

History of Data Visualization

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Psych 6135

<https://friendly.github.io/6135>

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What motivated graphical inventions?

What was the communication goal?

How does it relate to other developments?

- What were the pre-cursors?

How has this idea been used or re-invented today?

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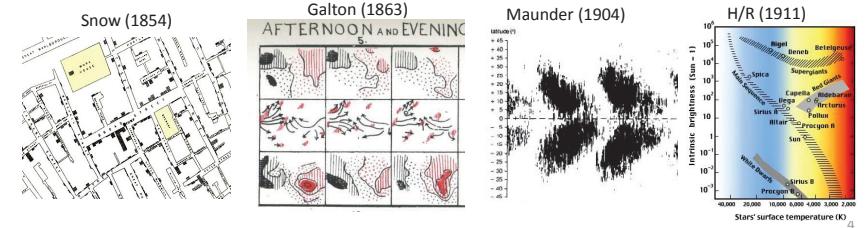
Outline

- 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

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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



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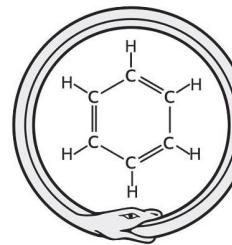
Orienting Q: Visualization-based discoveries ??

- In the history of graphs, what features, and data led to such discoveries?
 - What were they thinking??
 - 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?

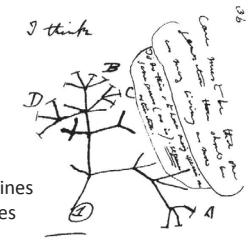


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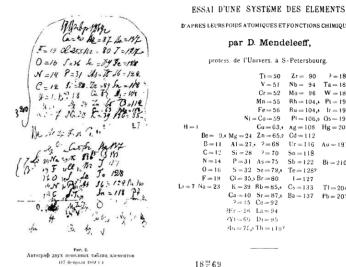
Visual thinking & scientific discovery



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>

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How to visualize travel? A route map!

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

What was he thinking?

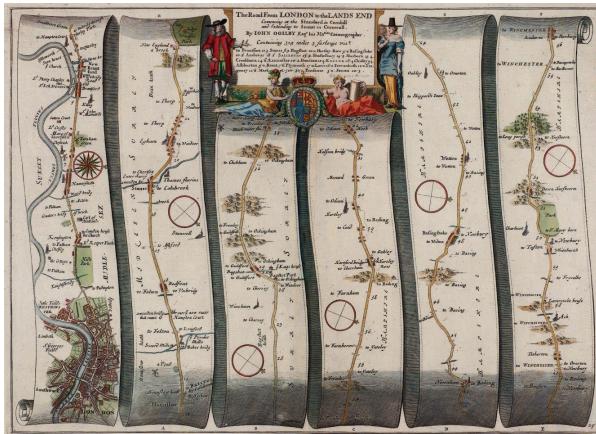
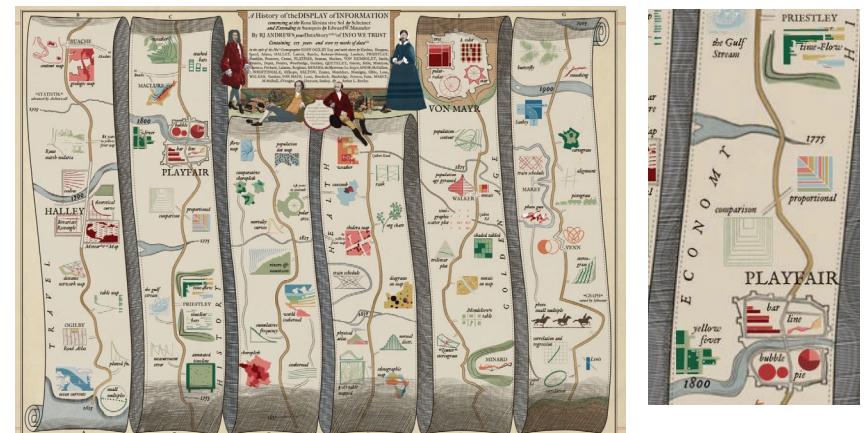


Image: [https://commons.wikimedia.org/wiki/File:Ogilby_-_The_Road_From_LONDON_to_the_LANDS_END_\(1675\).jpg](https://commons.wikimedia.org/wiki/File:Ogilby_-_The_Road_From_LONDON_to_the_LANDS_END_(1675).jpg)

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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.

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The Milestones Project

Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization

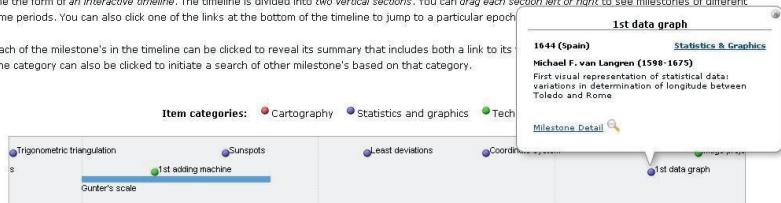
An illustrated chronology of innovations by Michael Friendly and Daniel J. Denis



Timeline

This page provides a graphic overview of the events in the history of data visualization that we call "milestones." These milestones are shown below in the form of an *interactive timeline*. The timeline is divided into two vertical sections. You can drag each section left or right to see milestones of different time periods. You can also click one of the links at the bottom of the timeline to jump to a particular epoch.

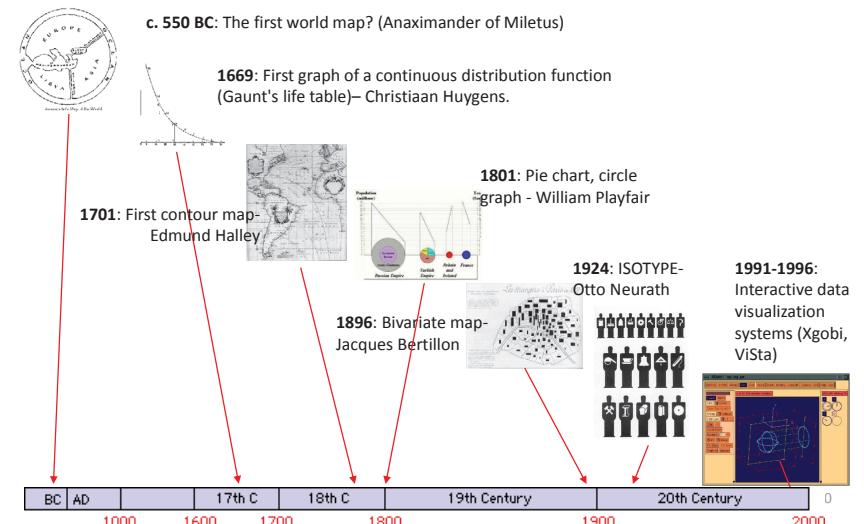
Each of the milestone's in the timeline can be clicked to reveal its summary that includes both a link to its category and also a search of other milestone's based on that category.



