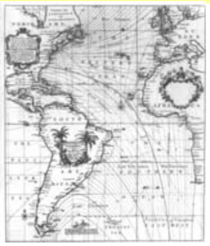
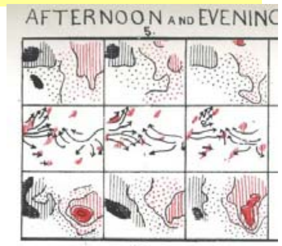
Milestones in the History of Scientific Visualization





Michael Friendly, York University

"Seeing Science", AAAS, Boston, Feb. 18, 2008

Slides: www.math.yorku.ca/SCS/Papers/aaas/

AAAS
ADVANCING SCIENCE, SERVING SOCIETY

Visualization-based scientific discoveries ??

- When have graphics led to scientific discoveries that might not have been achieved otherwise?
  - Snow (1854): cholera as a water-borne disease
  - Galton (1883): anti-cyclonic weather pattern
  - E.W. Maunder (1904): sunspot cycle
  - Hertzsprung/Russell (1911): temperature classes of stars (spectral type)
  - Moseley (1913): concept of atomic number
  - Phillips (1958): "Phillips curve" --- inverse relation between inflation and unemployment
- In the history of graphs, what features led to these?

Vignettes from the history of data visualization

Topics:

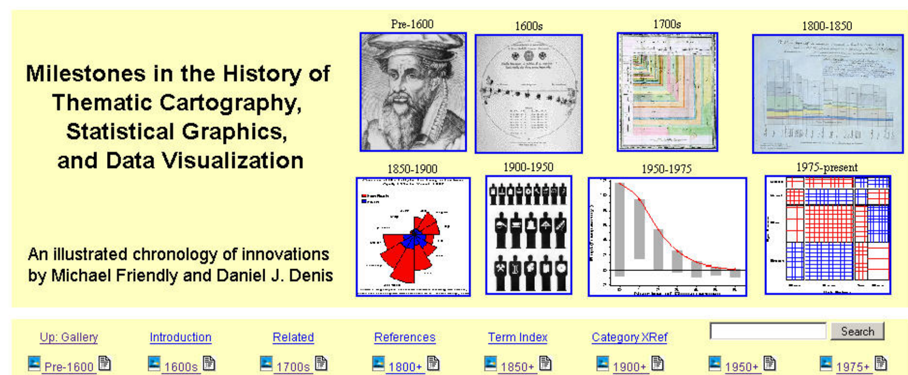
- Early graphical successes
- Sunspots: Galileo → Maunder
- Graphic vision of Minard
- ISOs: Halley → Galton
- Galton's greatest graphical discovery

Themes:

- Visual thinking & explanation
- Escaping flatland
- Mapping the invisible
- Data →Theory →Practice
- Graphical excellence

Context: Milestones Project

www.math.yorku.ca/SCS/Gallery/milestone

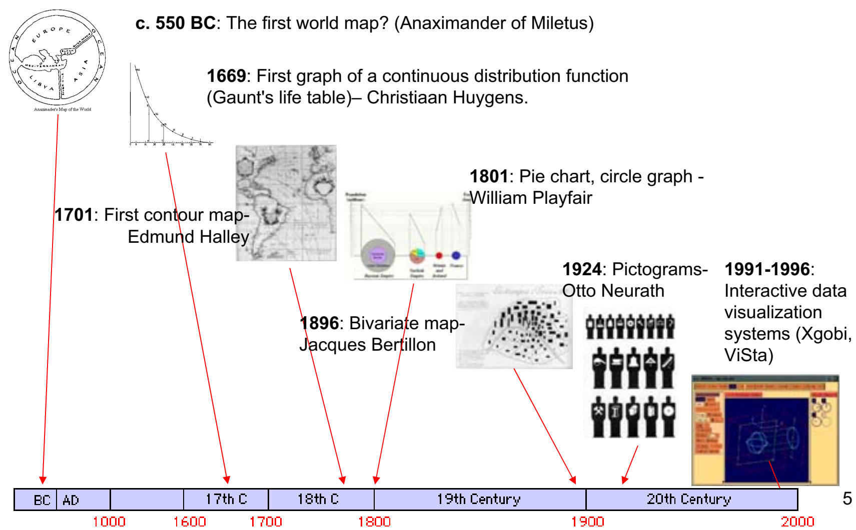


Project goals:

- Comprehensive **catalog** of developments in history of data visualization
- **Tool** to study themes, antecedents, influences, patterns, trends, etc.

