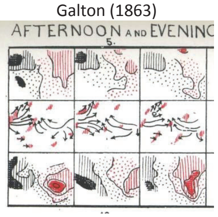
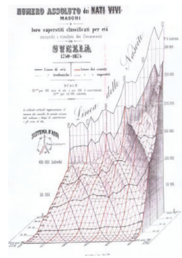
Galton (1863)





History of Data Visualization

Michael Friendly

Psych 6135

http://euclid.psych.yorku.ca/www/psy6135

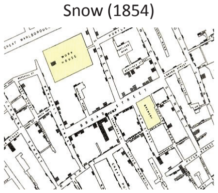
Outline

- Overview:
  - Roles of graphics in scientific discovery
  - Visualizing history: The *Milestones Project*
- Milestones tour of the history of data vis
  - Pre-history of visualization
  - The first statistical graph
  - The Big Bang: William Playfair
  - Influence of data, technology & visual thinking
- Other topics (later):
  - Moral statistics: the birth of social science
  - Graphs in the public interest: Nightingale, Farr and Snow
  - The Golden Age of statistical graphics

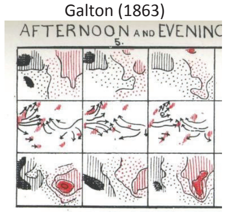
Orienting Q: Visualization-based discoveries ??

- When have graphics led to discoveries that might not have been achieved otherwise?
  - Snow (1854): cholera as a water-borne disease
  - Galton (1883): anti-cyclonic weather patterns
  - E.W. Maunder (1904): 11-year sunspot cycle
  - Hertzsprung/Russell (1911): spectral classes of stars

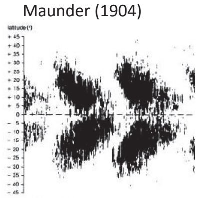
Snow (1854)



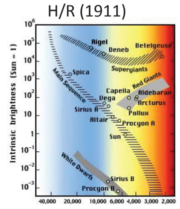
Galton (1863)



Maunder (1904)



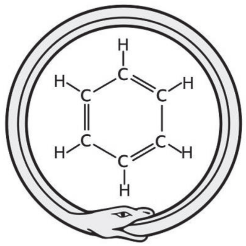
H/R (1911)



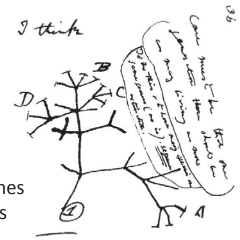
Orienting Q: Visualization-based discoveries ??

- In the history of graphs, what features, and data led to such discoveries?
  - What visual ideas/representations were available?
  - What was needed to see/understand something new?
- As we go forward, are there any lessons?
  - What are the Big Questions for today?
  - How can data visualization help?

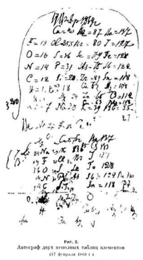
Visual thinking & scientific discovery

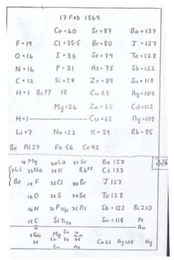


Dreams and snakes
August Kekulé (1862) discovers the structure of benzene in a dream



Tree of evolution
Darwin (1859) imagines generations of species





Solitaire and the periodic table
Mendeleev (1869) organized chemical elements after a mental image of cards on a table.

See: https://medium.com/@michael.friendly/visual-thinking-graphic-discoveries-128468677592

How to visualize travel? A route map!

In 1675, chartmaker John Ogliby told a graphic story of what you would see on a travel from London to Land's End

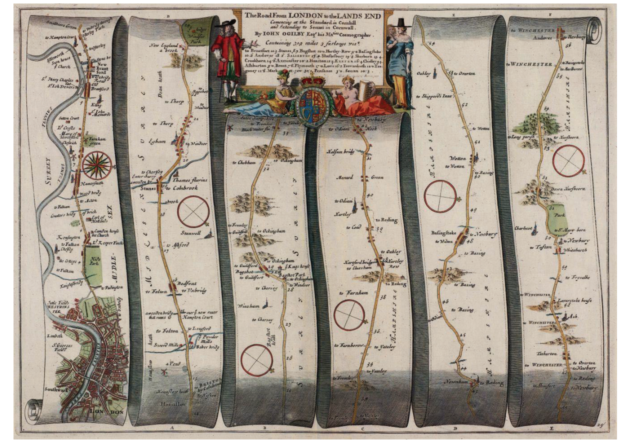
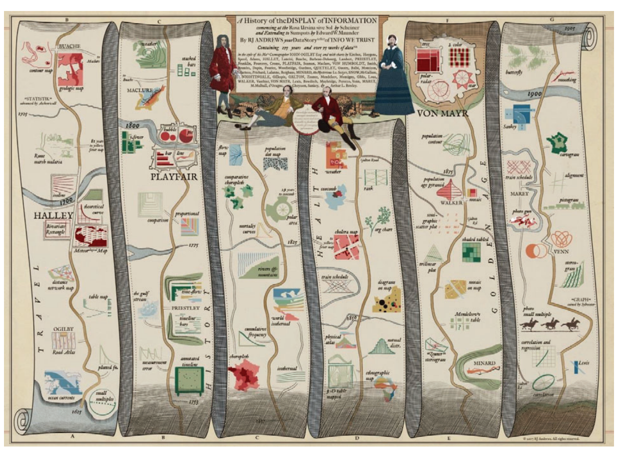


Image: https://commons.wikimedia.org/wiki/File:Ogilby_-_The_Road_From_LONDON_to_the_LANDS_END_(1675).jpg

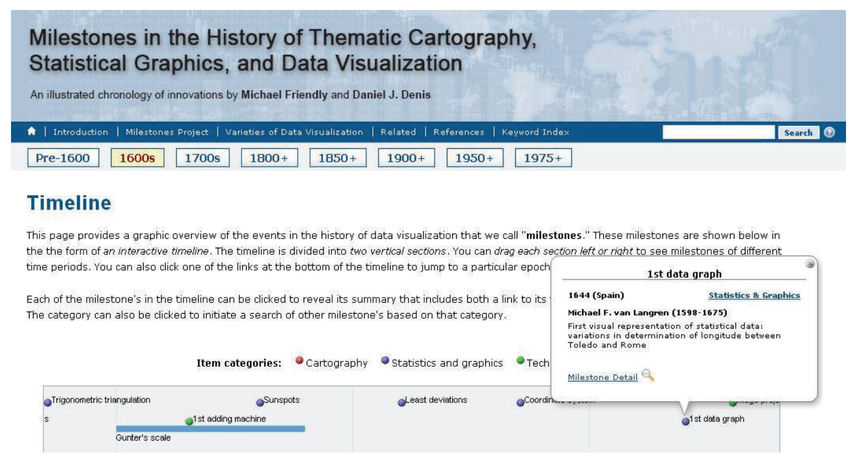
How to visualize history? A route map!

In 2017, graphic storyteller RJ Andrews adopted Ogilby's form to show the history of data visualization.



The online version, https://history.infowetrust.com/ is fully interactive, with details about the images on this journey.