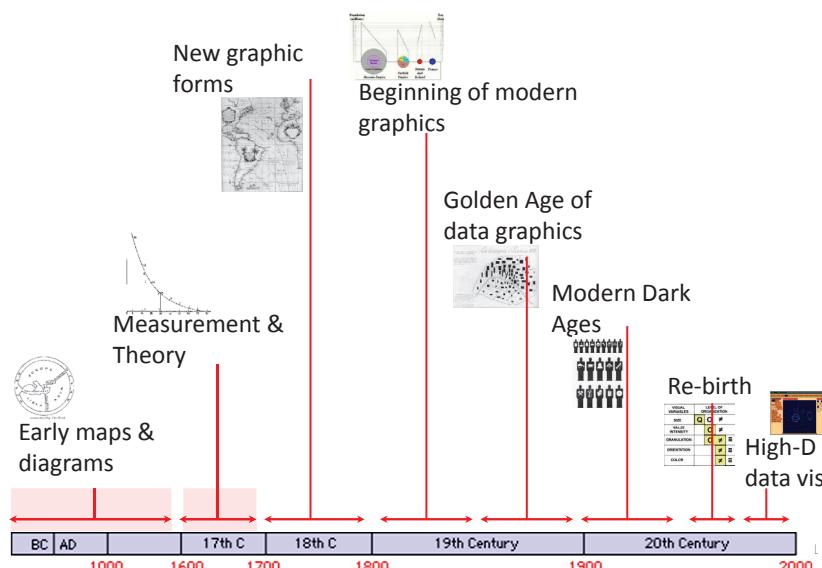
The web site: <http://datavis.ca/milestones> has an interactive timeline, allowing different kinds of search

Milestones: Content Overview

Every picture has a story – Rod Stewart

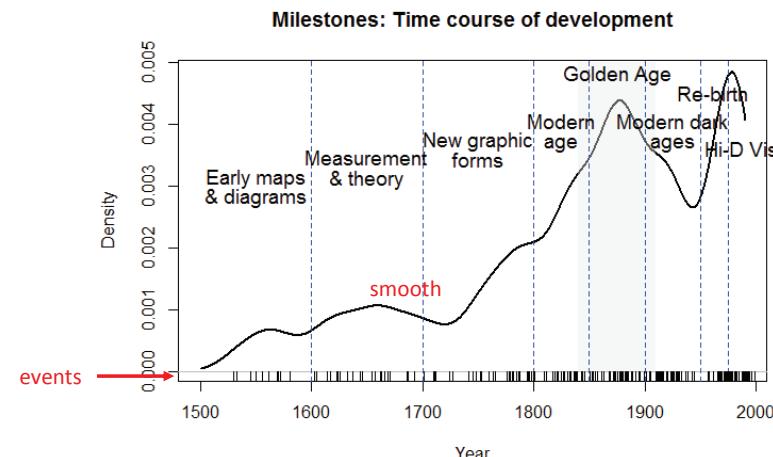


Milestones Tour: Epochs



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 13

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), ...

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Prehistory: Diagrams, graphic stories

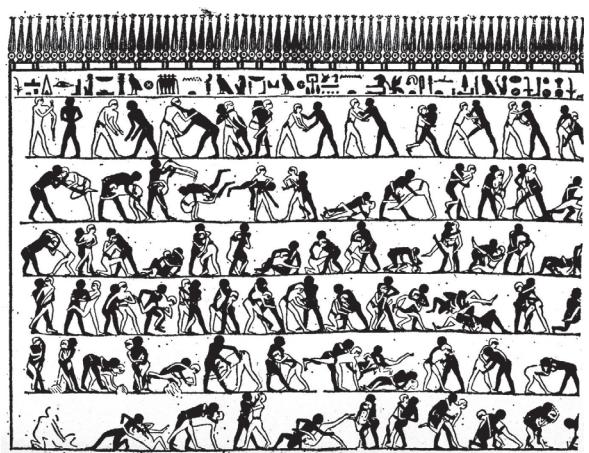
Early Egyptian animated graphic diagram

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

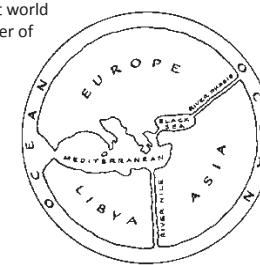
Why? Perhaps Baqt's
last lesson as a
wrestler in his youth
and later as a coach



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Pre 17th C.: Early maps & diagrams

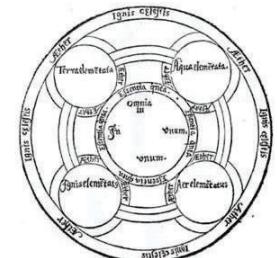
c. 550 BC: The first world map? (Anaximander of Miletus)



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



1305: Mechanical diagram of
knowledge- Ramon Llull,
Spain



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

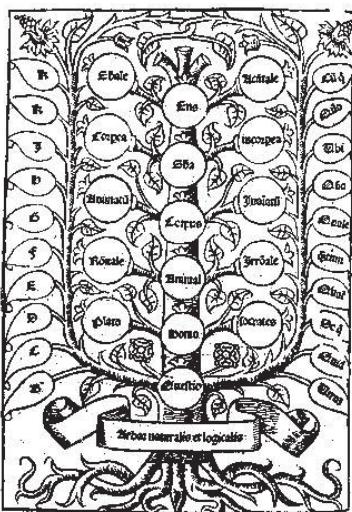
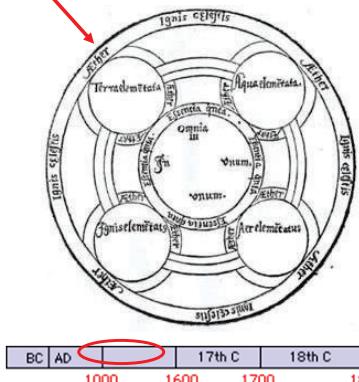
BC AD 1000 17th C 18th C 19th Century 20th Century 2000 16