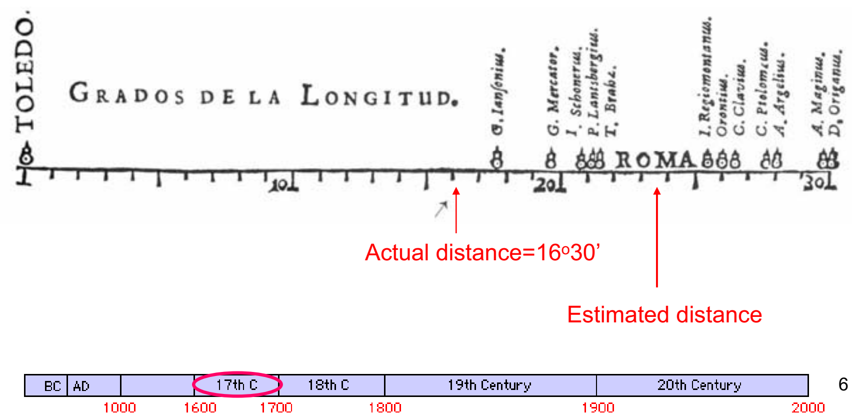
Milestones: Content Overview

Every picture has a story – Rod Stewart



Why the 1st statistical graph got it right

1644: First visual representation of statistical data: determination of longitude between Toledo and Rome- Michel 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

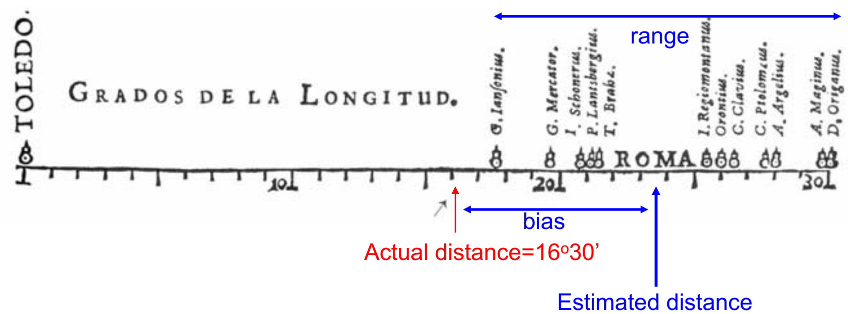
- … he could have sorted by *longitude* to show the *range*.

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

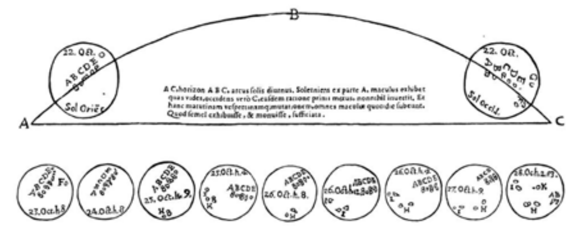


See: Friendly, M., & Kwan, E. (2003). Effect Ordering for Data Displays. *Computational Statistics and Data Analysis, 43*(4), 509--539.

Sunspots: Galileo → Maunder

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

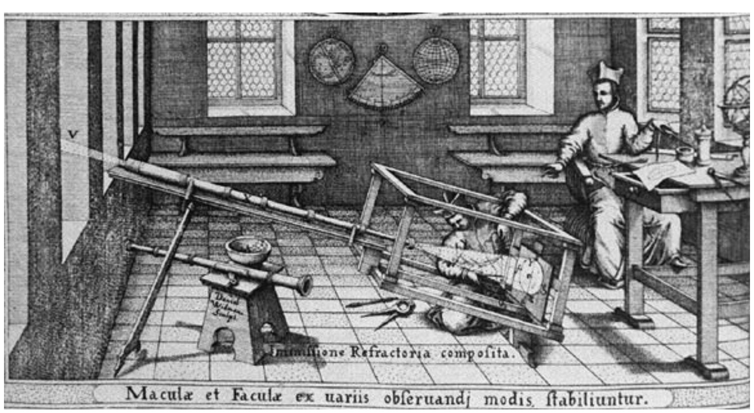
Visual ideas:
- Animated graphic
- “Small multiples”
- Allows comparison
- Self-explaining diagram



A+ for info design!