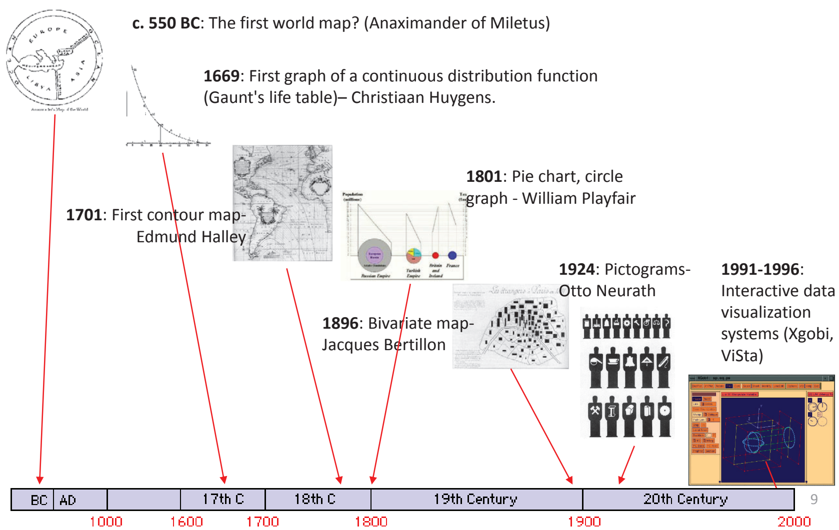
The *Milestones Project*



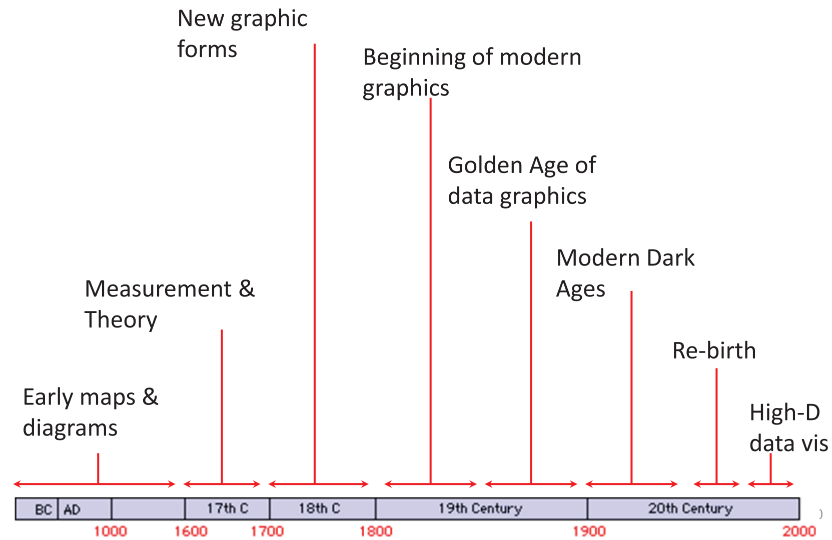
The web site: http://datavis.ca/milestones has an interactive timeline, allowing different kinds of search

Milestones: Content Overview

Every picture has a story – Rod Stewart

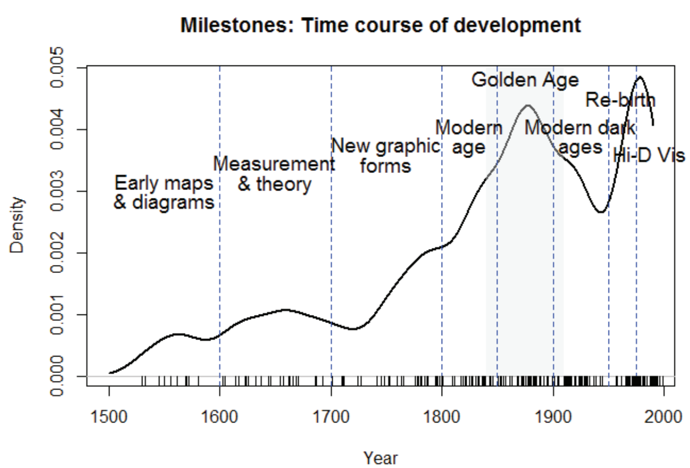


Milestones Tour: Epochs



Statistical historiography

Historical information, suitably organized can be treated as data, and analyzed.
This plot shows a smoothed frequency distribution of 248 milestones items over time, in relation to the named time periods.



Prehistory of visualization

Lascaux Cave, ~ 15000 BCE, the "Sistine Chapel of pre-historic art"

Lascaux II, Main chamber

Lascaux: What were they thinking?

Lascaux II, Chamber of the Bulls

- Visual features:
  - show perspective, a sense of motion, rich use of color & texture
- What was the purpose?
  - Hunting success? NO (they hunted reindeer)
  - mostly symbolic – visual language, story of communal myths
- How to understand them?
  - A **cognitive revolution:** evidence for the modern human mind in Cro Magnon man
  - inner vision, visual thinking, mental imagery– a gleam in the mind's eye
- Other cave art [20000BC – 10000BC]: Altamira (Spain); Chauvet (France), Cueva de las Manos (Argentina), …

Prehistory: Diagrams, graphic stories

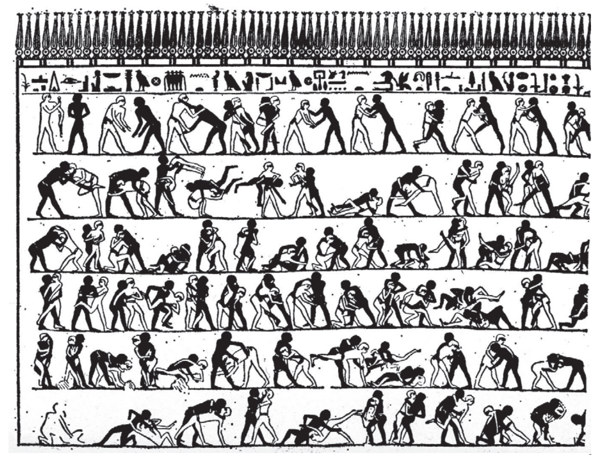
Early Egyptian animated graphic diagram

Wrestling scene on east wall, tomb of Baqt at Beni Hasan (ca. 2000 BCE).

A **visual explanation** of a wrestling match

Anticipates modern graphic novels

Why? Perhaps Baqt's last lesson as a wrestler in his youth and later as a coach

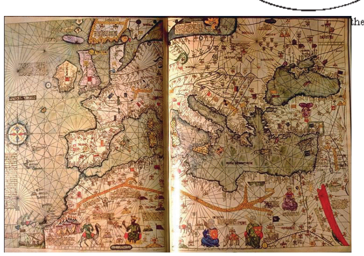


Pre 17th C.: Early maps & diagrams

c. 550 BC: The first world map? (Anaximander of Miletus)

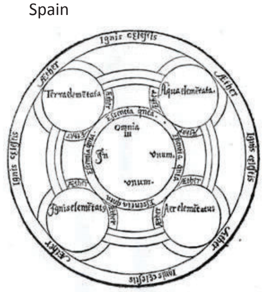
1350: Bar graph of theoretical function N. Oresme, France

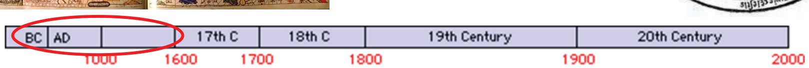
the World



1375: Catalan Atlas, an exquisitely beautiful visual cosmography, perpetual calendar, and thematic representation of the known world- Abraham Cresques, Spain