1305: Mechanical diagram of knowledge- Ramon Llull, Spain

Ars Magna → inspiration for symbolic logic

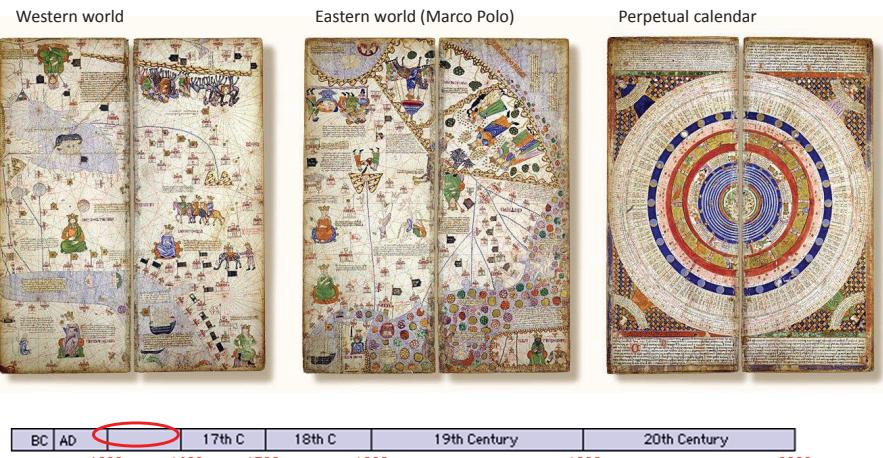
Tree of porphyry: Aristotle's categories of knowledge (center)

- Left: questions
- Right: rotating disks → answers



BC AD 17th C 18th C 19th Century 20th Century
1000 1600 1700 1800 1900 2000 7

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



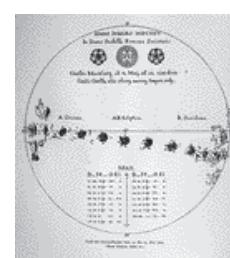
1600-1699: Measurement and Theory

- 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)

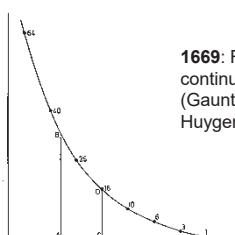
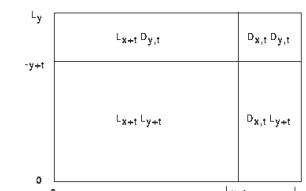
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1600-1699: Measurement and Theory

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 (Gaut's life table)- Christiaan Huygens.

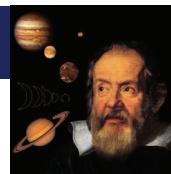
BC AD 1000 1600 1700 1800 1900 2000 20

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

Sunspots: Galileo

1608: telescope (Hans Lippershey, NL)

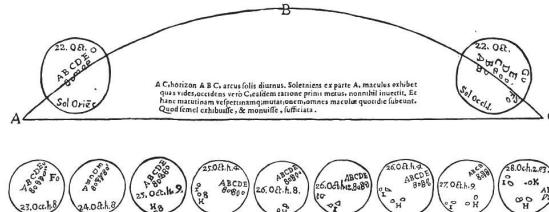
1610: Galileo (*Sidereus Nuncius*)



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

Visual ideas:

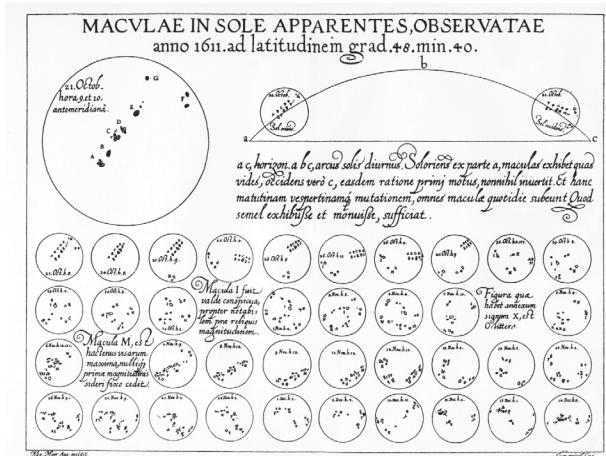
- Animated graphic
- "Small multiples"
- Allows comparison
- Self-explaining diagram



A+ for info design!

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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.

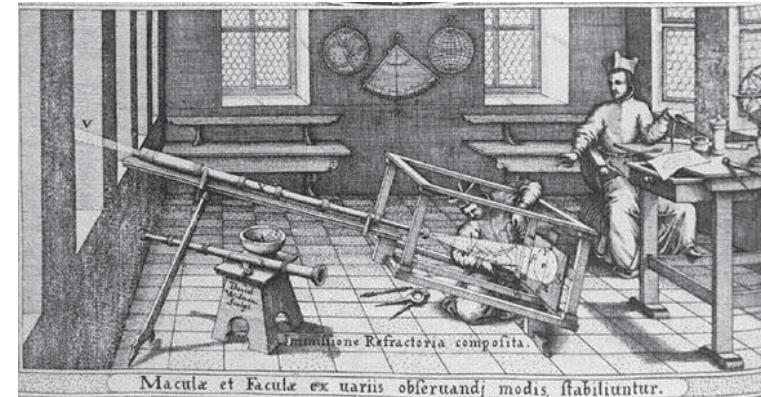
The idea of graphs for visualizing phenomena had arrived.