Scheiner: systematic recording

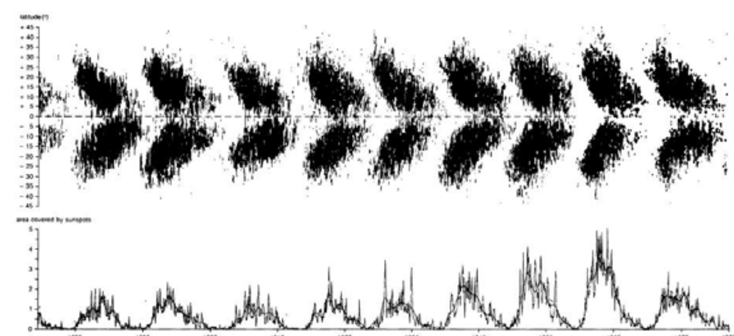
1626: Christoph Scheiner invents helioscope & camera obscura to record sunspots (*Rosa Ursina sive Sol* , 1626-1630)



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)

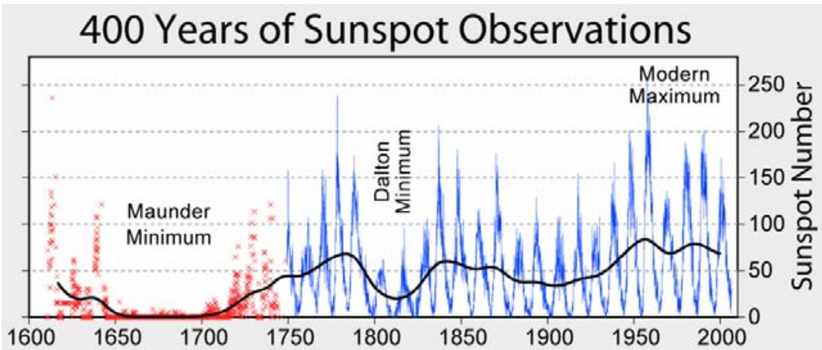


Maunder: Butterfly diagram

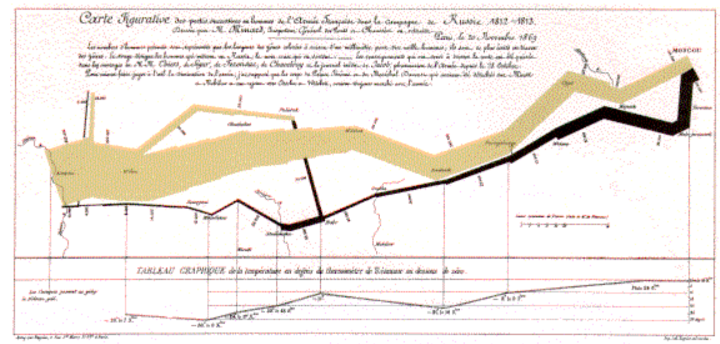
1904: E.W. Maunder plots distribution of sunspots in sun's latitude by time

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

• Smoothing reveals other extrema



The graphic vision of C. J. Minard

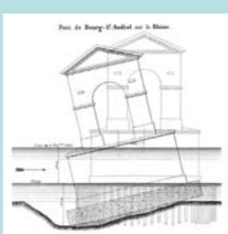


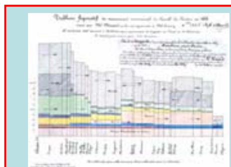
- Marey (1878): *"defies the pen of the historian in its brutal eloquence"*
- Tufte (1983): *"the best statistical graphic ever produced"*

Why Minard?

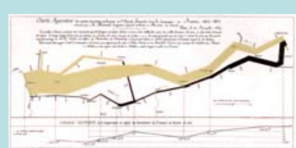
- Study breadth and depth of his work
  - How related to work in his time?
  - How related to modern statistical graphics?
  - How related to his personal history?

Civil Engineer for ENPC (1810-1842)





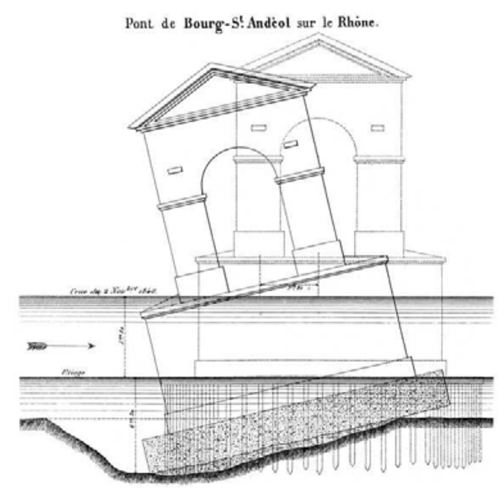
Visual Engineer for France (1843-1869)



Visual thinking, visual explanation

1840: Why did the bridge at Bourg-St. Andèol collapse?