1305: Mechanical diagram of knowledge- Ramon Llull, Spain

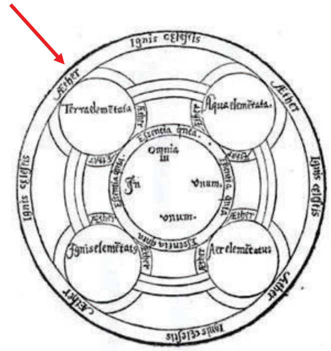


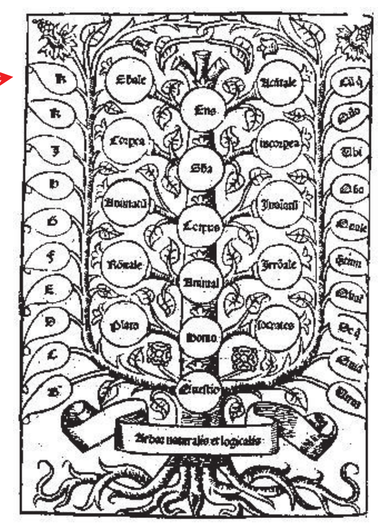


1305: Mechanical diagram of knowledge- Ramon Llull, Spain

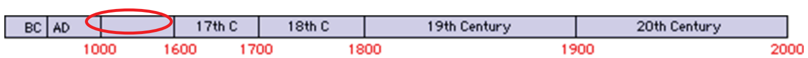
Tree of porphyry: Aristotle's categories of knowledge (center)

- Left: questions
- Right: rotating disks → answers





1375: Catalan Atlas, an exquisitely beautiful visual cosmography, perpetual calendar, and thematic representation of the known world- Abraham Cresques, Majorca, Spain [BNF: ESP 30]

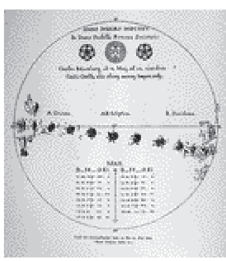


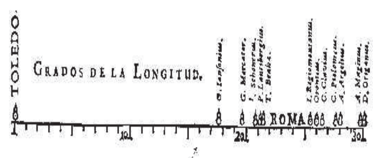
1600-1699: Measurement and Theory

- The 17th century saw growth in theory and the dawn of attempts at visualization.
- Featured in this were:
  - the rise of analytic geometry: (x, y) coordinates (Descartes),
  - theories of errors of measurement: astronomical observations (Laplace)
  - the birth of probability theory-- games of chance, annuities (Fermat, DeMoivre, ...),
  - automatic graphic recording (Scheiner)
  - the first graphical representations of statistical data (van Langren)

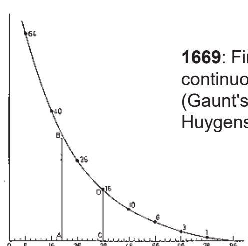
1600-1699: Measurement and Theory

1626: Visual representations used to chart the changes in sunspots over time- Christopher Scheiner

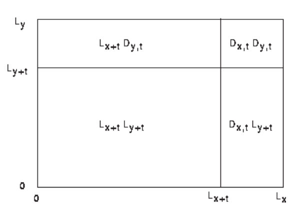




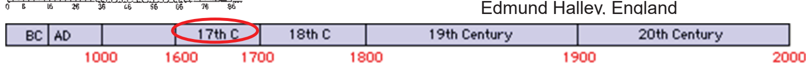
1644: First visual representation of statistical data- M.F. van Langren, Spain



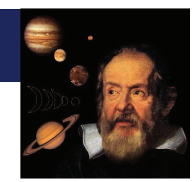
1669: First graph of a continuous distribution function (Gaunt's life table)– Christiaan Huygens.



1693: First use of areas of rectangles to display probabilities of independent binary events- Edmund Halley, England

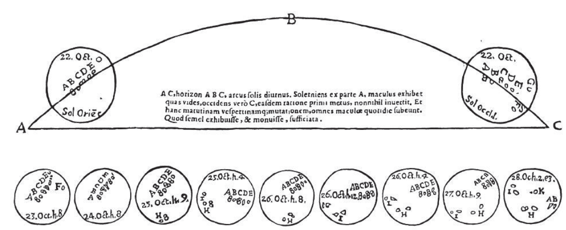


Sunspots: Galileo



1611: Galileo records **movement** of sunspots over time (*Three letters on sunspots*, 1613)

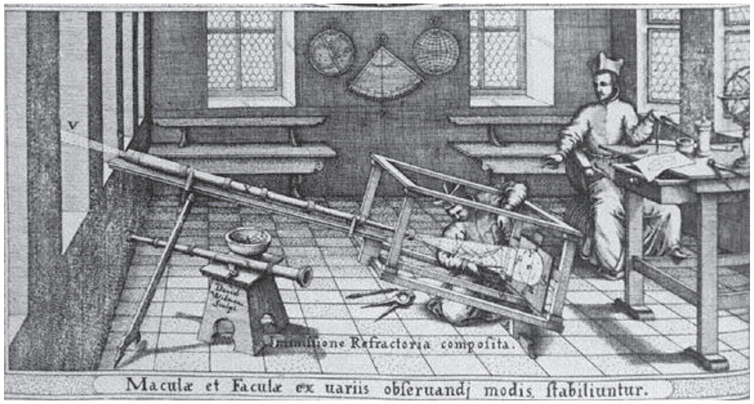
Visual ideas:
- Animated graphic
- "Small multiples"
- Allows comparison
- Self-explaining diagram



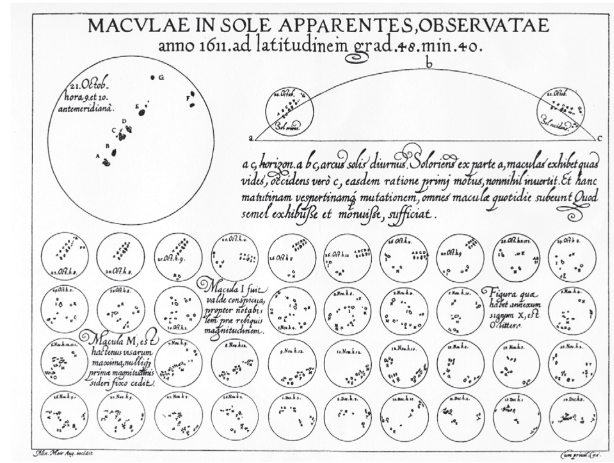
A+ for info design!

Scheiner: systematic recording

1626: Christoph Scheiner invents helioscope & camera obscura to record sunspots (*Rosa Ursina sive Sol* , 1626-1630)



Sunspots: Great graph, wrong theory



1626: Christopher Scheiner's graph of **changes** in sunspots over time.

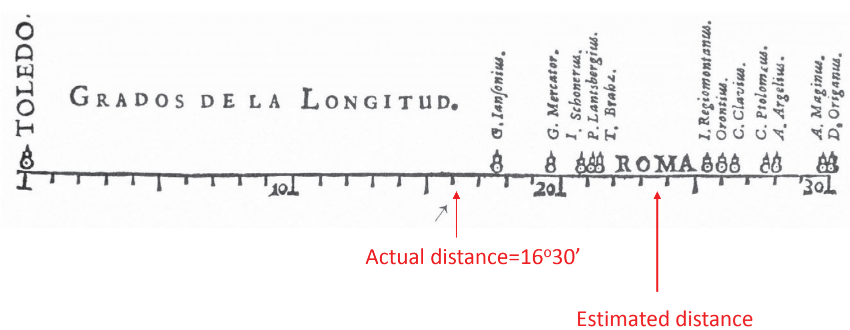
- "small multiples"
- allows comparison
- multiple legends
- A+ for info design!