BC	AD	17th C	18th C	19th Century	20th Century
1000	1600	1700	1800	1900	2000

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Scheiner: systematic recording

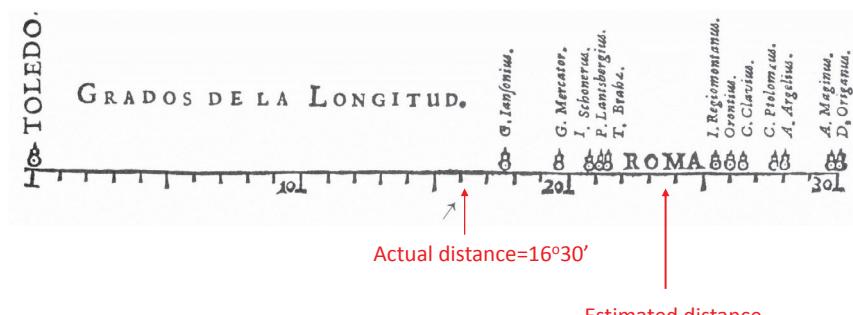
1626: Christoph Scheiner invents helioscope & camera obscura to record sunspots (*Rosa Ursina sive Sol*, 1626-1630)



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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



BC	AD	17th C	18th C	19th Century	20th Century
1000	1600	1700	1800	1900	2000

2000

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	

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- ... 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

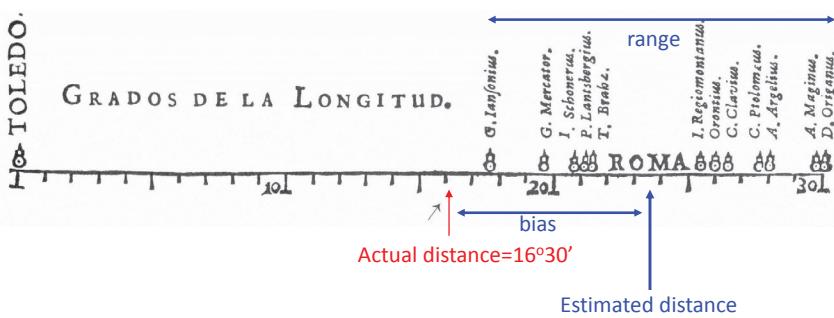
Sorted by Longitude

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	Ortonius	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	

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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 et al (2010). The First (Known) Statistical Graph: Michael Florent van Langren and the "Secret" of Longitude
The American Statistician, 64, 185–191

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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

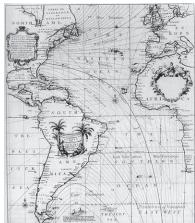
The Big Bang



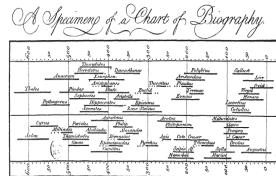
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1700-1799: New graphic forms

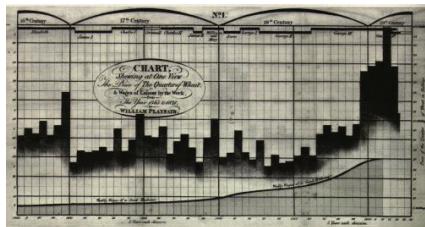
1701: Isobar map, lines of equal magnetic declination – Edmund Halley



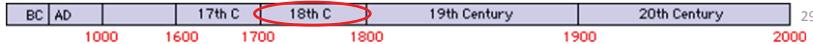
1765: Historical time line (life spans of famous people) Joseph Priestley



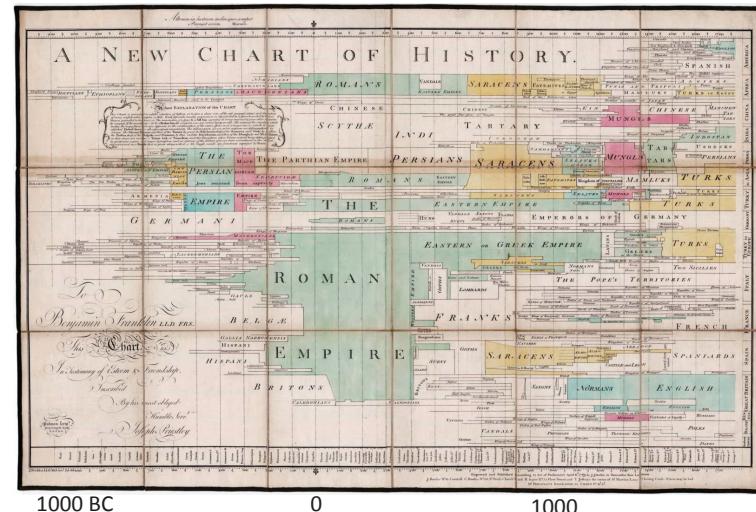
1786: Bar chart, line graphs of economic data- William Playfair



1782: First topographical map- Marcellin du Carla-Boniface



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



America
China

Italy
France
Spain

30

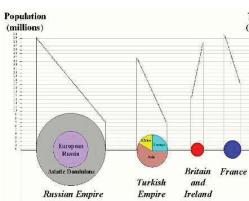
1800-1849: Beginning of modern data graphics

- 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

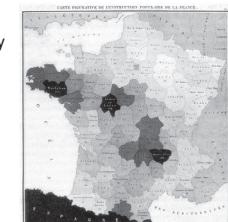


1800-1849: Beginning of modern data graphics

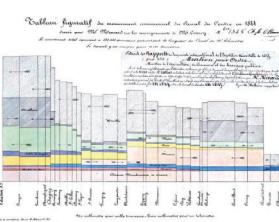
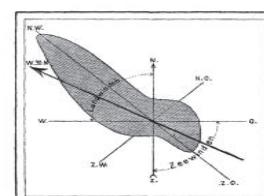
1801: Pie chart, circle graph invented- William Playfair



1826: First modern statistical map (illiteracy in France)- Charles Dupin



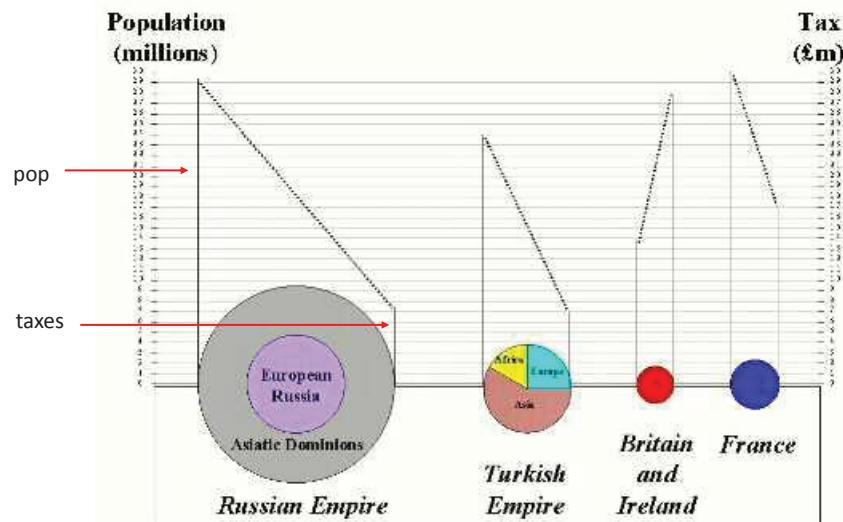
1843: Wind-rose (polar coordinates)- L. Lalanne