Minard's report consisted essentially of this self-explaining diagram.

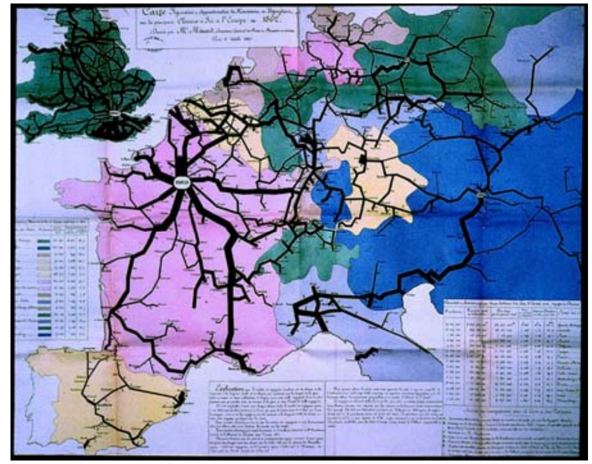


Visual tools for state planning

- 1830—1860: emergence of modern French state, dawn of globalization
- Trade, commerce, transportation:
  - Where to build railroads, canals?
  - Visualizing changes over time, differences over space
  - → Flow maps and other graphical innovations

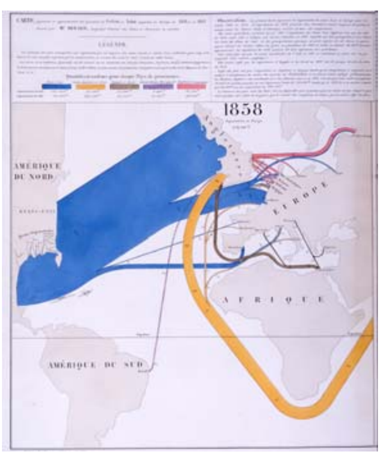
Flow maps as visual tools

Transport of passengers on the principal railroads in Europe in 1862

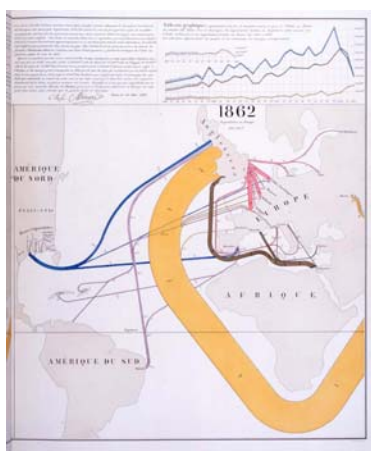


Effect of US civil war on cotton trade

Before



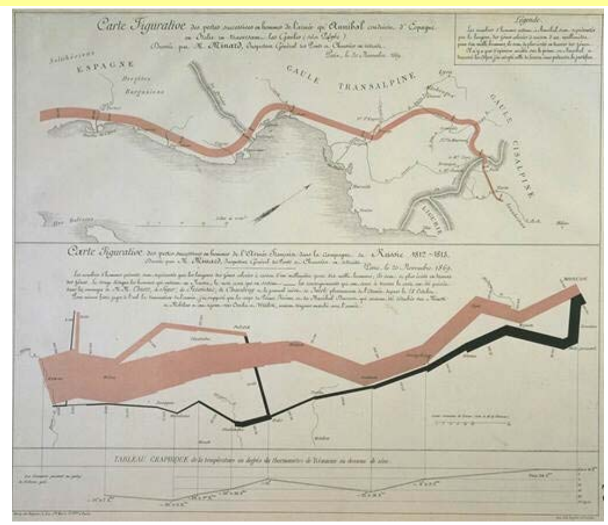
After



The March Re-Visited (1869)