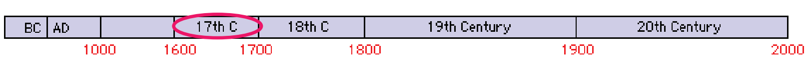
He argued (incorrectly) that these were evidence for solar satellites.

The idea of graphs for visualizing phenomena had arrived.

Why the 1st statistical graph got it right

1644: First visual representation of statistical data: determination of longitude between Toledo and Rome- Michael Florent van Langren, Spain





What else could he have done?

- What would occur to men of his time to convey a message to the king?
- … he could used a *table* have sorted by *year* to establish *priority* (or show change).

Sorted by Priority

Year	Name	Longitude	Where
150	Ptolomeus, C.	27.7	Egypt
1471	Regiomontanus,	25.4	Germany
1501	Ianfonius, G.	17.7	
1530	Lantsbergius, P.	21.1	
1536	Schonerus, I.	20.8	Germany
1541	Argelius, A.	28.0	
1542	Ortonius	26.0	France
1567	Mercator, G.	19.6	Flanders
1567	Clavius, C.	26.5	Germany
1578	Brahe, T.	21.5	Denmark
1582	Maginus, A.	29.8	Italy
1601	Organus, D.	30.1	

- … he could have sorted by *name*, to show *authority*.

Sorted by Authority

Name	Longitude	Year	Where
Argelius, A.	28.0	1541	
Brahe, T.	21.5	1578	Denmark
Clavius, C.	26.5	1567	Germany
Ianfonius, G.	17.7	1501	
Lantsbergius, P.	21.1	1530	
Maginus, A.	29.8	1582	Italy
Mercator, G.	19.6	1567	Flanders
Organus, D.	30.1	1601	
Ortonius	26.0	1542	France
Ptolomeus, C.	27.7	150	Alexandria
Regiomontanus, I.	25.4	1471	Germany
Schonerus, I.	20.8	1536	Germany

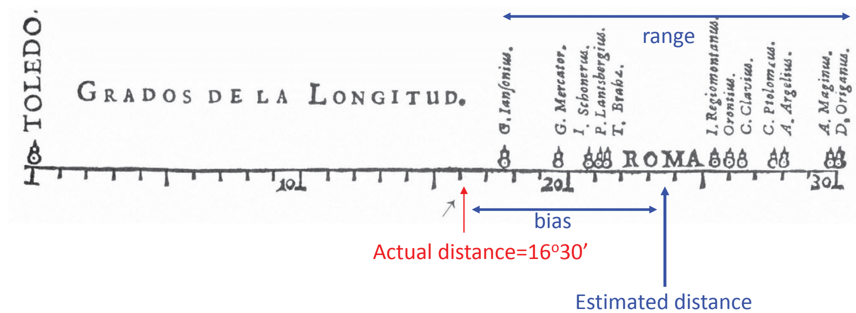
- … he could have sorted by *longitude* to show the *range*.

Sorted by Longitude

Longitude	Name	Year	Where
17.7	G. Ianfonius	1501	
19.6	G. Mercator	1567	Flanders
20.8	I. Schonerus	1536	Germany
21.1	P. Lantsbergius	1530	
21.5	T. Brahe	1578	Denmark
25.4	I. Regiomontanus	1471	Germany
26.0	Orontius	1542	France
26.5	C. Clavius	1567	Germany
27.7	C. Ptolomeus	150	Egypt
28.0	A. Argelius	1541	
29.8	A. Maginus	1582	Italy
30.1	D. Organus	1601	

Only a graph shows…

- central location
- bias
- name labels– avoiding overplotting
- wide variability
- clustering, detached observations

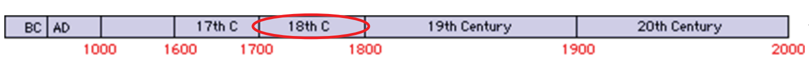


See: Friendly, M., & Kwan, E. (2003). Effect Ordering for Data Displays. *Computational Statistics and Data Analysis, 43*(4), 509—539; Friendly etal (2010),The First (Known) Statistical Graph: Michael Florent van Langren and the ``Secret'' of Longitude *The American Statistician, 64*, 185-191

1700-1799: New graphic forms

- The 18th century witnessed the germination of the seeds of visualization & visual thinking, planted earlier.
- Map-makers began to try to show more than just geographical position-- the beginnings of thematic mapping of physical quantities
  - topographical maps
  - iso- contour maps
- New graphic forms were invented:
  - bar chart,
  - line chart,
  - timelines

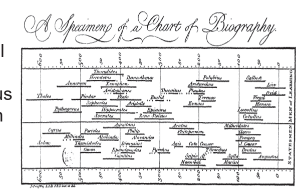
} The Big Bang



1700-1799: New graphic forms

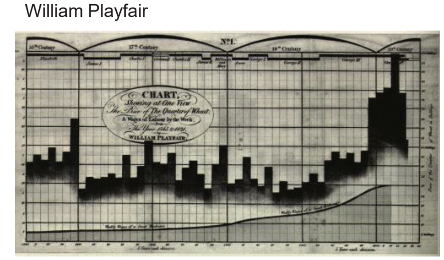
1701: Isobar map, lines of equal magnetic declination – Edmund Halley

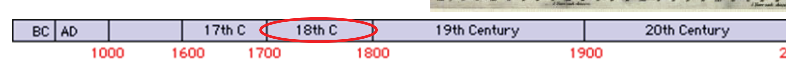
1765: Historical time line (life spans of famous people) Joseph Priestley



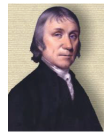
1782: First topographical map- Marcellin du Carla-Boniface

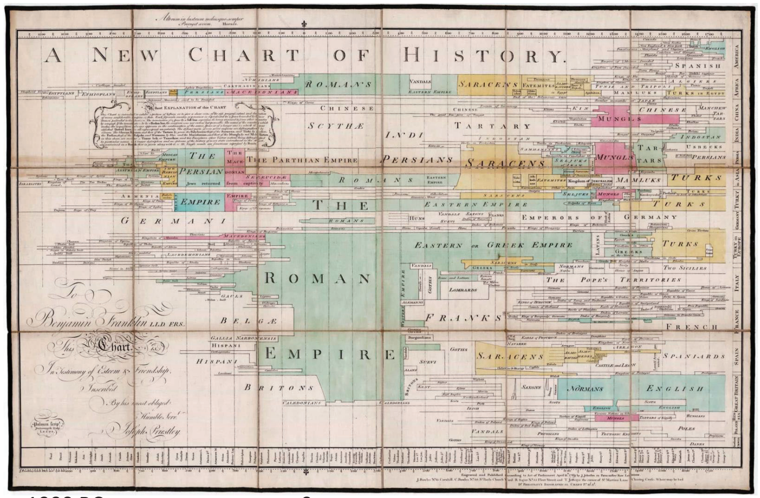
1786: Bar chart, line graphs of economic data- William Playfair





1769: Visualization of the history of civilizations & empires over ~3000 years --Joseph Priestley





