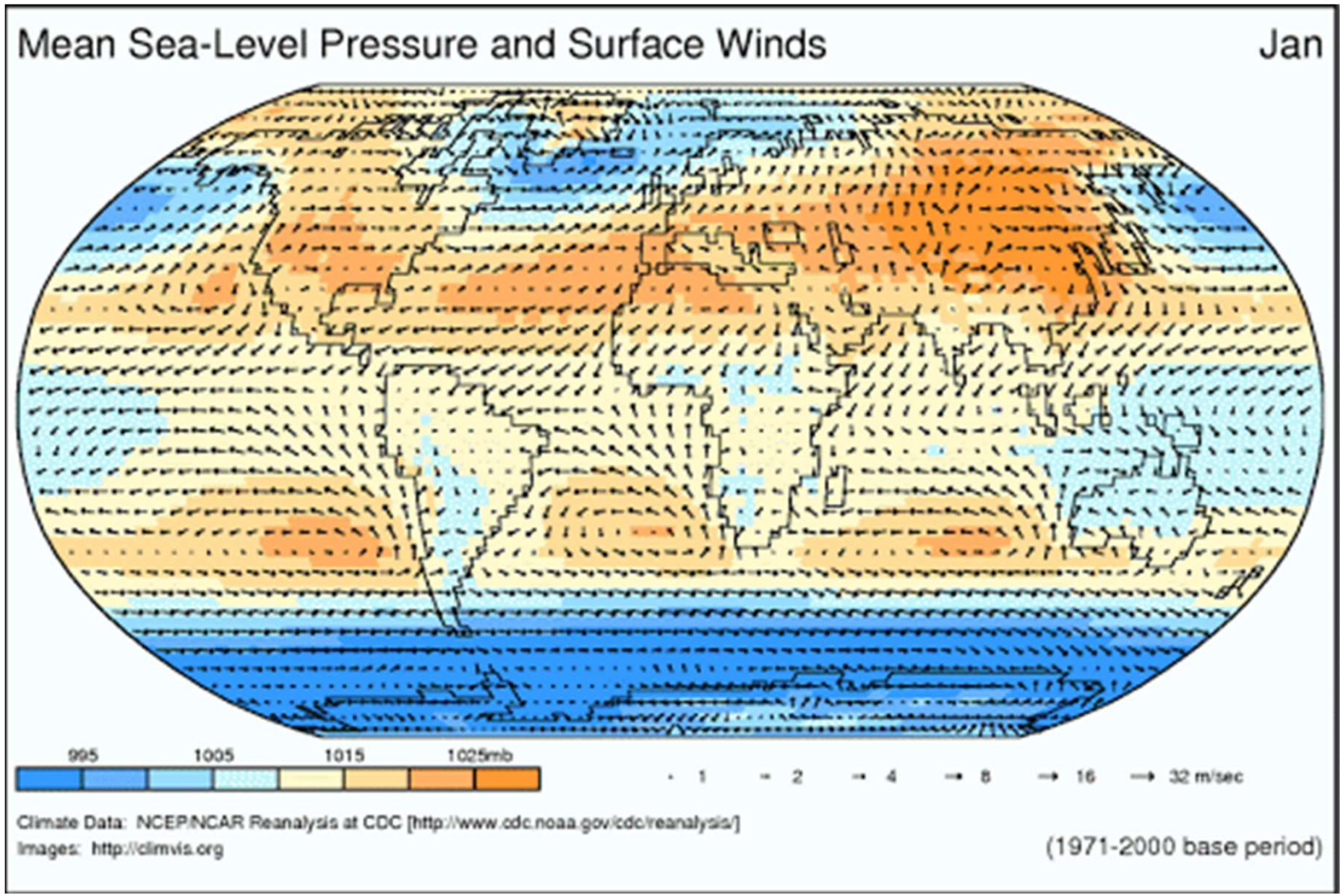


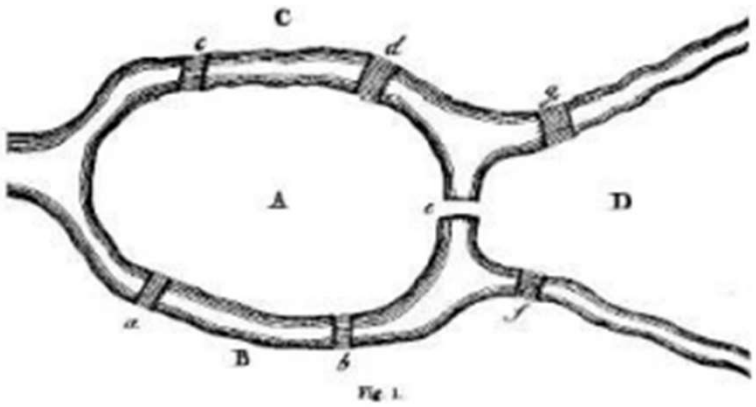
Network graph

Show relationships between members of a set

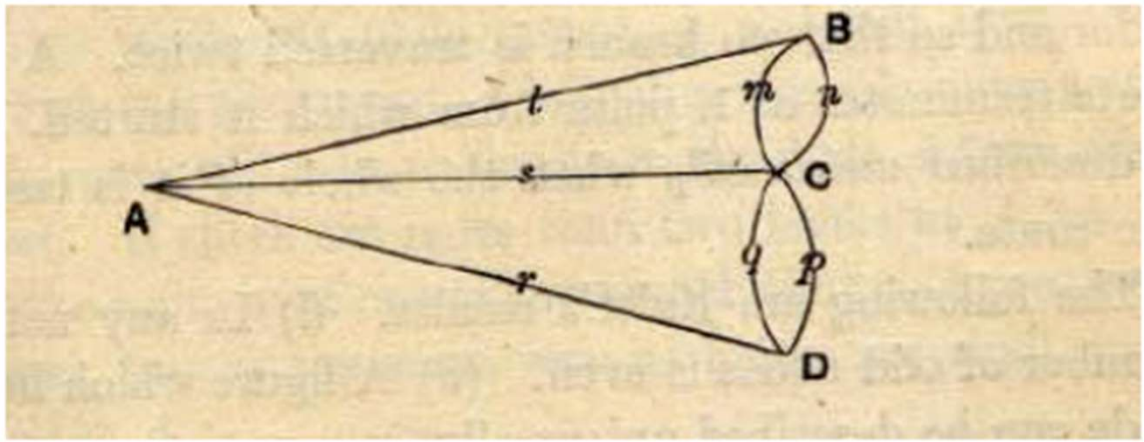
Node=entity Edge=relationship

The seven bridges of Königsberg problem, Euler (1736), Rouse Ball (1892)

Is it possible to take a walk through the town in such a way as to cross over every bridge once, and only once?

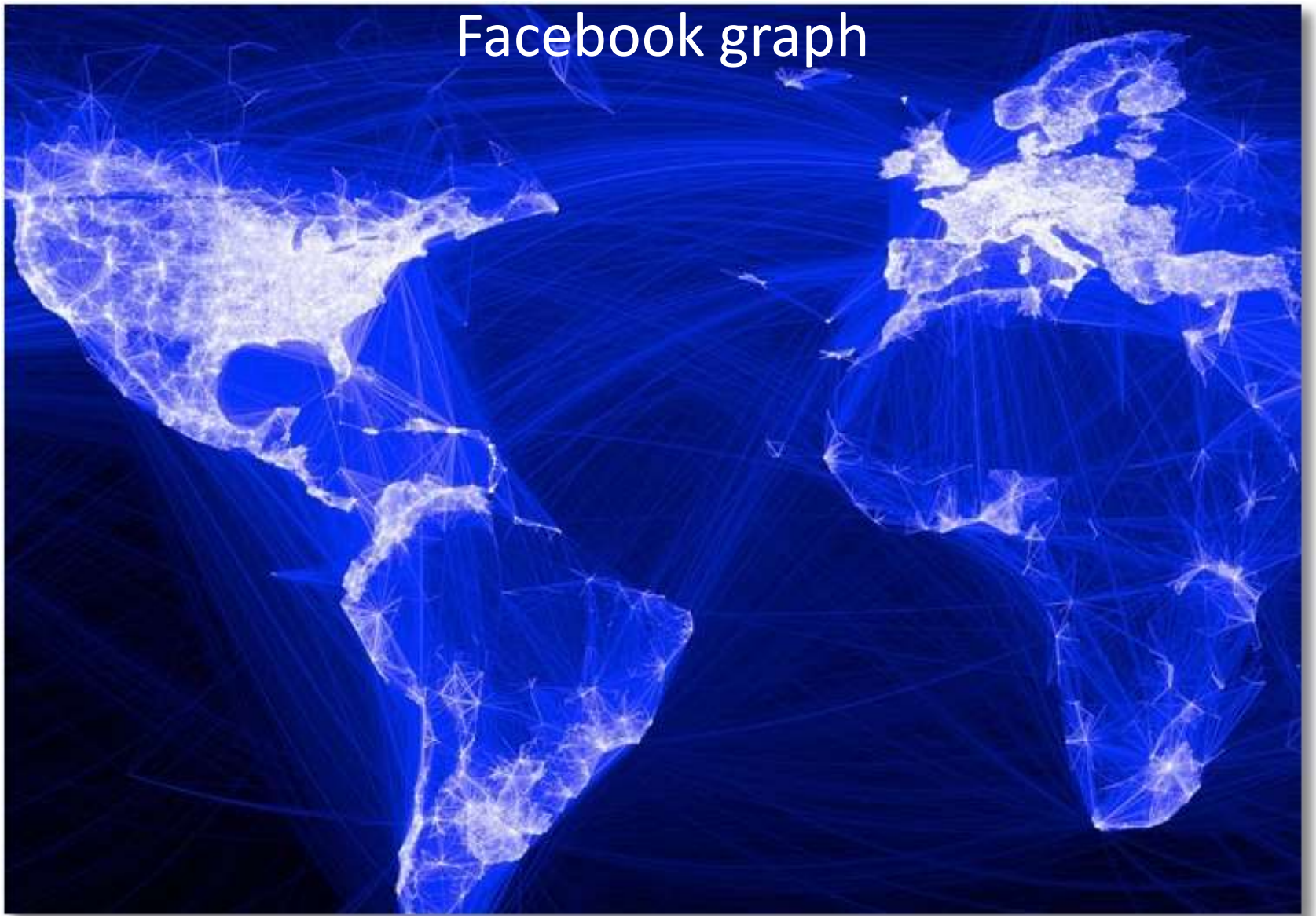


(a)



(b)

Network Graph



Principles of Graphical Excellence

What makes a good visualization?