Hannibal's retreat

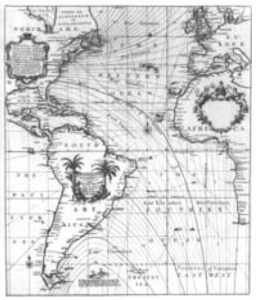
Napoleon's 1812 campaign



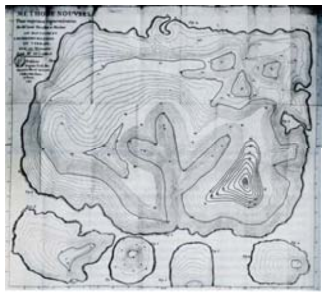
Escaping flatland

3D maps & graphs from Halley to Galton

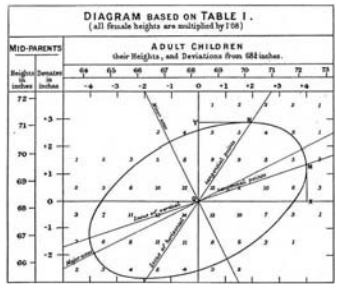
1701: Halley

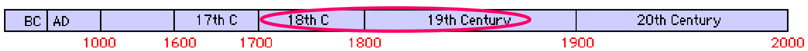


1782: du Carla-Boniface



1866: Galton



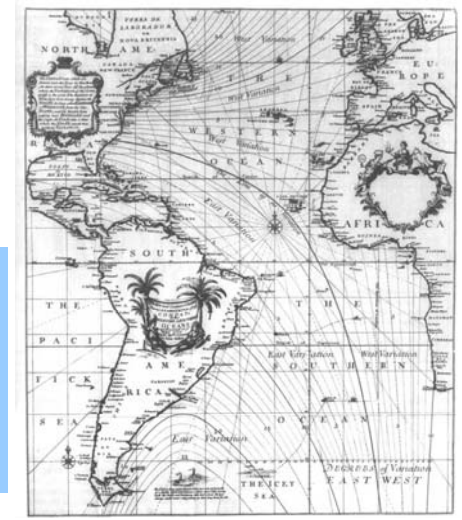


Halley: Mapping the invisible

1701: Halley's contour maps (an isogonic map: lines of equal magnetic declination for the world) -- first thematic contour map of a data-based variable.

Visual ideas:

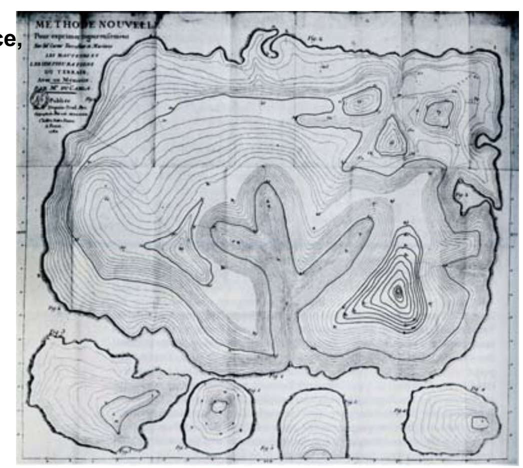
- Smooth curves of equal value
- Depicted an entire corpus of systematic & organized information
- Theory of magnetism → interpolated values where data missing



Topo maps as 3D level-slices

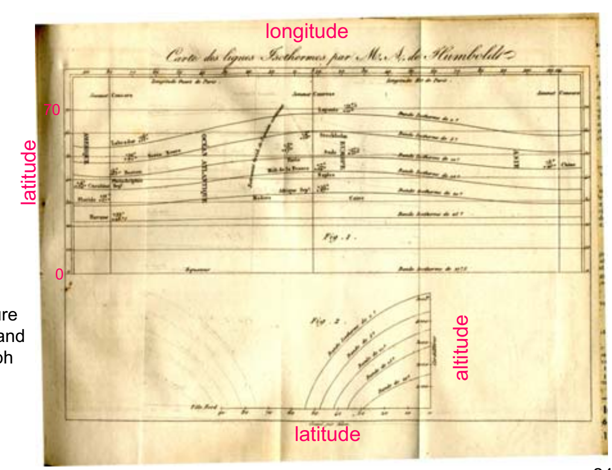
1782: **Marcellin du Carla-Boniface, France**
First topographical map, showing contours of equal elevation.

Visual ideas:
- Contours: horizontal slices of a landscape
- Spacing indicates slope



1817: Alexander von Humboldt (1769-1859) Germany
First **graph** of isotherms, showing mean temperature around the world by latitude and longitude.