America

China

Italy

France

Spain

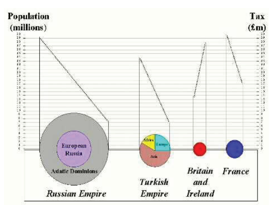
1000 BC 0 1000

1800-1849: Beginning of modern data graphics

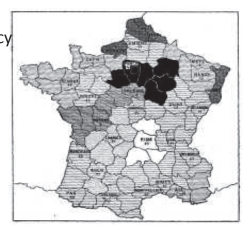
- The first half of the 19th century witnessed an explosive growth in statistical graphics and thematic mapping
  - Polar coordinates, log axes
  - Shaded (choropleth) maps of social data (literacy, crime)
- The birth of data: widespread national collection of data on social and medical issues
  - France: data on crime, literacy, prostitution, … collected centrally
  - England: Births, deaths, disease mortality collected by Registrar General

1800-1849: Beginning of modern data graphics

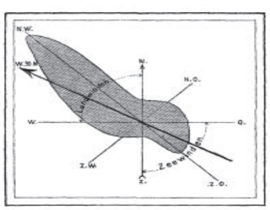
1801: Pie chart, circle graph invented- William Playfair

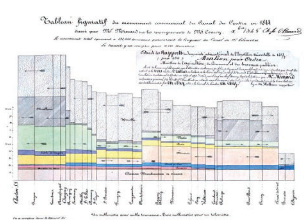


1819: First modern statistical map (illiteracy in France)- Charles Dupin



1843: Wind-rose (polar coordinates)- L. Lalanne



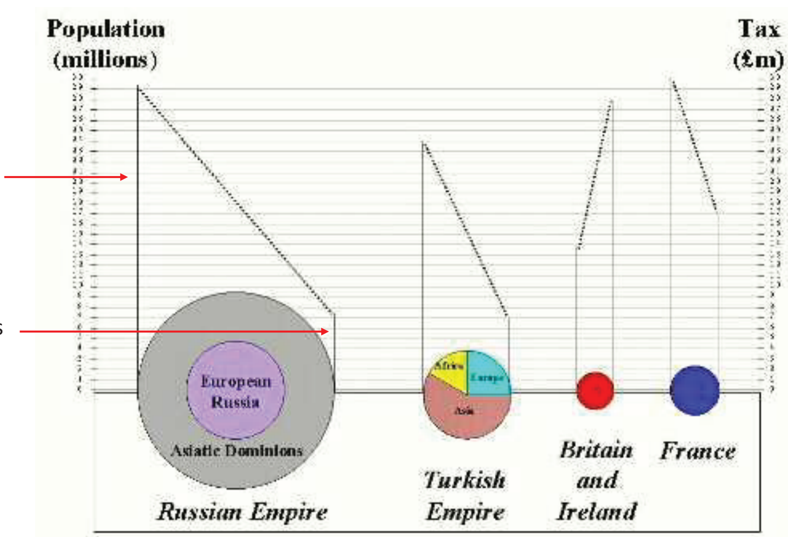


1844: variable-width, divided bars, area ~ cost of transport- C. J. Minard

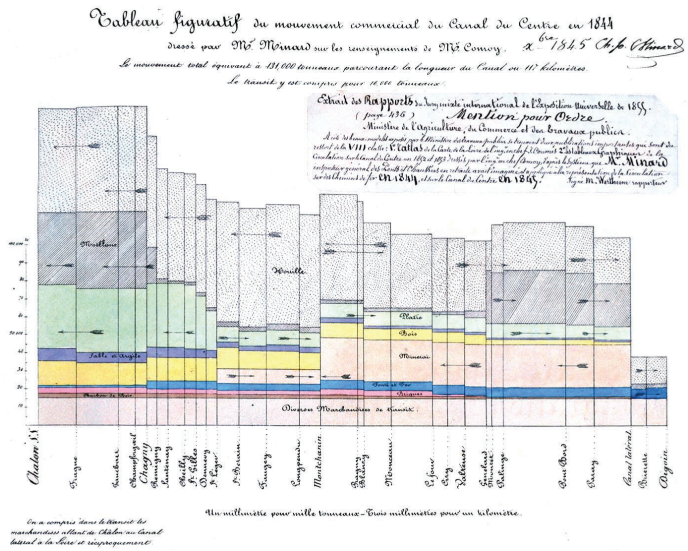
1801: Pie chart, circle graph invented- William Playfair

pop

taxes

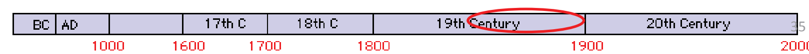


1844: *Tableau-graphique*: variable-width, divided bars, area ~ cost of transport- Charles Joseph Minard

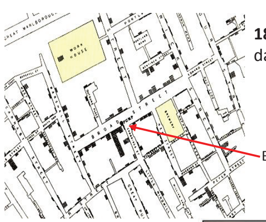


1850-1900: Golden Age

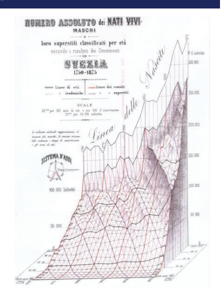
- By the last half of the 19th century the conditions for rapid growth of visualization had been established:
  - widespread data collection for planning, commerce, social theory
  - the beginnings of statistical theory and visual thinking
  - a wide range of graphic forms, reasonably well understood
  - technology:
    - lithography and color printing
    - automatic recording devices
    - calculation: machines & graphical calculators
- The result was a perfect storm-- among the most exquisite graphics ever produced.



1850-1900: Golden Age

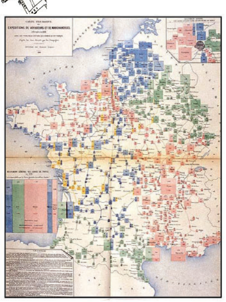


1855: Dot map of disease data (cholera)- John Snow

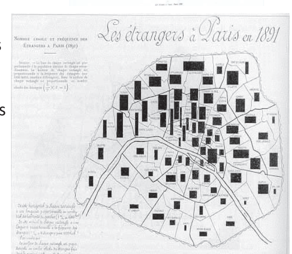


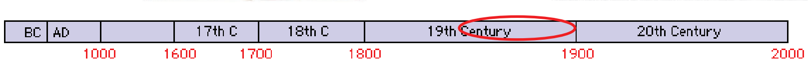
1879: Stereogram (3D population pyramid)- Luigi Perozzo

1884: Recursive multi-mosaic on a map- Emile Cheysson

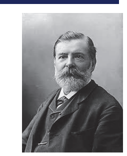


1896: Area rectangles on a map to display two variables and their product- Jacques Bertillon





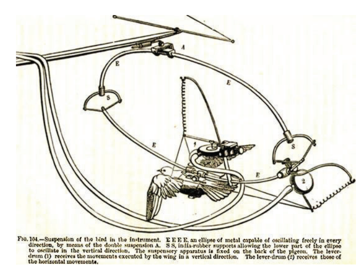
E.-J. Marey: *La Méthode Graphique*



- How to make human and animal motion subject to precise scientific study?
- e.g., aerial locomotion of flying insects & birds
  - What is the frequency of wings of different species?
  - What are the mechanisms of wings to produce lift and forward motion?

A harness, designed to register the trajectory, force and speed of a bird's wing in flight

Marey (1870) *Animal Mechanism*



E.-J. Marey: Chronophotography

Rather than separate frames, Marey's "fusil photographique" allowed one to see motion continuously in a single static image.