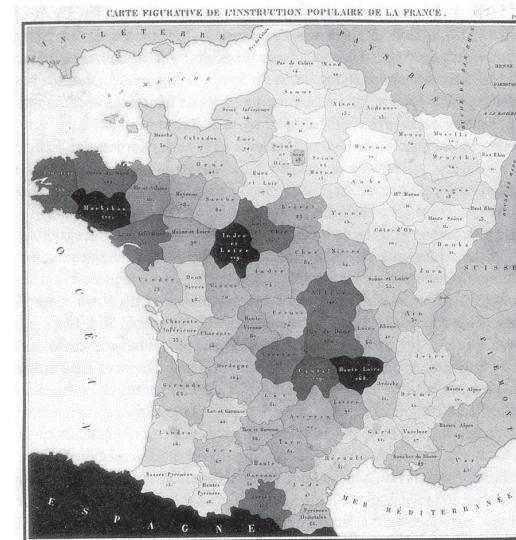
1844: variable-width, divided bars, area ~ cost of transport- C. J. Minard



1801: Pie chart, circle graph invented- William Playfair



1826: The 1st choropleth map, showing the distribution of literacy in France – Baron Charles Dupin

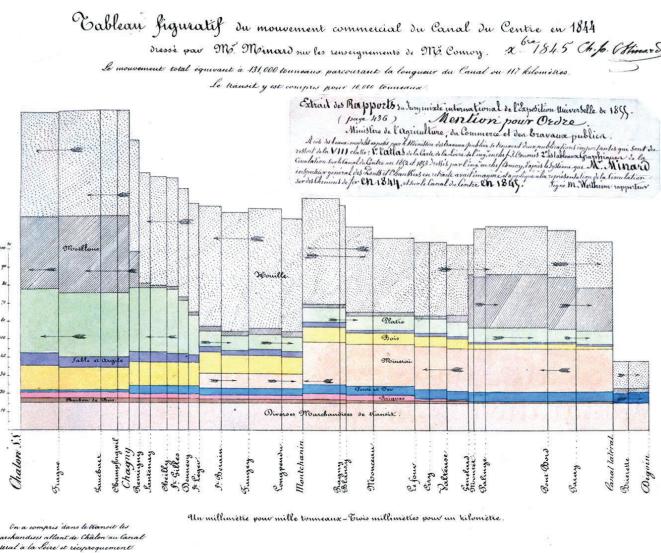


Social variables became:

- visual
- subject to scientific discussion

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

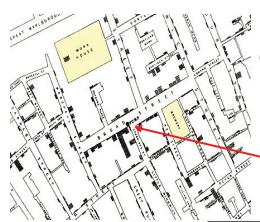


1850-1900: Golden Age

- 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.

BC	AD	17th C	18th C	19th Century	20th Century
		1000	1600	1700	1800

1850-1900: Golden Age

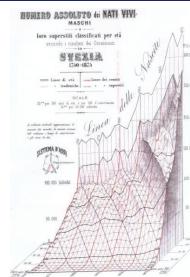


1855: Dot map of disease data (cholera)- John Snow

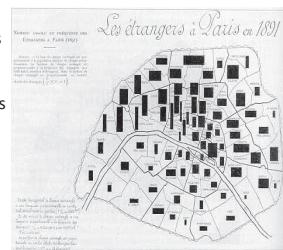


1884: Recursive multi-mosaic on a map- Emile Cheysson

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



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



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 $\frac{1}{2}$ 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

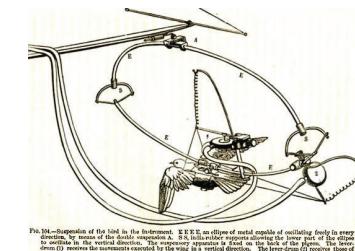


Source: <https://lightsmellscloud.wordpress.com/tag/etienne-jules-marey/>

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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*

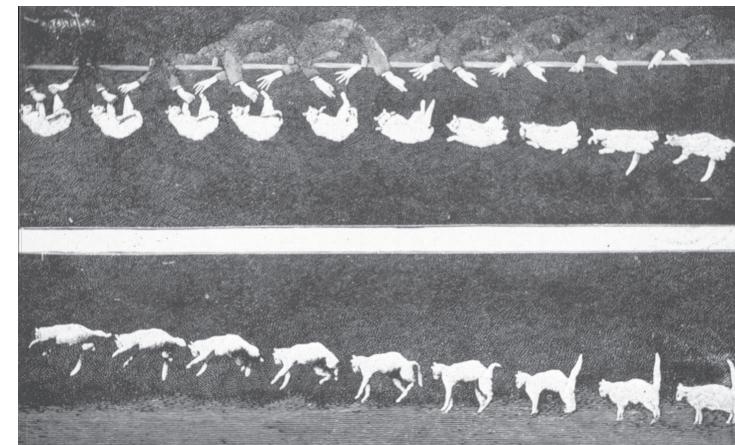
Fig. 14.—Suspension of the bird in the instrument. E E E E: an ellipse of metal wire of oscillating freely in every direction in the vertical direction. The suspensory organ is fixed on the back of the plumb. The lever of the horizontal movement is suspended by the ring at a vertical division. The lever itself records those of the horizontal movements.