What is a good data visualization?

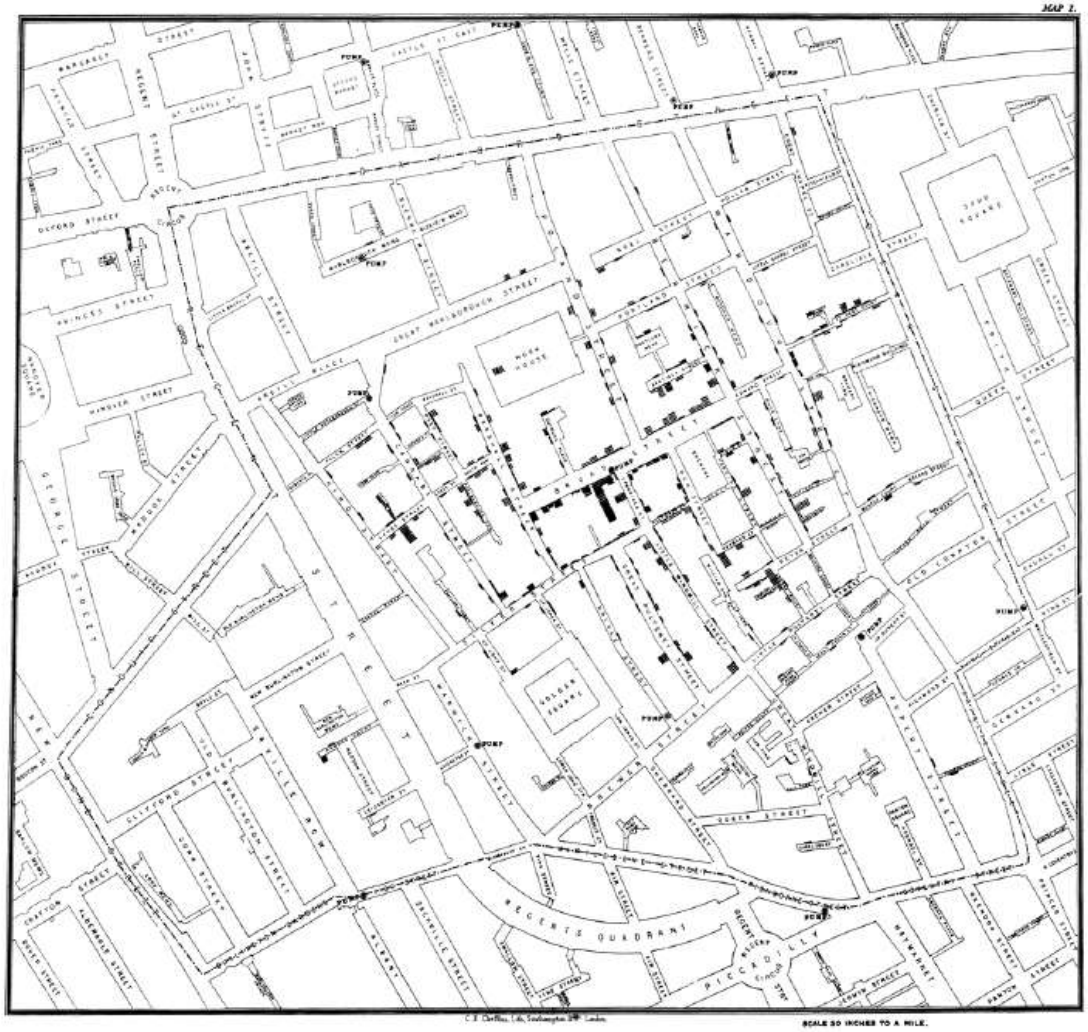
Pretty charts and graphics?

What is a good data visualization?

- Help viewer **understand the structure** of the data
- Help viewer **gain insight** into the data
- Help viewer **do tasks** more effectively

  (e.g. presentation, story telling, question answering, analysis, exploration, decision making)

Classic Example: Dr.John Snow's Cholera Map (1855)



To stop the outbreak of cholera in London in 1854, **Dr. John Snow marked the cholera deaths on a map**. This map visualization indicated that the water from a pump on **Broad Street** was to blame as a large number of deaths were marked close to that pump. Snow's visualization is one of the most important early examples of epidemiology, that **clearly linked cholera's spread to water and not air**.

Snow, 1855 in
On the Mode of Communication of Cholera

Is Dr.Snow's visualization good?

☑Help viewer **understand the structure** of the data

☑ Help viewer **gain insight** into the data

☑ Help viewer **do tasks** more effectively

Principles of Graphical Excellence (Edward Tufte)

- Graphical excellence is well-designed presentation of interesting data,
- consists of complex ideas communicated with clarity, precision, and efficiency,
- gives the greatest number of ideas in the shortest time with the least ink in the smallest space,
- and tells the truth about the data.

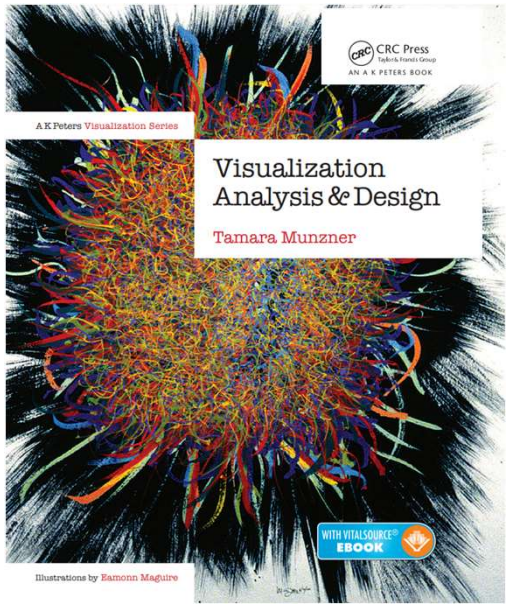
Summary

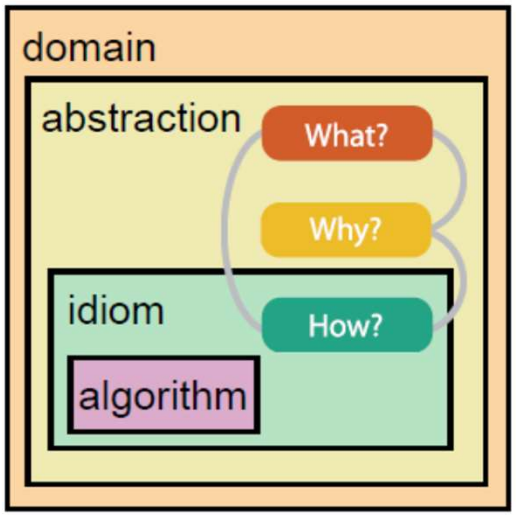
- Definition of visualization
- Types of visualization
- Principles of graphical excellence
- Examples of visualization

Visualization Design

Munzner's Visualization Design Methodology

- What is shown?
  - Data abstraction
- Why is the user looking at it?
  - Task abstraction
- How is it shown?
  - Visual encoding





What is shown?

Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
32	7/16/07	2-High	Small Pack	0.79	7/17/07
32	7/16/07	2-High	Jumbo Box		7/17/07
32	7/16/07	2-High	Medium Box		7/18/07
32	7/16/07	2-High	Medium Box		7/18/07
35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
69	6/6/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/6/05	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
96	4/17/05	2-High	Small Box	0.55	4/19/05

attribute

item

cell

Data Types

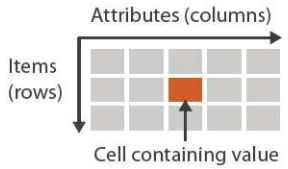
→ Items → Attributes → Links → Positions → Grids

Data and Dataset Types

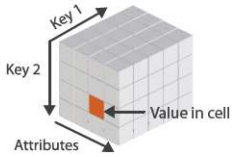
Tables	Networks & Trees	Fields	Geometry
Items	Items (nodes)	Grids	Items
Attributes	Links	Positions	Positions
	Attributes	Attributes	

Dataset Types

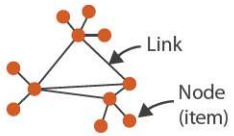
→ Tables



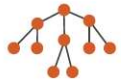
→ *Multidimensional Table*



→ Networks

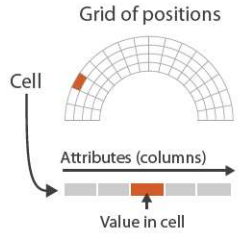


→ *Trees*



→ Spatial

→ Fields (Continuous)



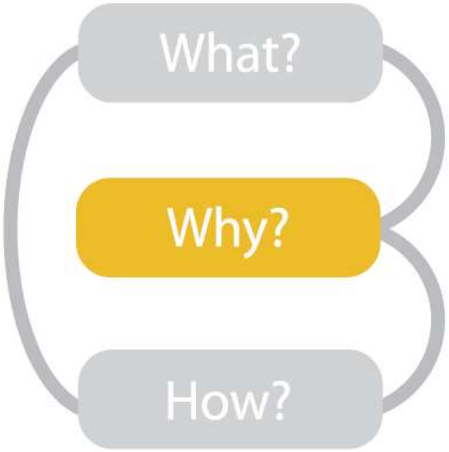
→ Geometry (Spatial)

Attribute Types

- **Attribute Types**
  - Categorical

  - Ordered
    - *Ordinal*

    - *Quantitative*



- {action, target} pairs
  - *discover distribution*
  - *compare trends*
  - *locate outliers*
  - *browse topology*

Why?