This provides a visual analysis of a sprint:

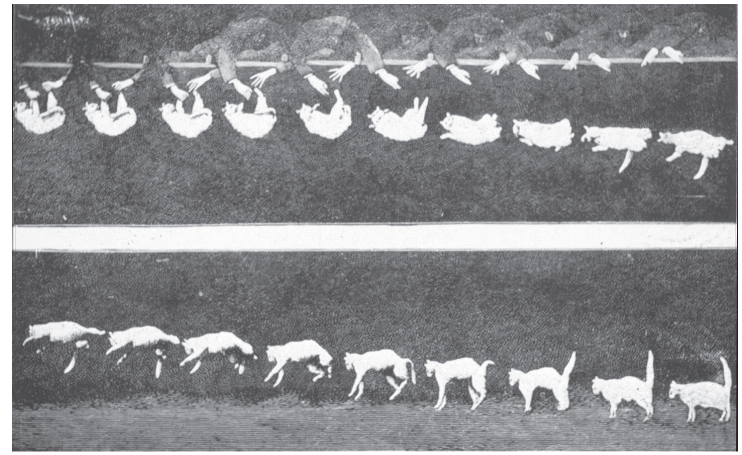
- The runner takes about ½ second (7 frames) to make it to an upright position
- Successive frames alternate between power push from the hind leg to landing on the opposite leg

Source: https://lightsmellsloud.wordpress.com/tag/etienne-jules-marey/

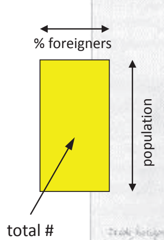
The Falling Cat Problem

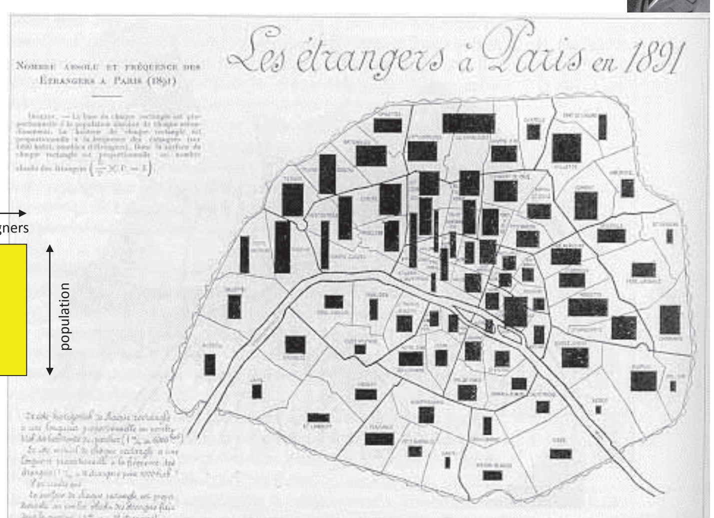
Another fundamental problem answered by chronophotography:

- How does a falling cat usually land on her feet? An OMG moment!



1896: Area rectangles on a map to display two variables and their product- Jacques Bertillon



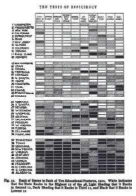


1900-1949: The Modern Dark Ages

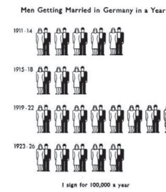
- By the 1930s, the growth of statistical methods supplanted enthusiasm for graphics
  - There were few graphic innovations
  - In statistics: numbers were precise; graphs were just pretty pictures
- But graphical methods had entered the mainstream & were popularized
  - Text books, college courses
- There were several graphic-based scientific discoveries
- Electronic computers were born

1900-1949: The Modern Dark Ages

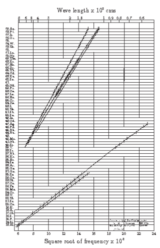
1914: Brinton: *Graphic Methods for Presenting Facts*



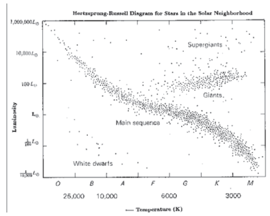
1924: ISOTYPE method of pictorial graphics—Otto Neurath



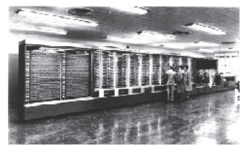
1913: Discovery of atomic number, based on graphical analysis- H. Mosely



1911-1913: The Hertzsprung-Russell diagram & evolution of stars



1944: Harvard's Mark I, the first digital computer- Howard Aiken, Grace Hopper



1914: Willard C. Brinton publishes *Graphic Methods for Presenting Facts*, the 1st popular book on the topic

heatmap

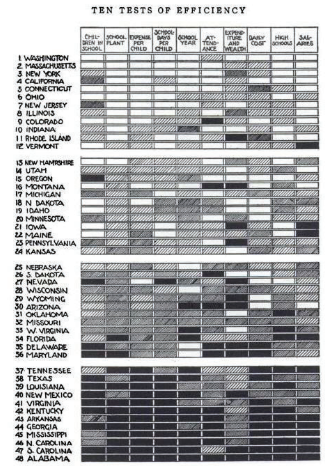


Fig. 33. Rank of States in Each of Ten Educational Features, 1910. White Indicates that the State Ranks in the Highest 12 of the 48, Light Shading that it Ranks in Second 12, Dark Shading that it Ranks in Third 12, and Black that it Ranks in Lowest 12

pictogram

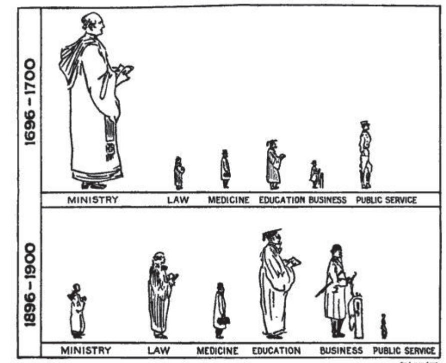
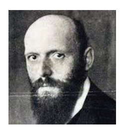


Fig. 39. Proportion of College Graduates in Different Professions in 1696-1700 and in 1896-1900

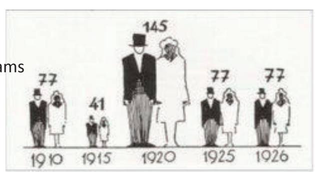
Charts of this kind with men represented in different sizes are usually so drawn that the data are represented by the height of the man. Such charts are misleading because the area of the pictured man increases more rapidly than his height. Considering the years 1696-1700, the pictured minister has about two and one-half times the height of the man representing public service. The minister looks over-important because he has an area of more than six times that of the man drawn to represent public service. This kind of graphic work has little real value

1924: Otto Neurath developed the Isotype (International System of Typographic Picture Education) method to communicate statistical information to the broad public in an intuitive, pictorial way.