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The Falling Cat Problem

Another fundamental problem answered by chronophotography:

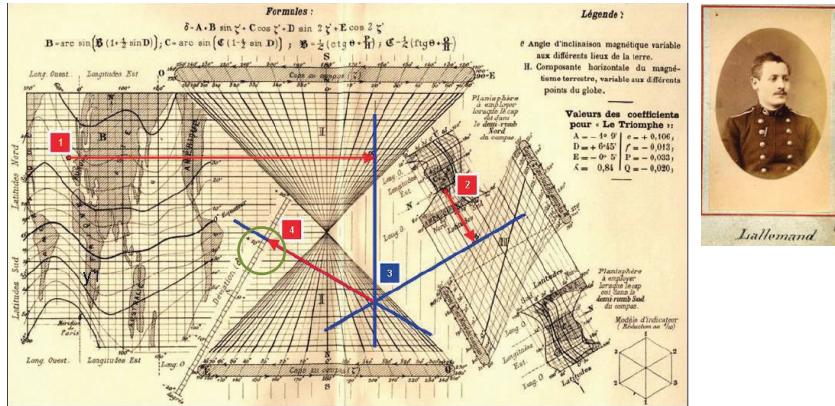
- How does a falling cat usually land on her feet? An OMG moment!



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Nomography

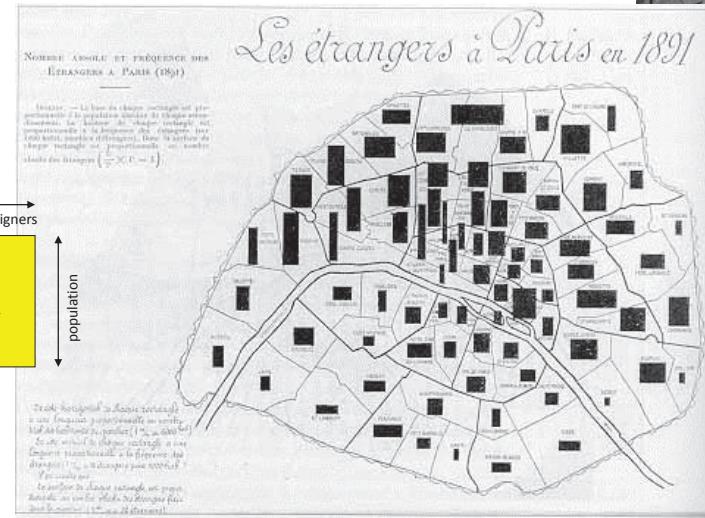
1885: Charles Lallemand, graphical calculator for compass course corrections of a ship at sea
combines: anamorphic maps, hexagonal coordinates, trigonometric scales (5 eqns)



<https://deadreckonings.files.wordpress.com/2010/05/lallemandhexagonalcharttriangularcoordinates.pdf>

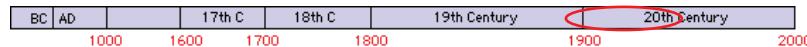
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1896: Area rectangles on a map to display two variables and their product- Jacques Bertillon



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*



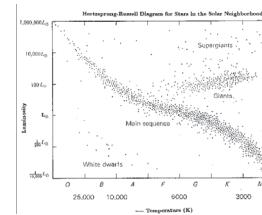
1924: ISOTYPE method of pictorial graphics—Otto Neurath



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



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



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

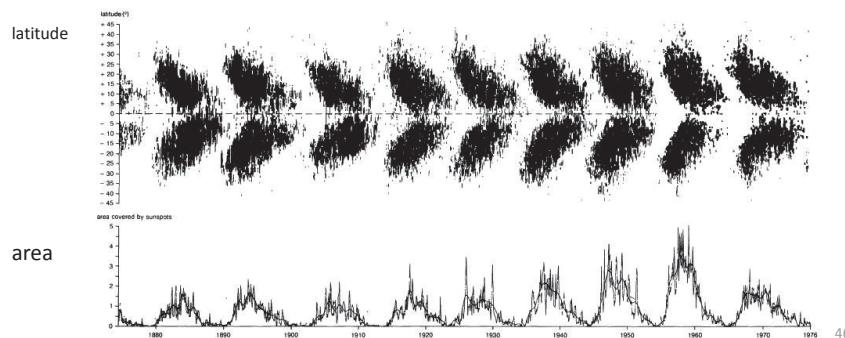


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Maunder: Butterfly diagram

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)



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

heatmap

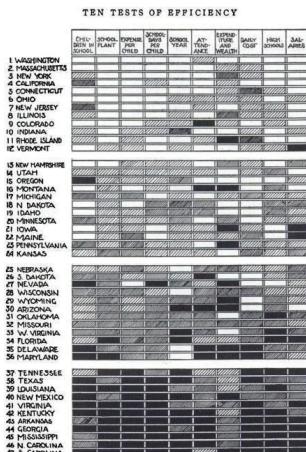


Fig. 33. Rank of States in Each of Ten Educational Features 1910. White Indicates That the State Ranks in the Highest 12, Light Shading that it Ranks in Second 12, Dark Shading that it Ranks in Third 12, and Black that it Ranks in Lowest 12

pictogram

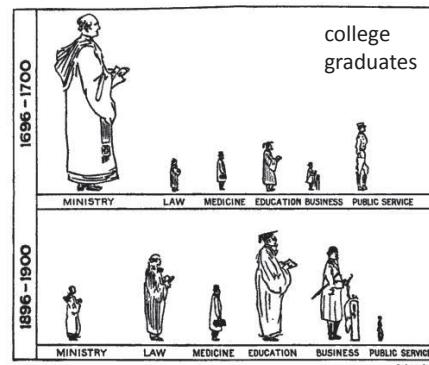


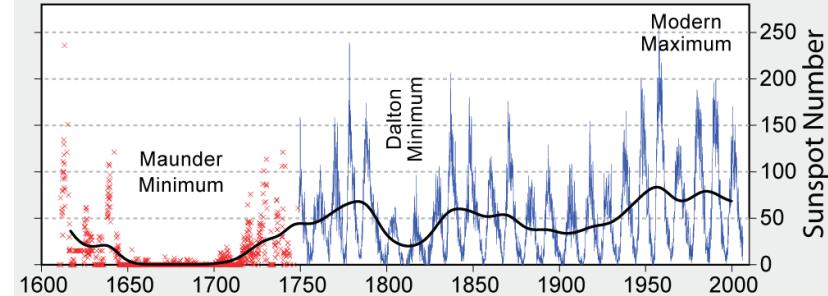
Fig. 39. Proportion of College Graduates in Different Professions in 1696-1700 and in 1896-1900
Charts of this kind with men represented in different sizes are usually so drawn that the data are represented by the height of the man. Such charts are misleading because the area of the pictured man increases more rapidly than his height. Considering the years 1696-1700, the pictured minister has about two and one-half times the area of the man representing public service. The minister looks over-imported, 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.