Actions

Analyze

→ Consume

→ *Discover* → *Present* → *Enjoy*

→ Produce

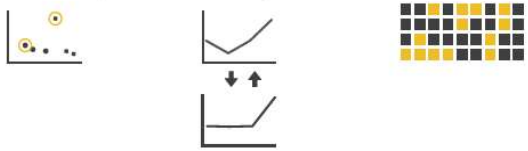
→ *Annotate* → *Record* → *Derive*

Search

	Target known	Target unknown
Location known	*Lookup*	*Browse*
Location unknown	*Locate*	*Explore*

Query

→ Identify → Compare → Summarize



Targets

All Data

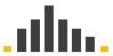
→ Trends → Outliers → Features

Attributes

→ One → Many

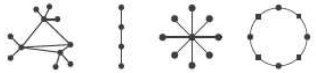
→ *Distribution* → *Dependency* → *Correlation* → *Similarity*

→ *Extremes*



Network Data

→ Topology

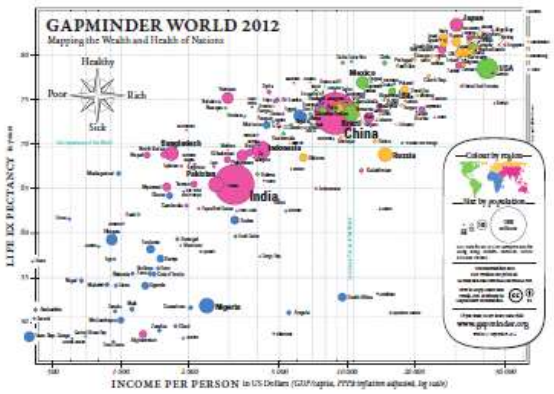


→ *Paths*

Spatial Data

→ Shape

Why look at it?



Why?

Actions

Analyze

- Consume
  - Discover
  - Present
  - Enjoy
- Produce
  - Annotate
  - Record
  - Derive

Search

	Target known	Target unknown
Location known	Lookup	Browse
Location unknown	Locate	Explore

Query

- Identify
- Compare
- Summarize

Targets

All Data

- Trends
- Outliers
- Features

Attributes

- One
  - Distribution
  - Extremes
- Many
  - Dependency
  - Correlation
  - Similarity

Network Data

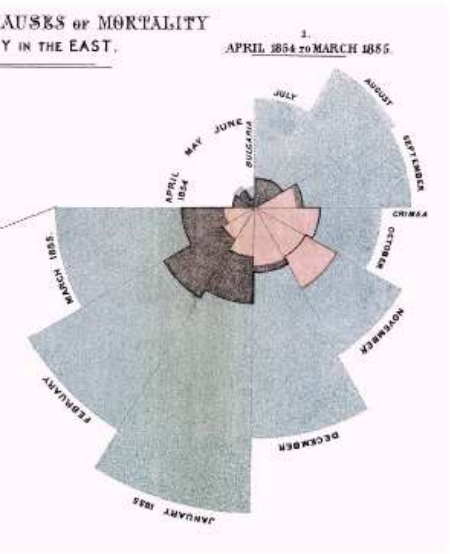
- Topology
- Paths

Spatial Data

- Shape

[Munzner, 2014]

Why look at it?



Why?

Actions

Analyze

- Consume
  - *Discover*
  - *Present*
  - *Enjoy*
- Produce
  - *Annotate*
  - *Record*
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Search

	Target known	Target unknown
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Query

- *Identify*
- *Compare*
- *Summarize*

Targets

All Data

- *Trends*
- *Outliers*
- *Features*

Attributes

- One
  - *Distribution*
  - *Extremes*
- Many
  - *Dependency*
  - *Correlation*
  - *Similarity*

Network Data

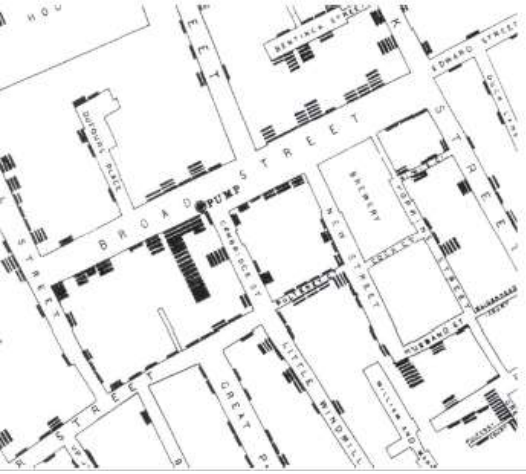
- Topology
- *Paths*

Spatial Data

- Shape

[Munzner, 2014]

Why look at it?



Why?

Actions

Analyze

→ Consume

→ *Discover* → *Present* → *Enjoy*

→ Produce

→ *Annotate* → *Record* → *Derive*

Search

	Target known	Target unknown
Location known	*Lookup*	*Browse*
Location unknown	*Locate*	*Explore*

Query

→ Identify → Compare → Summarize

Targets

All Data

→ Trends → Outliers → Features

Attributes

→ One → Many

→ *Distribution* → *Dependency* → *Correlation* → *Similarity*

→ *Extremes*

Network Data

→ Topology

→ *Paths*

Spatial Data

→ Shape

[Munzner, 2014]

How?

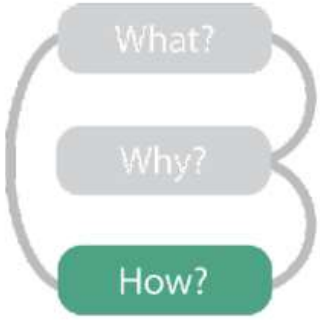
Encode

Arrange

- Express
- Separate
- Order
- Align
- Use

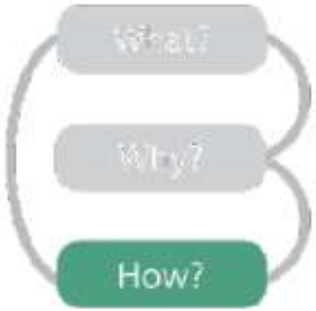
Map
from categorical and ordered attributes

- Color
  - *Hue*
  - *Saturation*
  - *Luminance*
- Size, Angle, Curvature, ...
- Shape
- Motion
  Direction, Rate, Frequency, ...



How shown?

visual encoding: how to draw



Marks and Visual Variables

Marks

Basic units with which any vis can be constructed

Points

Lines

Areas

Visual Variables

The properties or visual variables of marks that can be used to represent the data

Position

- Horizontal

- Vertical

- Both

Color

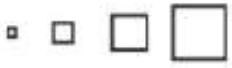
Shape

Tilt

Size

- Length

- Area

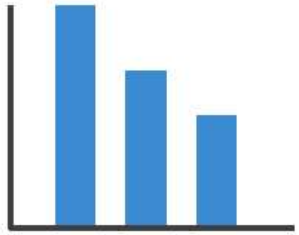


- Volume

[Bertin, 1986]

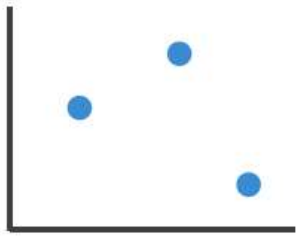
Visual Encoding

- Combination of marks and visual variables (channels)



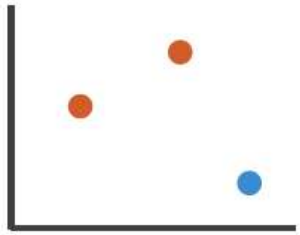
1:
vertical position

mark: line



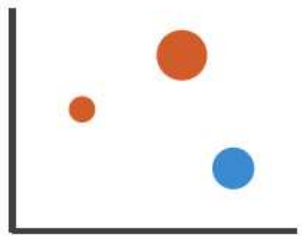
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

mark: point

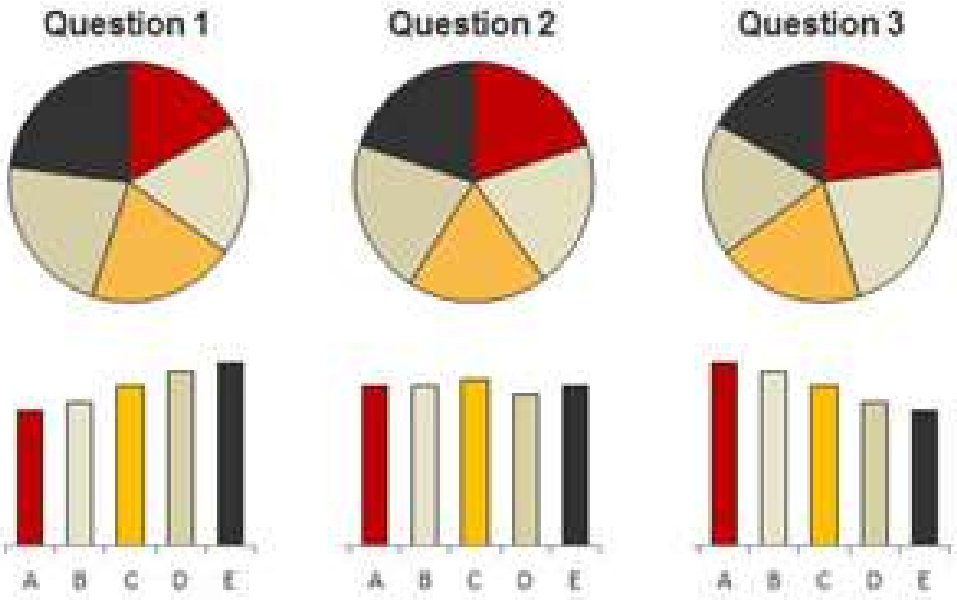


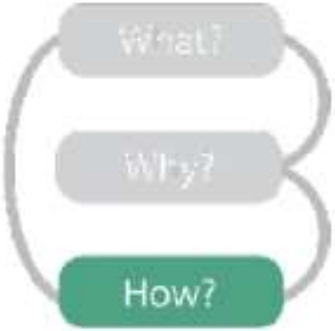
4:
vertical position
horizontal position
color hue
size (area)

mark: point

Effectiveness of Visual Variables

Pie Charts vs. Bar Charts
Which one is better?