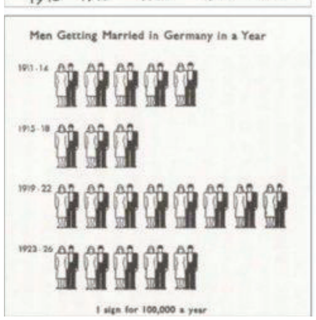


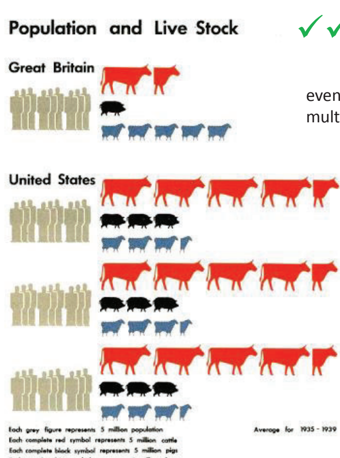
NOT pictograms

✘



✓





✓✓

even complex, multivariate data

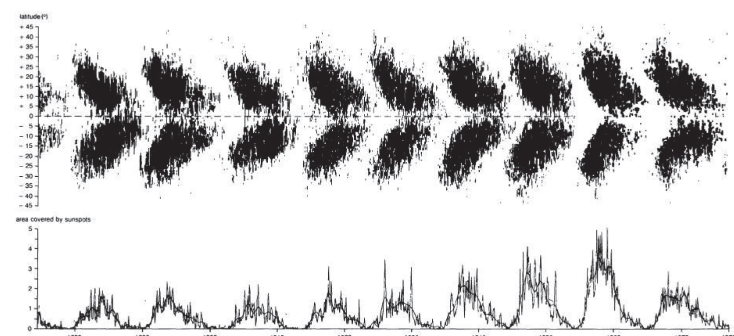
Maunder: Butterfly diagram

1904: E.W. Maunder plots distribution of sunspots in sun's latitude by time

- Discovery of 11-year sunspot cycles (& 22-yr: reversal of sun's magnetic field)

latitude

area

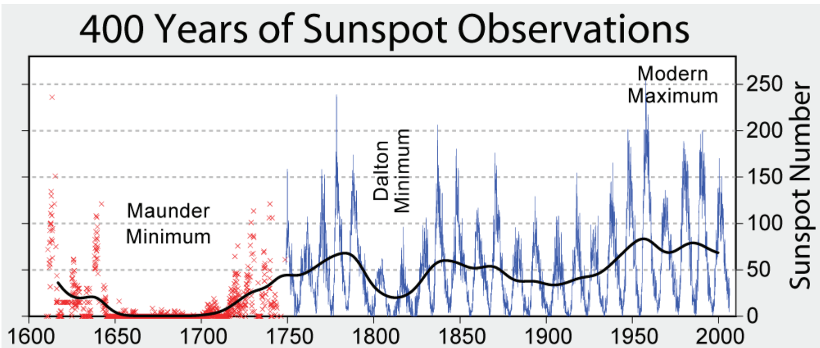


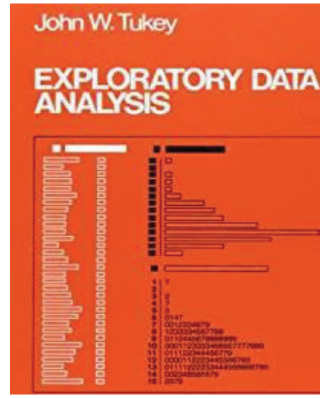
Maunder: Butterfly diagram

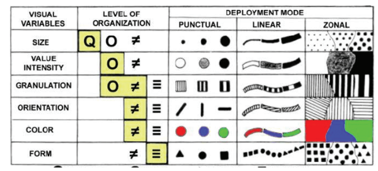
1904: E.W. Maunder plots distribution of sunspots in sun's latitude by time

• Discovery of "Maunder minimum" (1645-1715): "Little Ice Age"

• Smoothing reveals other extrema





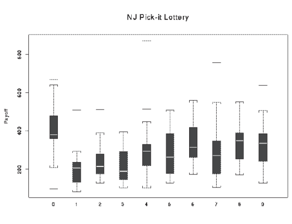


1950-1974: Re-birth of graphics

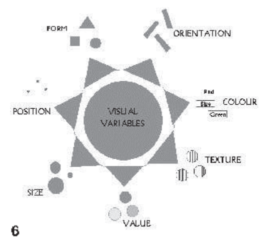
- Visualization began to rise from dormancy in the mid 1960s, spurred largely by:
  - J. W. Tukey's *Exploratory Data Analysis*: The power of graphics to show the unexpected in data analysis
  - Jacques Bertin's *Semiologie Graphique*: A general theory of composing graphs and maps
  - computer hardware for computation and display
  - the advent of statistical and graphics software

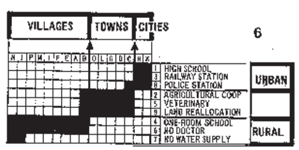
1950-1974: Re-birth of graphics

1969: Graphical innovations for EDA (stem-and-leaf, box-plots, etc.)- J.W. Tukey



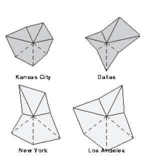
1967: Comprehensive theory of graphical symbols and modes of graphics representation- Jacques Bertin





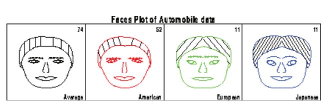
1967: Reorderable matrix- Jacques Bertin

Multivariate glyphs



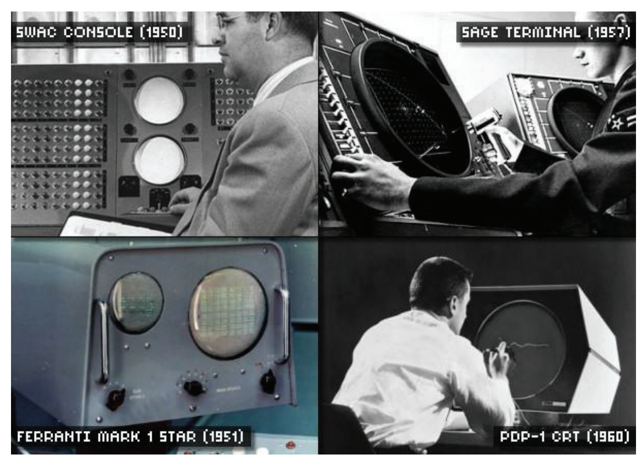
1971: Star plots- J. H. Siegel etal

1973: Face plots- Herman Chernoff



Digital display devices

The biggest limitation in the early development of dynamic and interactive graphics was in graphics display devices.



Only B/W, but for the first time, dynamic displays became possible.

By the late 1950s, pen-like input devices allowed rudimentary direct interaction

1975-present

Technology:

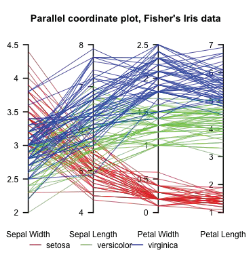
- Progressively more powerful computation & graphics
  - Mainframes → PCs → workstations → servers → cloud computing
  - pen plotters → CRTs → graphics hardware & firmware
  - stand-alone → client-server architecture
- Internet
  - email → file sharing (FTP) → www (HTML) → Java → javascript
  - data: open data initiatives with APIs
  - ecommerce: Amazon, Netflix, … → BIG data
- Software
  - Statistical packages: SAS, SPSS
  - Statistical programming environments: R, matlab, Stata
  - Contributed package archives: CTAN (latex), CPAN (perl), CRAN (R)
  - Collaborative development sites: github, bitbucket, …

1975-present

Themes in data visualization:

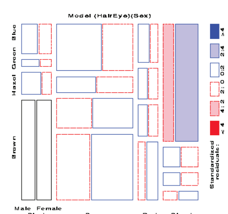
- high-D problems of progressively higher dimensions
  - grand tour: n-D → 2D projections
  - Dimension reduction methods (PCA, MDS, biplots)
- new data types:
  - categorical data,
  - networks, trees, …
- interactive data vis
  - linked views
  - direct manipulation: select, zoom, filter
  - dynamic graphics & animation