Visual ideas:
- average & smooth
- suppress the map
- moderating variable

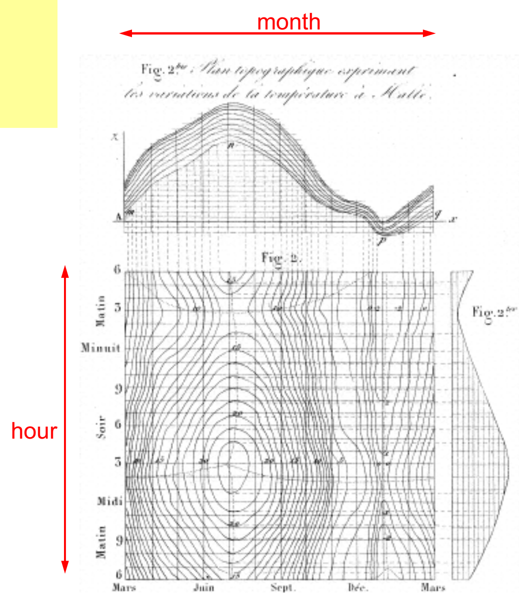


Recognizing that temperature depends more on **latitude** and **altitude**, a subscripted graph shows the direct relation of temperature on these two variables

3D maps → Graphs

1843: Léon Lalanne, France
Contour diagram of a table:
temperature ~ hour x month

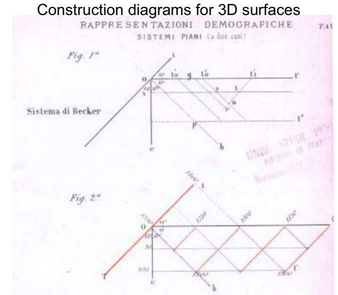
Visual ideas:
- Ordered table like a map
- 3D level curves
- 2D marginal projections
- multiple views: plan, elevation, section

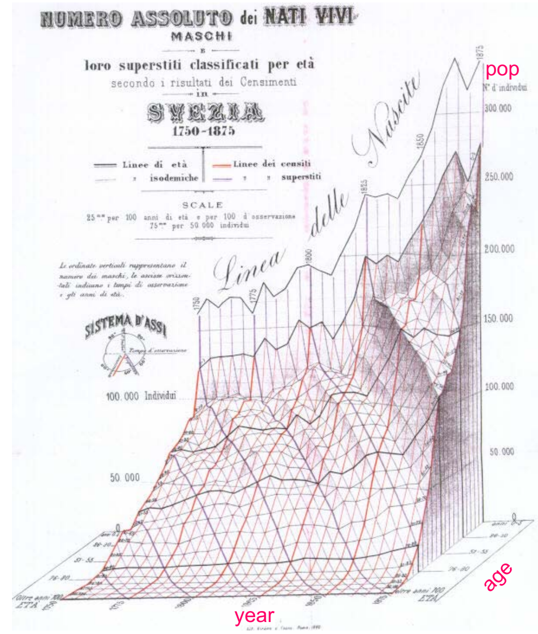


1879: Luigi Perozzo, Italy
Stereogram (3D population pyramid) modeled on actual data (Swedish census, 1750--1875)

Visual ideas:
- isometric projection
- 3D stereogram

Construction diagrams for 3D surfaces





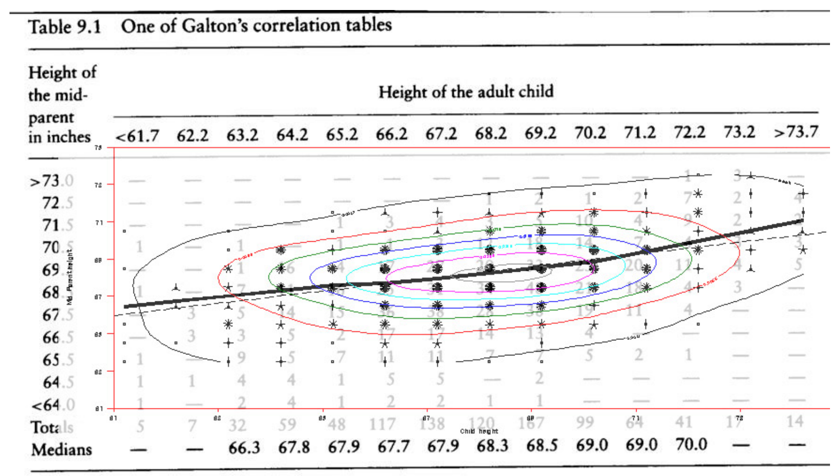
Galton's discovery of the bivariate normal correlation surface (1886)