How shown?

The effectiveness of the visual variable depends on the type of the data

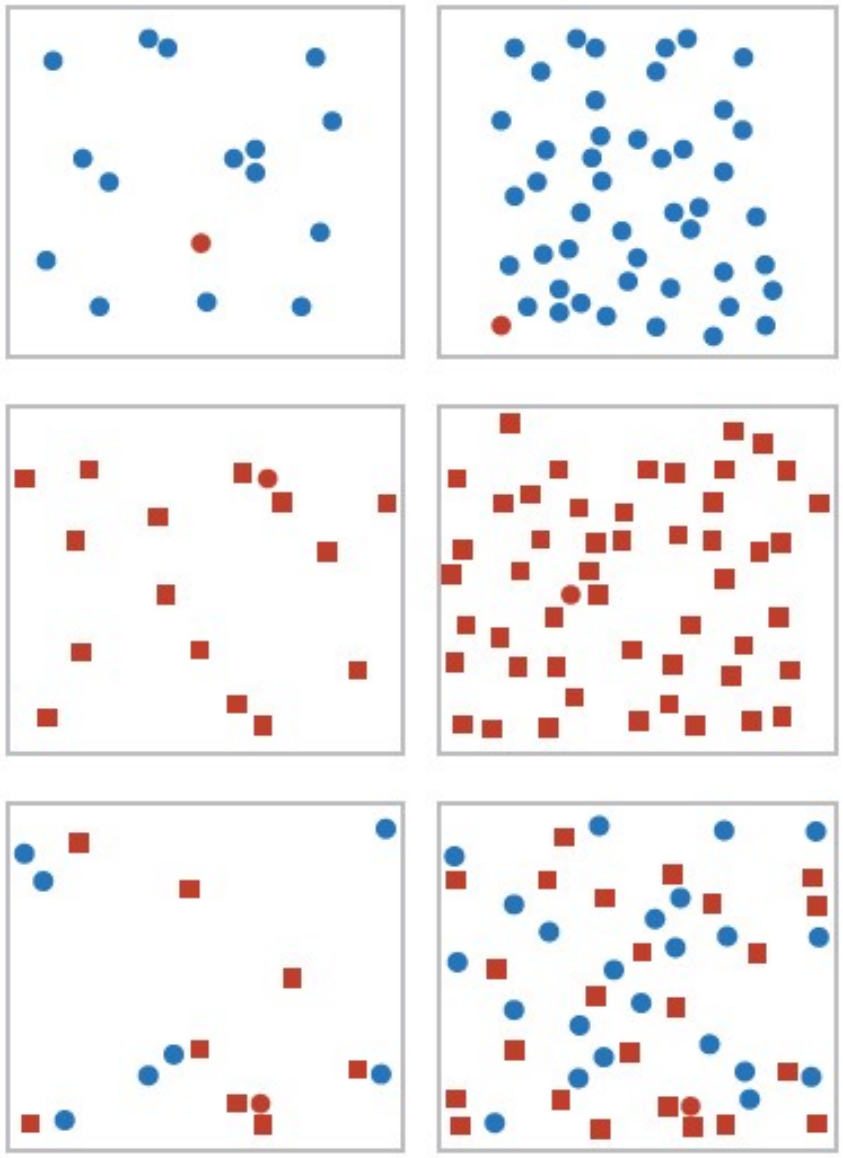
Mackinlay's ranking of visual variables based on how accurately human perform the corresponding perceptual task for the type of data

	Quantitative	Ordinal	Nominal
More Accurate	Position	Position	Position
	Length	Density	Hue
	Angle	Saturation	Density
	Slope	Hue	Saturation
	Area	Length	Shape
	Density	Angle	Length
	Saturation	Slope	Angle
	Hue	Area	Slope
Less Accurate	Shape	Shape	Area
	Ordered and continuous	Ordered and discontinuous	Unordered and discontinuous

[Mackinlay, 1986]

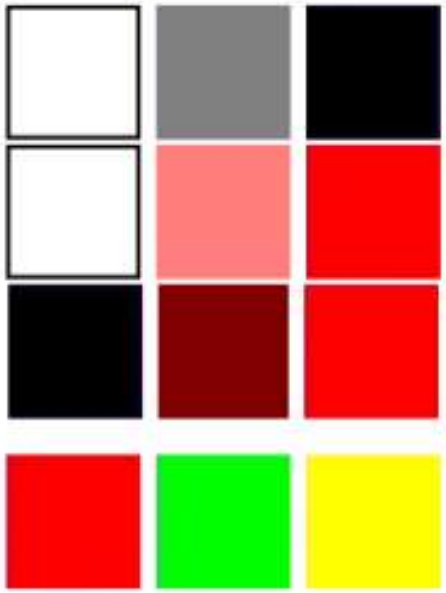
Popout Effect

- Find the red circular dot
- Speed depends on visual variable and amount of data points.

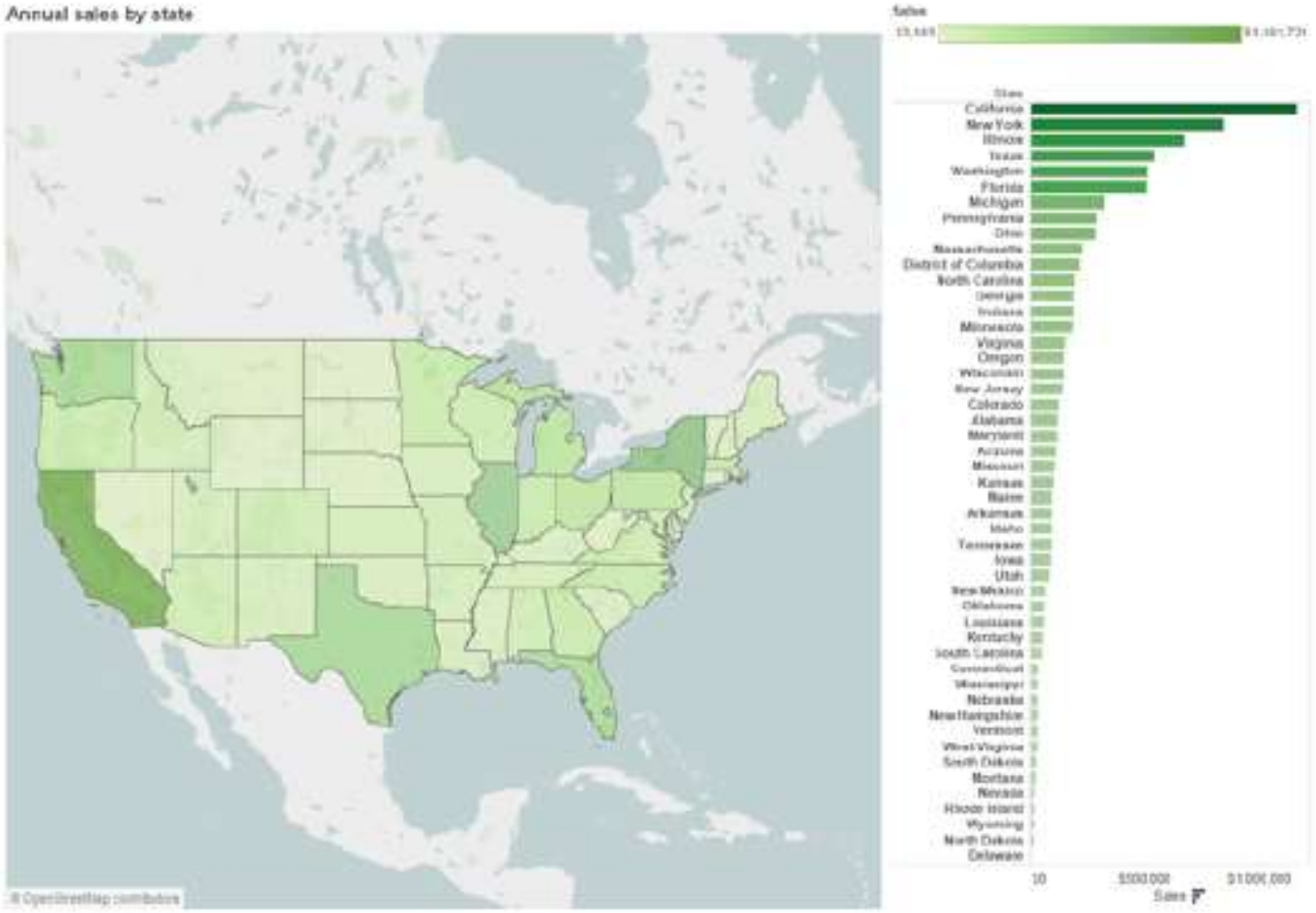


Coloring Ordered Data

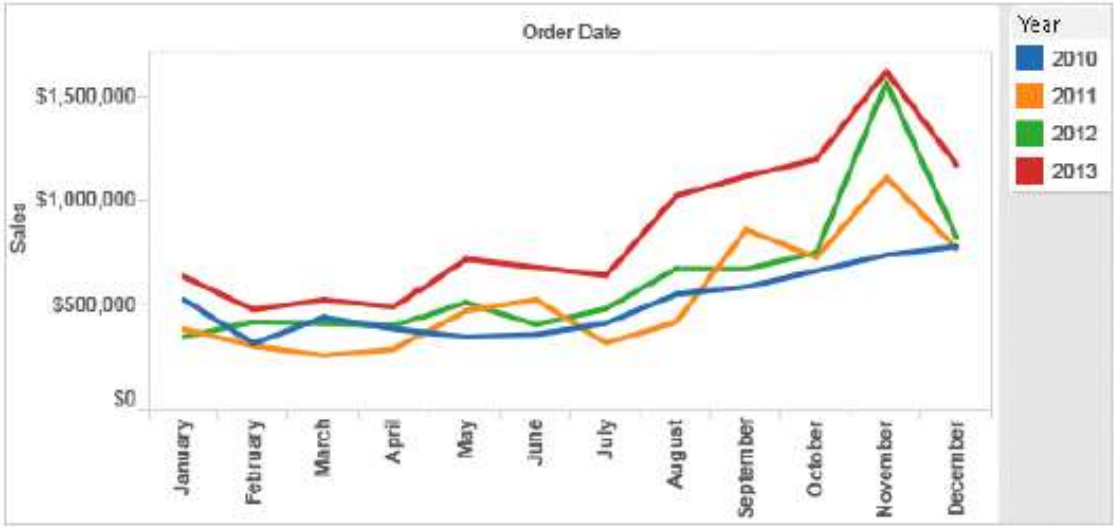
- innate visual order
  - greyscale/luminance
  - saturation
  - brightness
- unclear visual order
  - hue