Maunder: Butterfly diagram

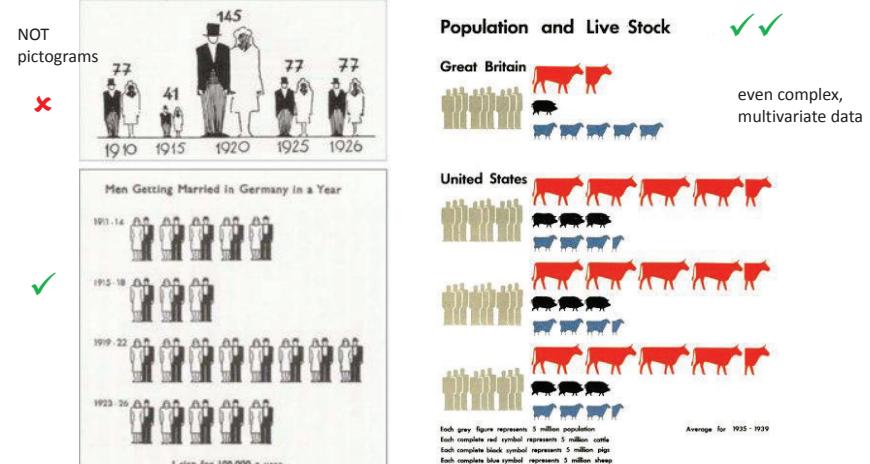
1904: E.W. Maunder plots distribution of sunspots in sun's latitude by time

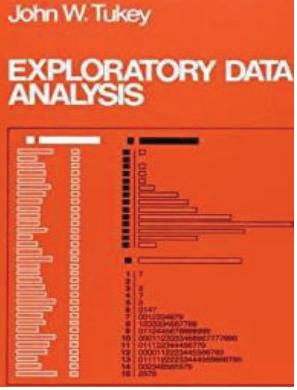
- Discovery of “Maunder minimum” (1645-1715): “Little Ice Age”
- Smoothing reveals other extrema

400 Years of Sunspot Observations

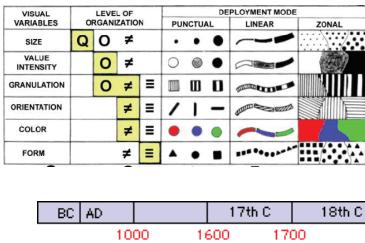


1924: Otto Neurath developed the **Isotype** (International System of Typographic Picture Education) method to communicate statistical information to the broad public in an intuitive, pictorial way.





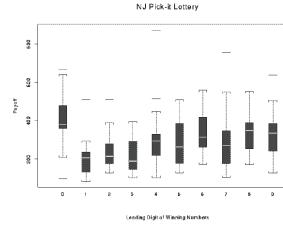
1950-1974: Re-birth of graphics



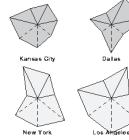
- Visualization began to rise from dormancy in the mid 1960s, spurred largely by:
 - J. W. Tukey's *Exploratory Data Analysis*: The power of graphics to show the unexpected in data analysis
 - Jacques Bertin's *Semiologie Graphique*: A general theory of composing graphs and maps
 - computer hardware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

1950-1974: Re-birth of graphics

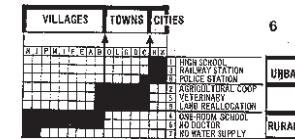
1969: Graphical innovations for EDA (stem-and-leaf, box-plots, etc.)- J.W. Tukey



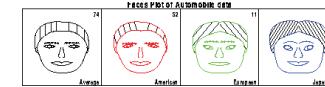
Multivariate glyphs



1971: Star plots- J. H. Siegel et al



1967: Reorderable matrix- Jacques Bertin

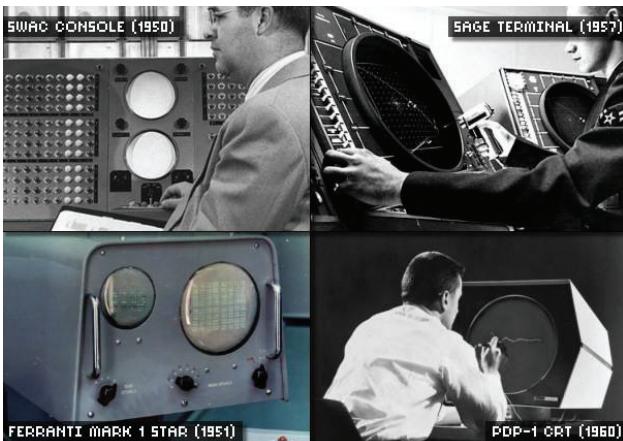


1973: Face plots- Herman Chernoff

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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 → bitnet → file sharing (FTP) → www (HTML) → Java → javascript
 - data: open data initiatives (~1995) → APIs (census, health, ...)
 - eCommerce: Amazon, Netflix, ... → BIG data, recommender systems
- Software
 - Graphics packages: SYSTAT, Data Desk, XGobi, ViSta
 - Statistical packages: SAS, SPSS
 - Statistical programming environments: R, matlab, Stata
 - Contributed package archives: CTAN (latex), CPAN (perl), CRAN (R)
 - Collaborative development sites: github, bitbucket, ...