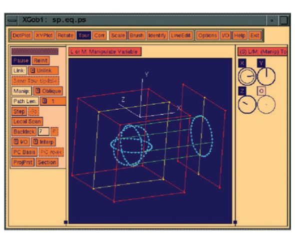
1975-present



1985: Parallel coordinates plots for high-D data- Alfred Inselberg

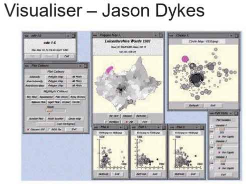
1991: Mosaic display for visual analysis of log-linear models- Michael Friendly





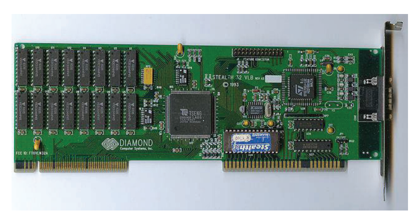
1991-1996: High-interaction systems for data analysis and visualization, e.g., *XGobi*, *ViSta*

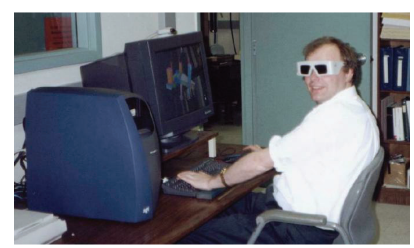
1996: Cartographic Data Visualiser – Jason Dykes



Next steps: Hardware

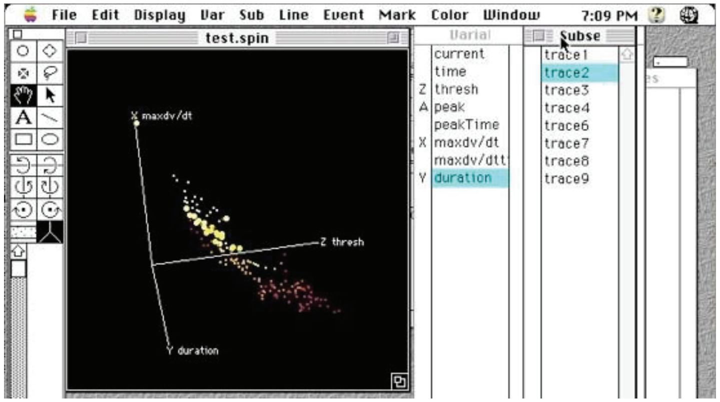
- Dynamic 3D graphics was painfully slow for larger data sets.
- Specialized 3D graphics hardware:
  - Early 1970s: Simple LSI graphics chips for video games
  - 70s—80s: Graphics co-processors (GPUs) with increasing graphics capabilities
  - 80s—90s: Silicon Graphics develops high-performance 3D graphics workstations





Next steps: Software

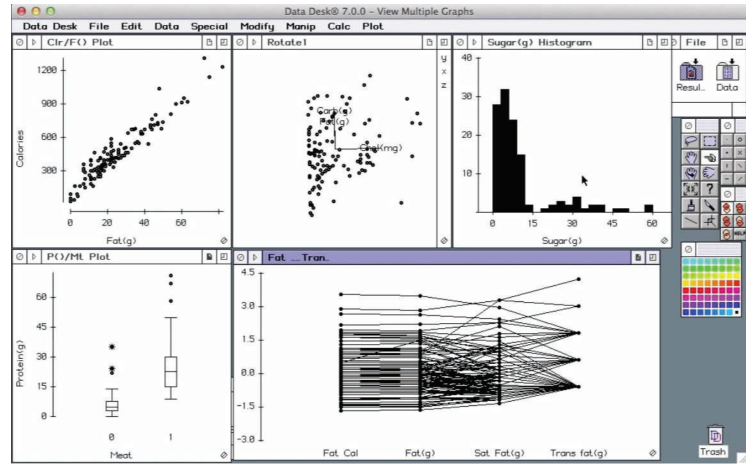
- MacSpin – Andrew & David Donoho (1984—85). At ASA meetings 1986, "dynamic graphics became as portable as a 25-lb Macintosh"



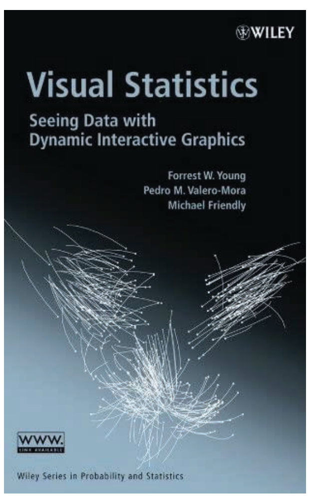
Linking, brushing, 3D rotation

Paul Velleman (~1985): Data Desk provided multiple 1D, 2D, 3D views

- **Brushing**: selection of points, regions, … via mouse
- **Linking**: Any action in one plot reflected in all others



Visual Statistics



Young, Valero-Mora & Friendly (2006)

A philosophy & pedagogy for statistics based on dynamic interactive graphics

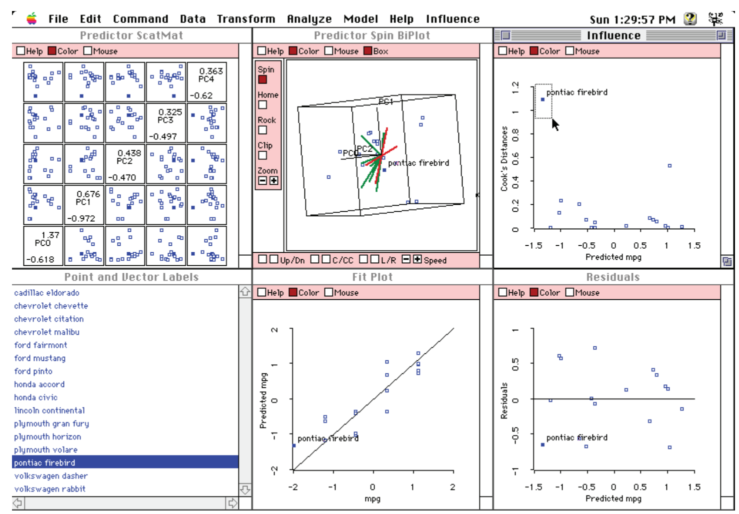
A theory of #datavis software:

- objects (data, model, …)
- methods (print, plot,)
- manipulating plot objects & dimensions
- spreadplots: dynamically linked views
- workmaps: visual record of analysis steps

Details: https://www.uv.es/visualstats/

See: The History of ViSta: The Visual Statistics System, https://onlinelibrary.wiley.com/doi/full/10.1002/wics.1203

ViSta: Visual Statistics



Conclusions

- Data Visualization has deep & wide roots:
  - **Cartography**: map-making, geo-measurement, thematic cartography, GIS, geo-visualization
  - **Statistics**: probability theory, distributions, estimation, models, stat-graphics, stat-visualization
  - **Data**: population, economic, social, moral, medical, …
  - **Visual thinking**: geometry, functions, mechanical diagrams, EDA, …
  - **Technology**: printing, lithography, computing…
- **Problem driven**: developments often driven by practical and theoretical problems of the day
- **Communication driven**: developments often arose from a desire to communicate better