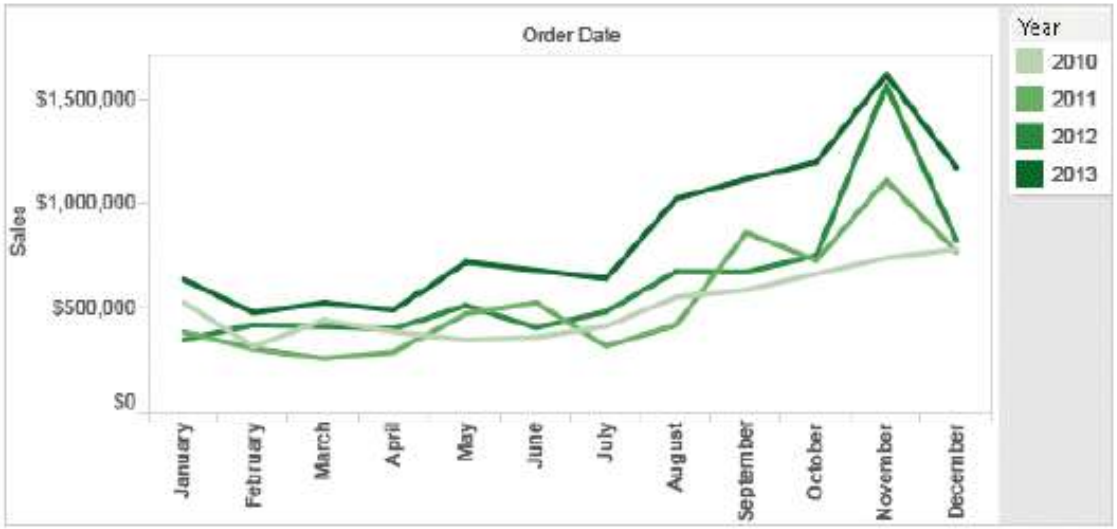


Ordered by Saturation



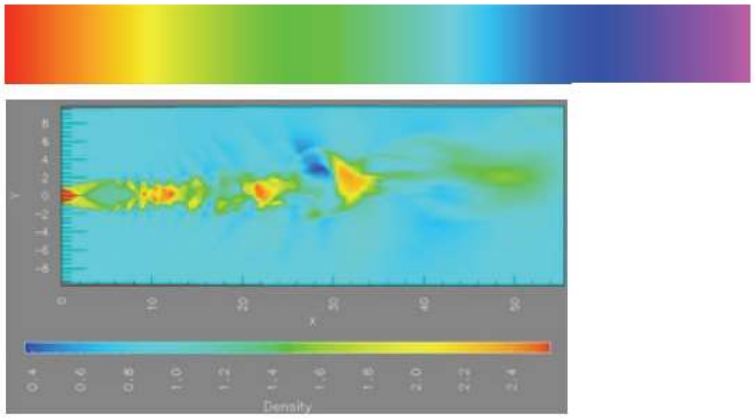
Categorical vs ordered color



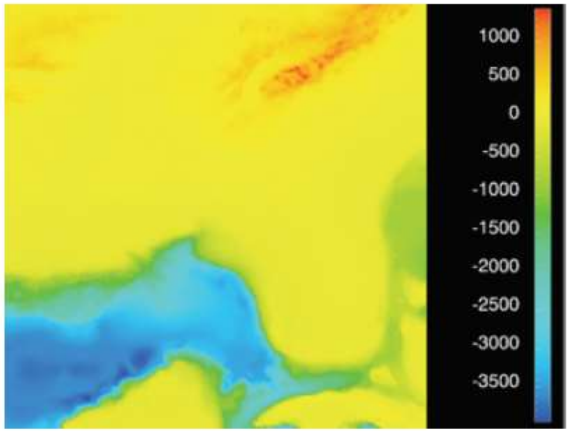


Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable



[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

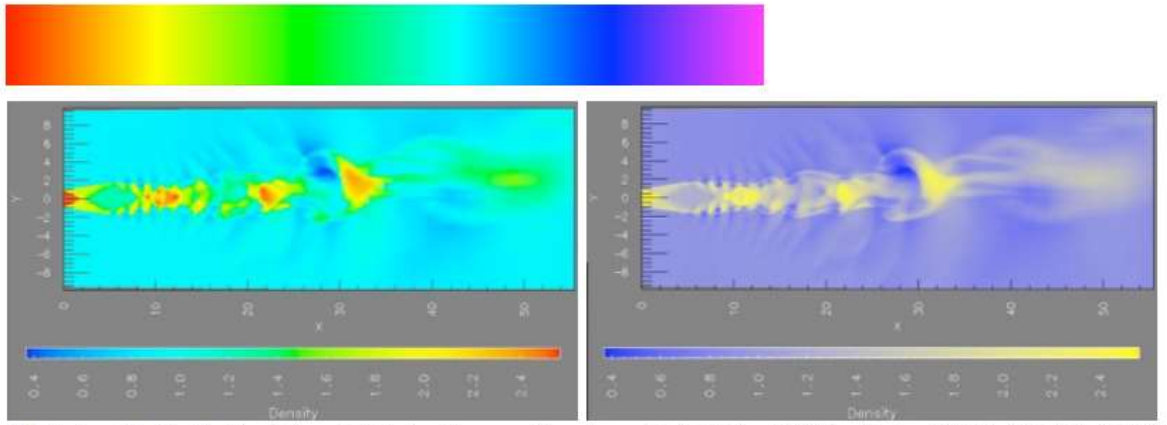


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM

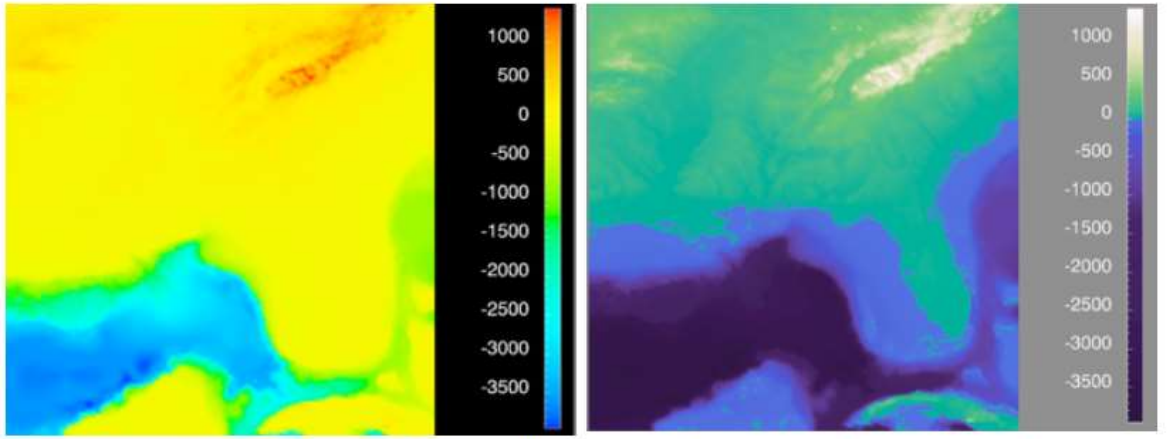
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Ordered color: Rainbow is poor default

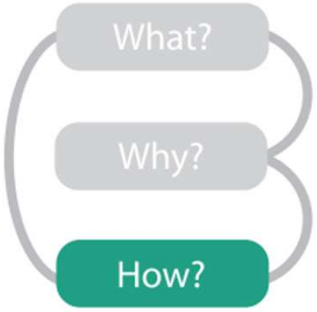
- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance



[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



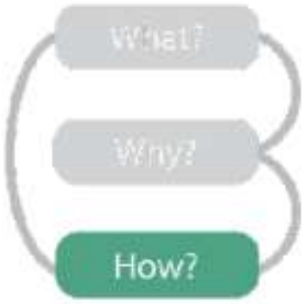
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]



How to select chart type

Based on

- Data [What is shown?]
- Task [Why look at it?]
- Effectiveness of visual variables
- Other factors (e.g. scalability)