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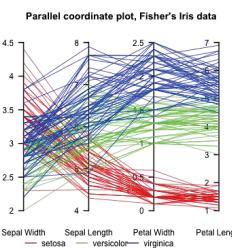
1975-present

Themes in data visualization:

- high-D problems of progressively higher dimensions
 - grand tour: n-D → 2D projections
 - Dimension reduction methods (PCA, MDS, biplots)
- graphics & methods for other data types:
 - categorical, frequency data,
 - networks, trees, ...
 - text (word clouds, ...)
 - spatial data & models
- interactive data vis
 - linked views
 - direct manipulation: select, zoom, filter
 - dynamic graphics & animation

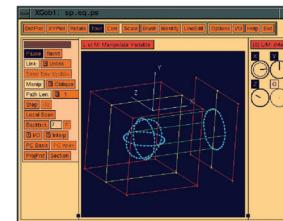
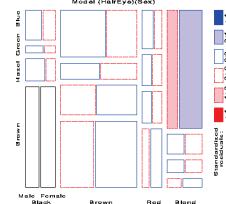
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1975-present



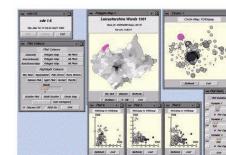
1985: Parallel coordinates plots for high-D data-Alfred Inselberg

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



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Tukey: PRIM-9

1973: a group at the Stanford Linear Accelerator developed PRIM-9

- Picturing, Rotating, Isolation, Masking in up to 9 dimensions
- \$400K graphic display & keypad; computations on a mainframe, \$500/hr



PRIM-9 Movie: <https://www.youtube.com/watch?v=sN2gCCd2Rr8>

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Next steps: Hardware

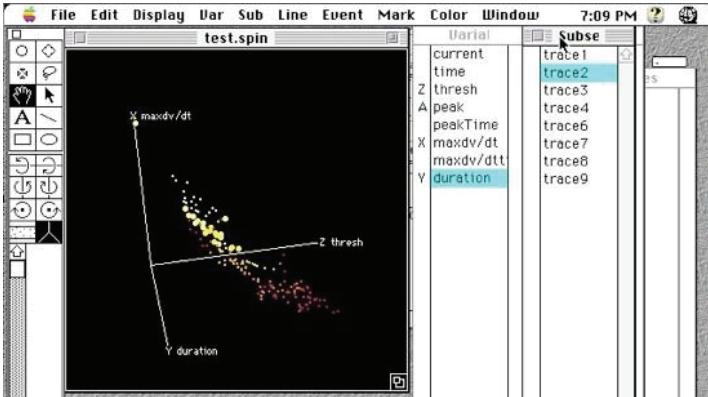
- Dynamic 3D graphics was painfully slow for larger data sets.
- Specialized 3D graphics hardware:
 - Early 1970s: Simple LSI graphics chips for video games
 - 70s–80s: Graphics co-processors (GPUs) with increasing graphics capabilities
 - 80s–90s: Silicon Graphics develops high-performance 3D graphics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



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Software

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

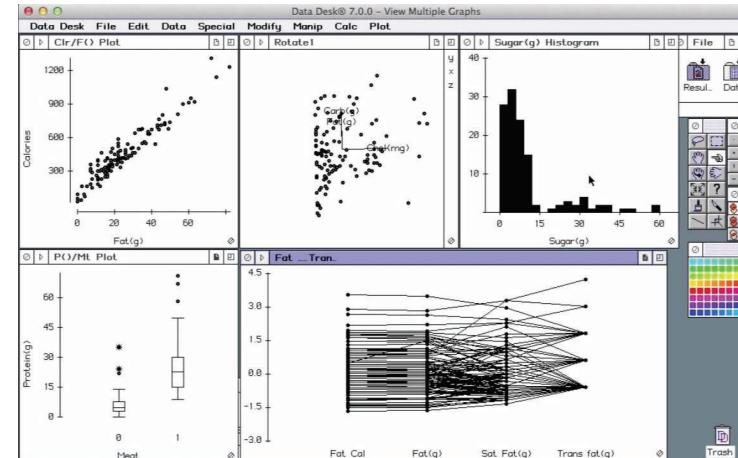


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Linking, brushing, 3D rotation

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

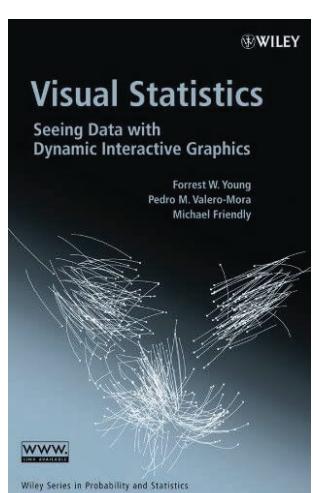


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Visual Statistics



Young, Valero-Mora & Friendly (2006)



A philosophy & pedagogy for statistics based on dynamic interactive graphics

A theory of #dataavis software:

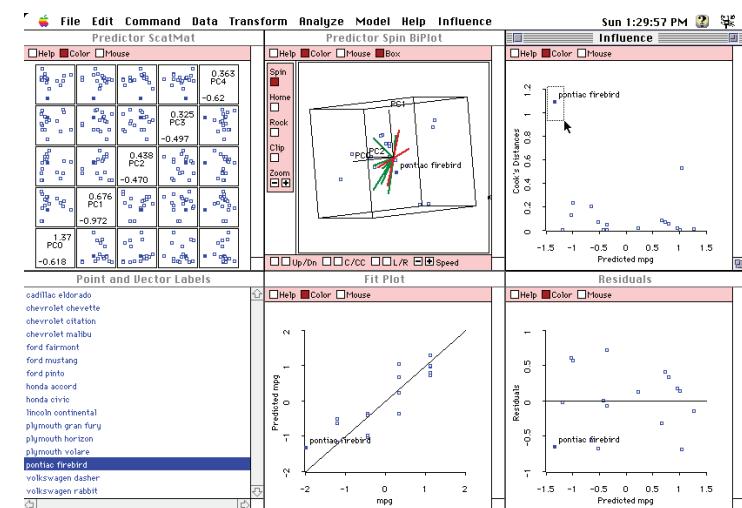
- objects (data, model, ...)
- methods (print, plot,)
- manipulating plot objects & dimensions
- spin plots: rotating 3D plots
- spreadplots: dynamically linked views
- workmaps: visual record of analysis steps

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>

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ViSta: Visual Statistics



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Summary

- 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

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Conclusions

- Why study the history of data visualization?

"The only new thing in the world is the history you don't know" – Harry S. Truman
"Those who cannot remember the past are condemned to repeat it." – George Santayana (*The Life of Reason*, 1905)
"No scientific discovery is named after its original discoverer" – Stigler's Law of Eponomy (1980). But: originally due to Merton!
- Today:
 - Narrow, specialized work in many fields
 - New methods “invented” and re-named w/o knowing history.
 - mosaic displays: Georg von Mayr (1877)
 - heatmaps: Loua (1873); Brinton (1914), Bertin (1967)
 - Nightingale (1859) rose diagram: polar diagrams by Guerry (1829), Lalanne (1843)

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