Idiom: **Bar Chart**

marks: lines

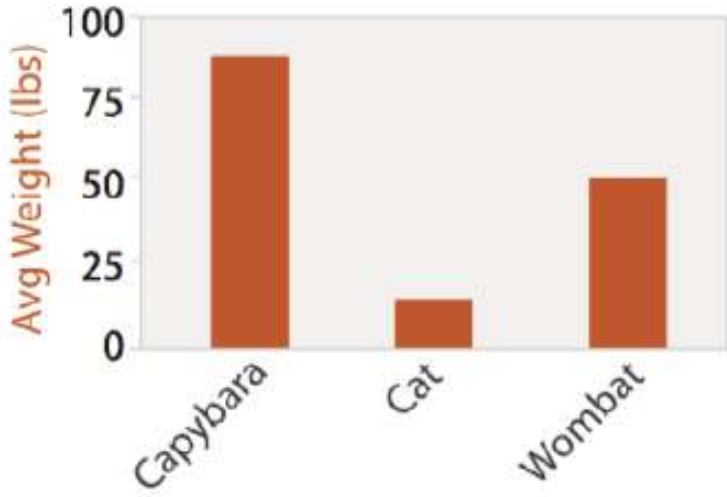
visual variables:

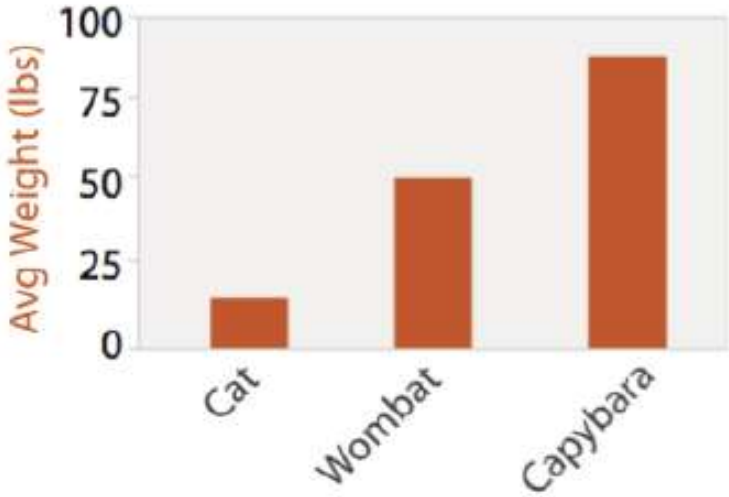
length for quantitative value,
each mark separated horizontally, aligned vertically and ordered by label or length

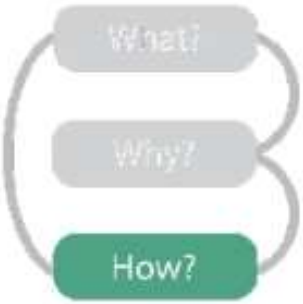
data: table with 1 category attribute (key attribute) and 1 quantitative attribute

tasks: compare, lookup values

scalability: dozens to hundreds of levels for key attribute







Idiom: **Scatterplot**

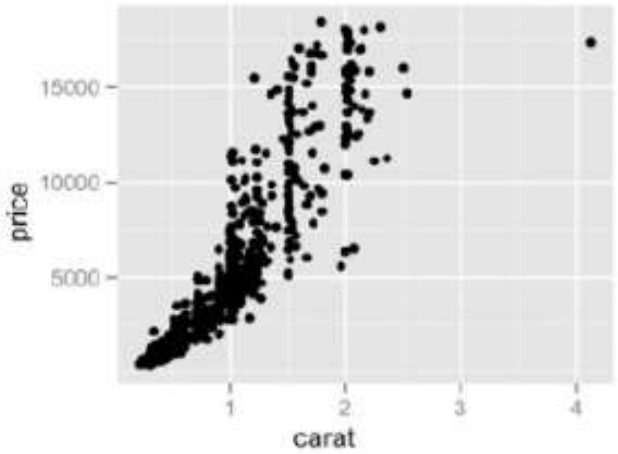
marks: points

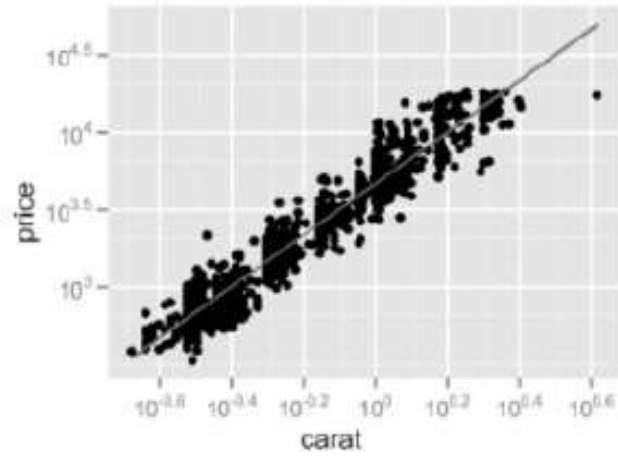
visual variables: position (horizontal + vertical)

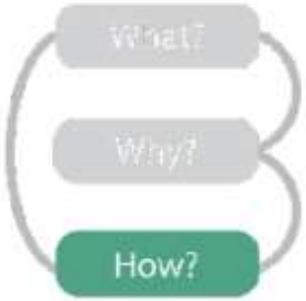
data: table with only 2 quantitative attributes and no key (only values)

tasks: finding trends, outlier, distribution, correlation, clusters

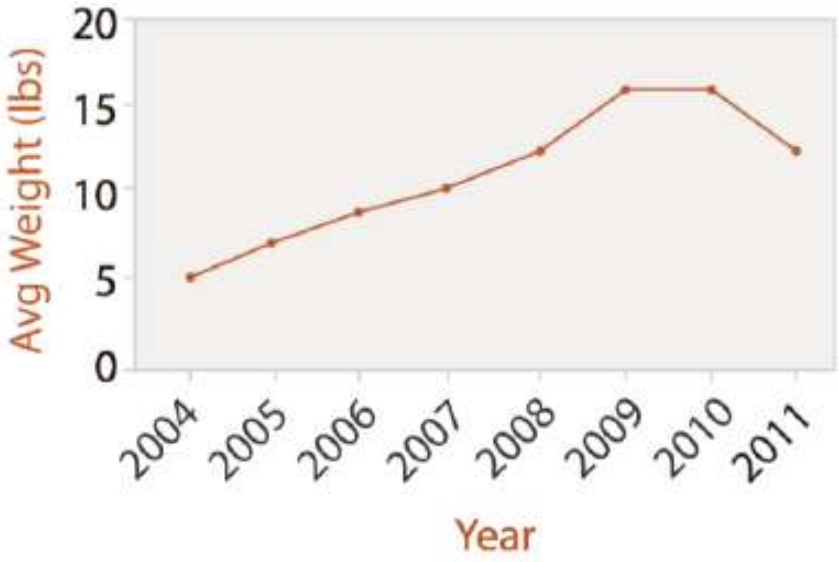
scalability: hundreds of items







Idiom: **Line Chart**



marks: points (a line connects the marks)

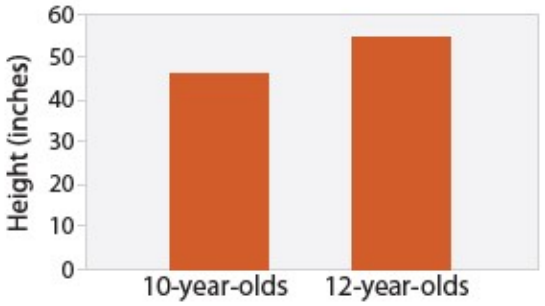
visual variables:
aligned length for quantitative value, horizontally separated and ordered by key attribute

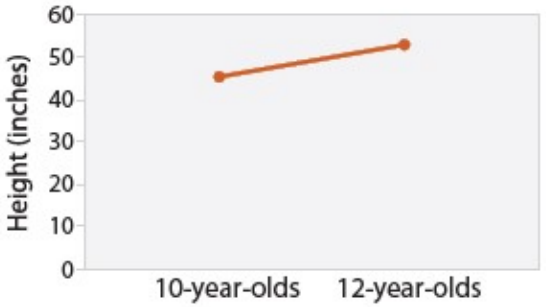
data: table with 1 ordered attribute (key attribute) and 1 quantitative attribute

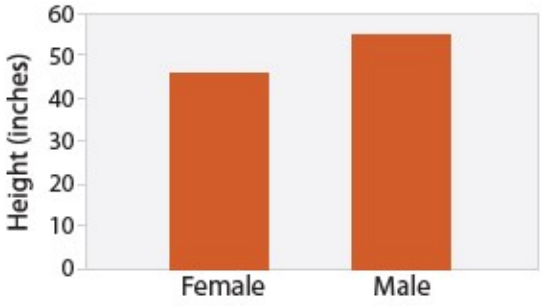
tasks: find trend (line connecting the marks emphasizes the ordering of the items along key axis)

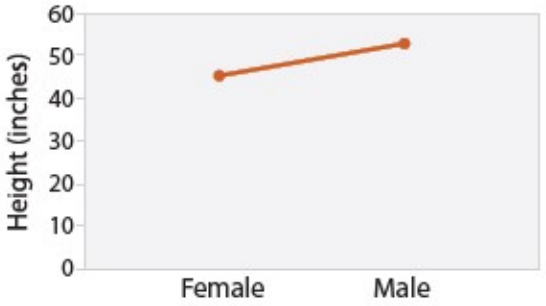
Choosing bar vs line charts

- depends on type of key attrib
  - –bar charts if categorical
  - –line charts if ordered
- do not use line charts for categorical key attribs
  - –violates expressiveness principle
    - implication of trend so strong that it overrides semantics!
      - – "The more male a person is, the taller he/she is"





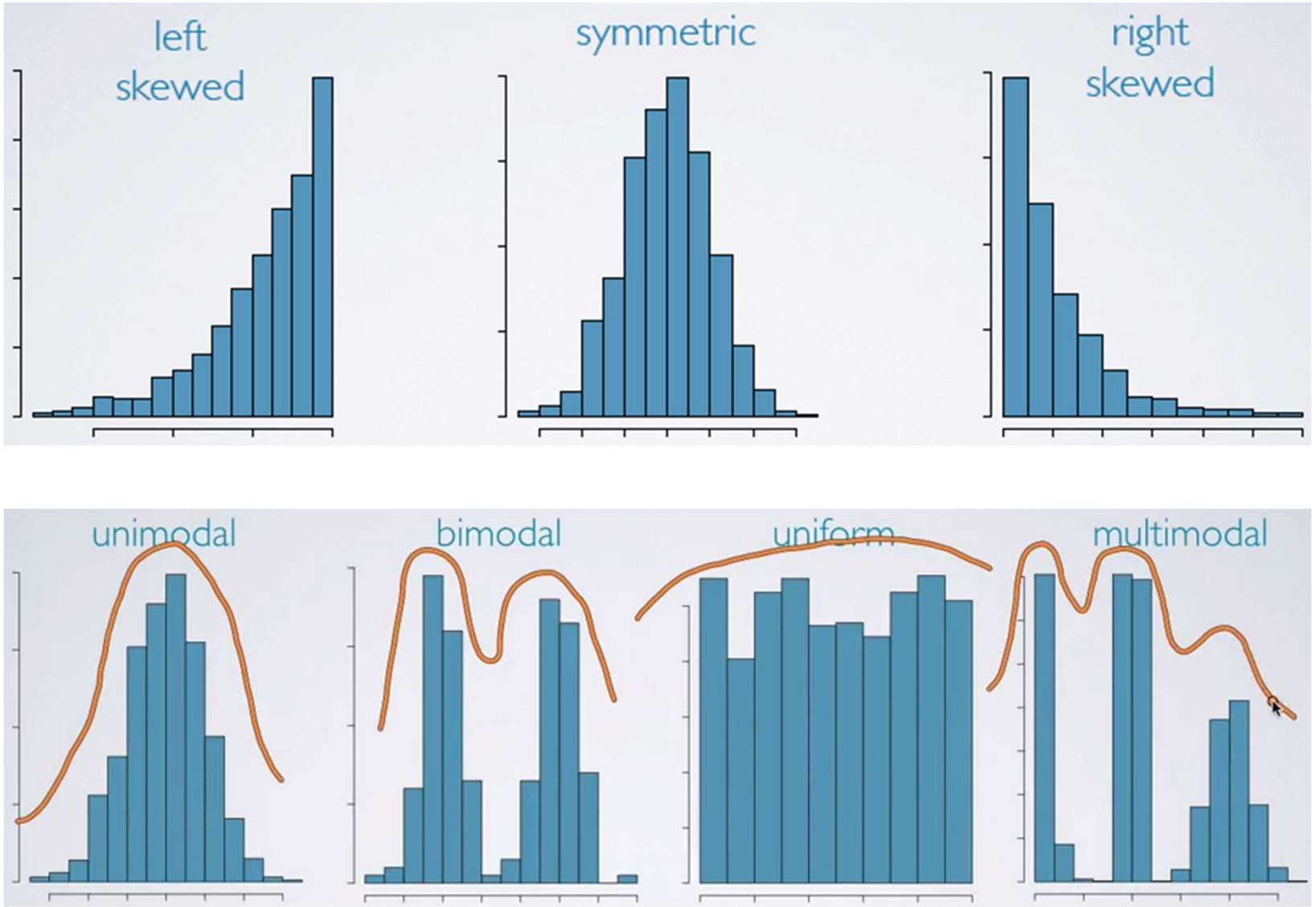




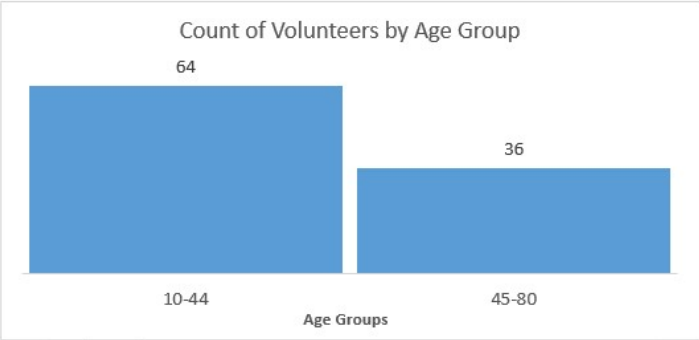
Idiom: **histogram**

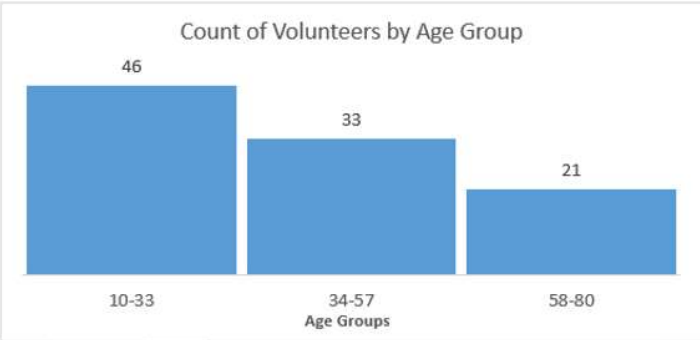
- static item aggregation
- task: find distribution
- data: table
- derived data
  - new table: keys are bins, values are counts
- bin size crucial
  - pattern can change dramatically depending on discretization
  - opportunity for interaction: control bin size on the fly

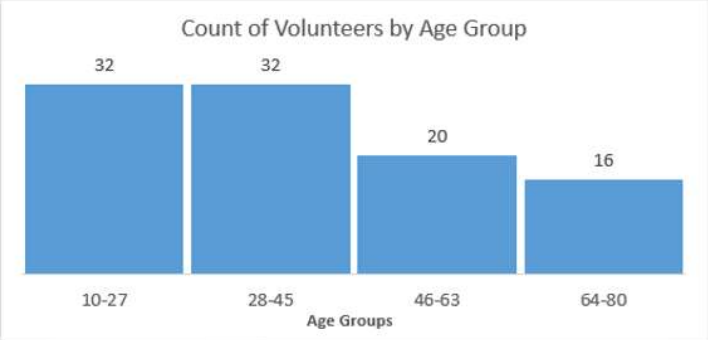
Histogram shows skewness and modality

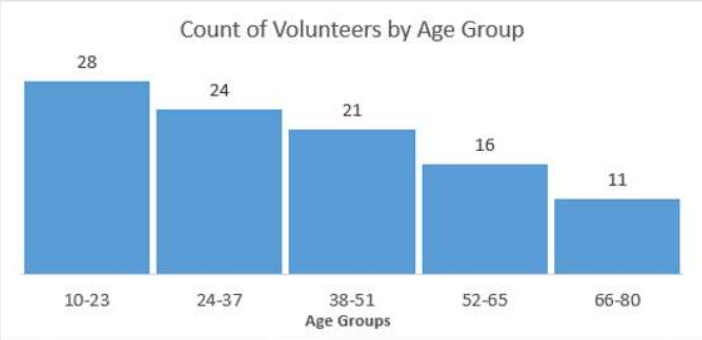


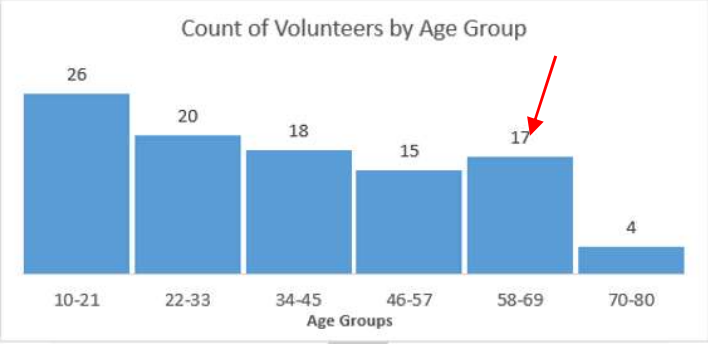
Histogram: different bin sizes tell different stories

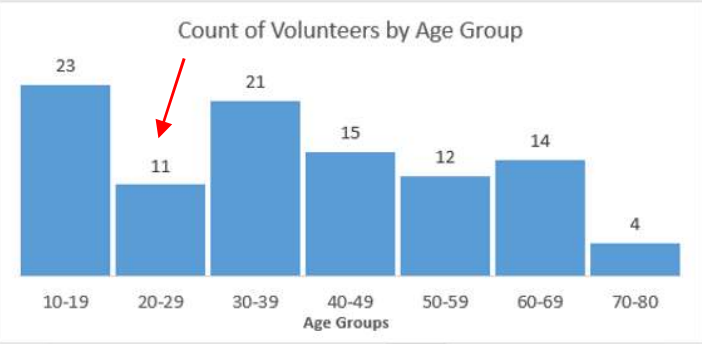






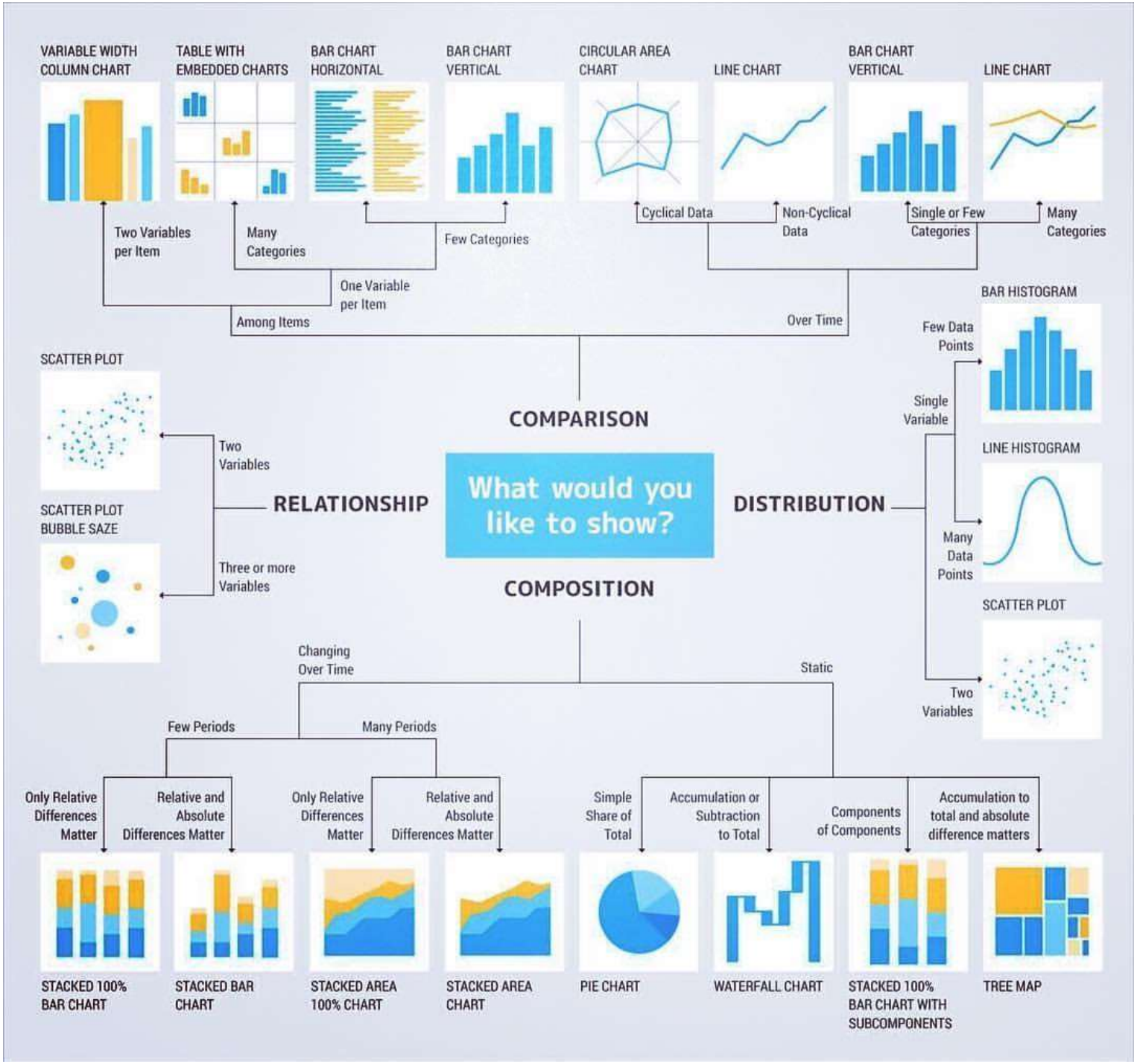






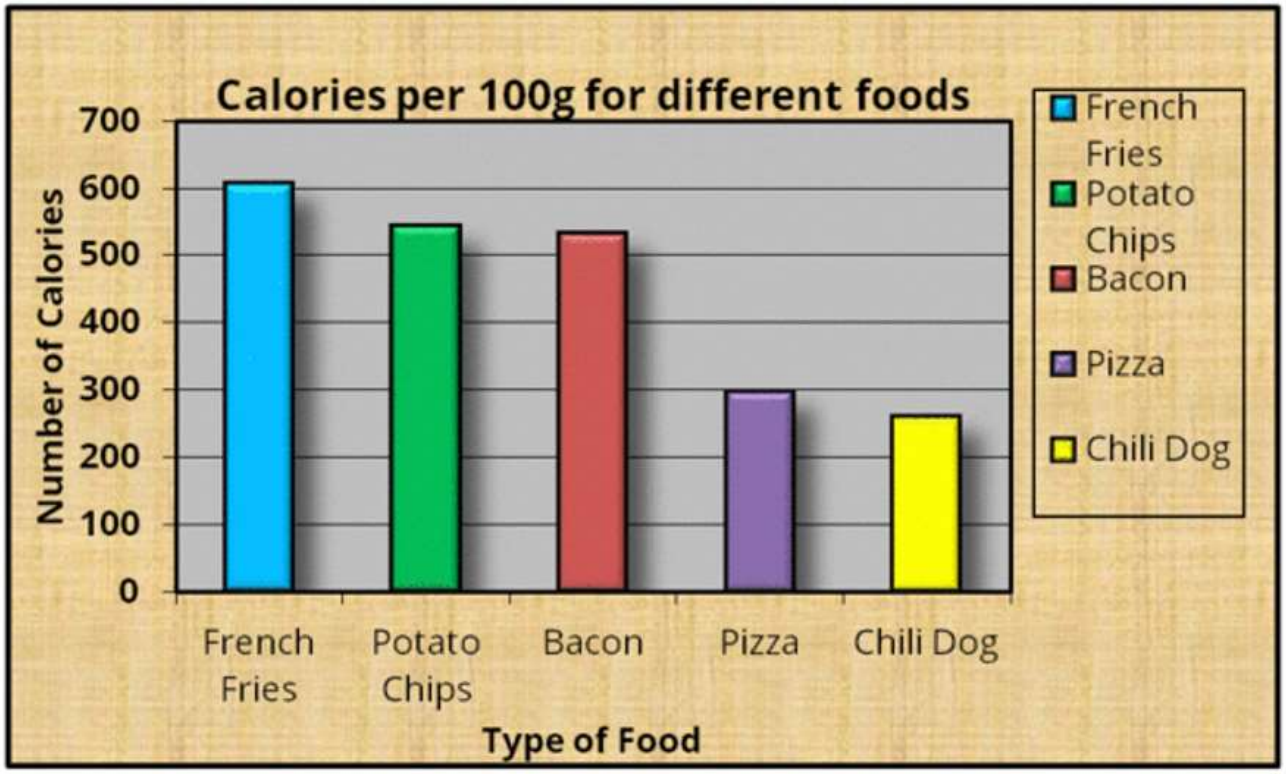
https://www.excelcampus.com/charts/dynamic-histogram/

How to choose your visualization



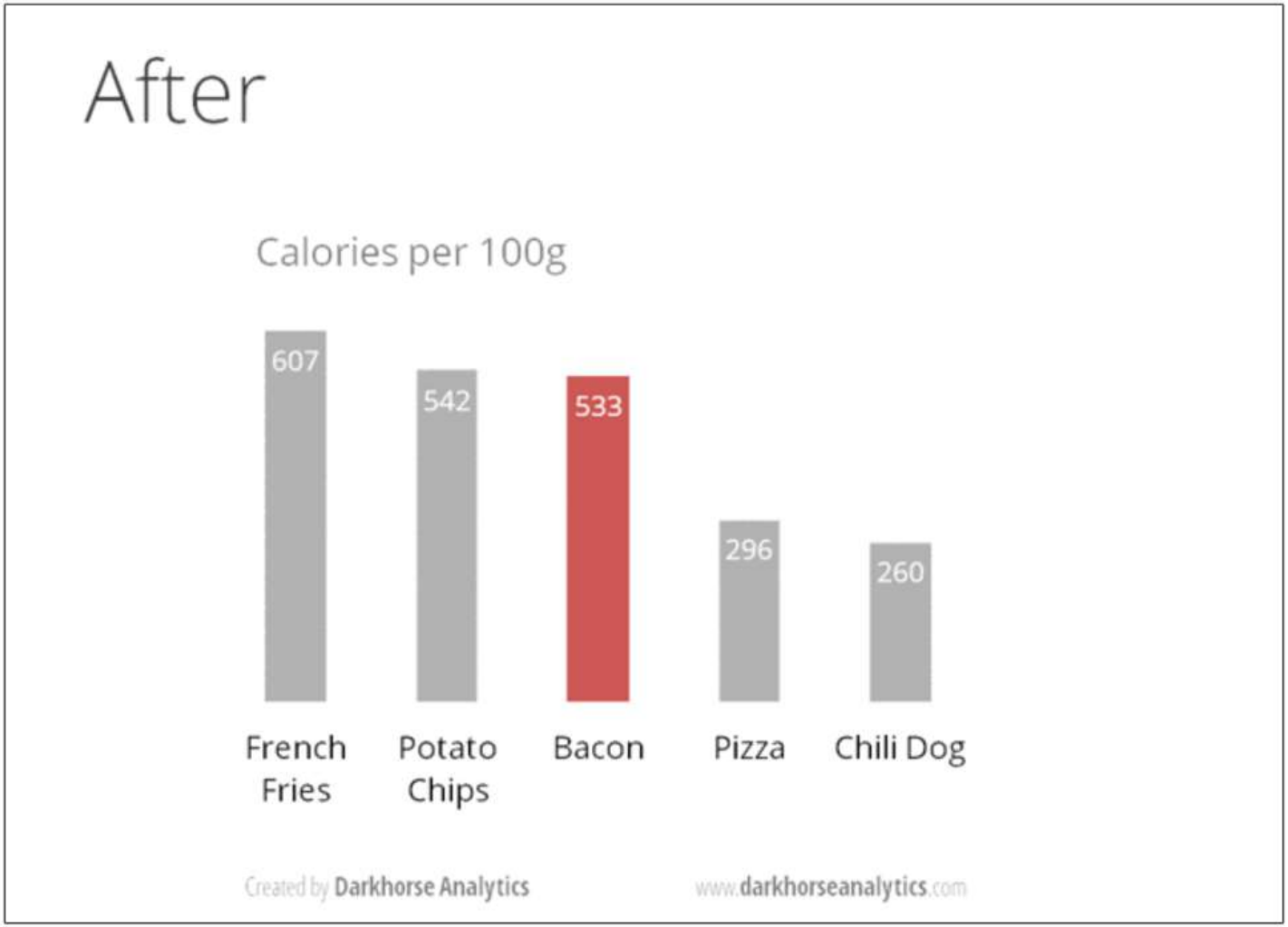
Less is More

Before



https://www.e-nor.com/blog/data-visualization/makes-good-visualization

Less is More



Note – In the above visual the author wanted to highlight the data for bacon so the bar for bacon was intentionally left red.

https://www.e-nor.com/blog/data-visualization/makes-good-visualization

Less is More

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