Table 9.1 One of Galton's correlation tables

Height of the mid-parent in inches	Height of the adult child <61.7	62.2	63.2	64.2	65.2	66.2	67.2	68.2	69.2	70.2	71.2	72.2	73.2	>73.7
>73.0	—	—	—	—	—	—	—	—	—	—	—	1	3	—
72.5	—	—	—	—	—	—	—	1	2	1	2	7	2	4
71.5	—	—	—	—	1	3	4	3	5	10	4	9	2	2
70.5	1	—	1	—	1	1	3	12	18	14	7	4	3	3
69.5	—	—	1	16	4	17	27	20	33	25	20	11	4	5
68.5	1	—	7	11	16	25	31	34	48	21	18	4	3	—
67.5	—	3	5	14	15	36	38	28	38	19	11	4	—	—
66.5	—	3	3	5	2	17	17	14	13	4	—	—	—	—
65.5	1	—	9	5	7	11	11	7	7	5	2	1	—	—
64.5	1	1	4	4	1	5	5	—	2	—	—	—	—	—
<64.0	1	—	2	4	1	2	2	1	1	—	—	—	—	—
Totals	5	7	32	59	48	117	138	120	167	99	64	41	17	14
Medians	—	—	66.3	67.8	67.9	67.7	67.9	68.3	68.5	69.0	69.0	70.0	—	—

Source: Galton (1886), p. 68.

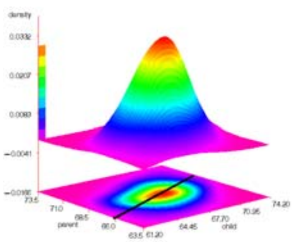
Visual smoothing → Insight



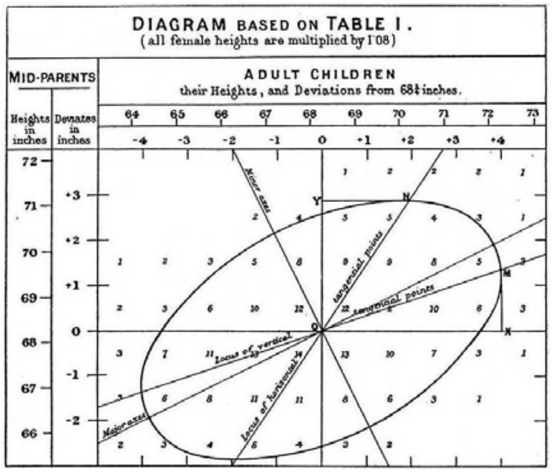
Source: Galton (1886), p. 68.

Visual insight → Theory

- Level curves are **ellipses**
- Regression lines are loci of conjugate **tangents**



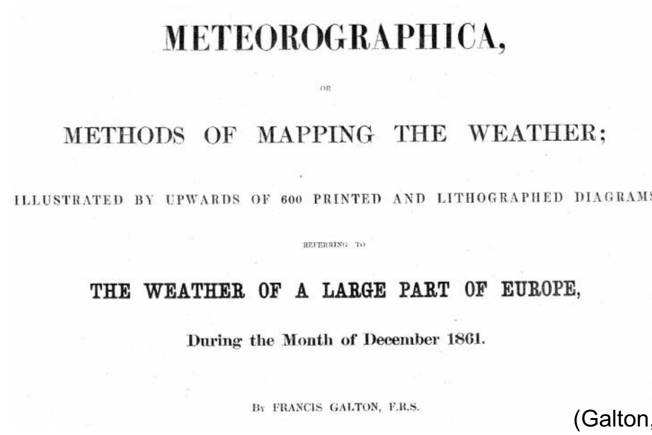
… that Galton should have evolved all this … is to my mind one of the most note-worthy scientific discoveries arising from analysis of pure observation (Pearson 1920, p37)



Galton (1886, Pl X): Smoothed contours of heights of parents and children

Galton's discovery of weather patterns-

Perhaps the most notable *purely graphic* discovery ever!



METEOROGRAPHICA,

OR

METHODS OF MAPPING THE WEATHER;

ILLUSTRATED BY UPWARDS OF 600 PRINTED AND LITHOGRAPHED DIAGRAMS

REFERRING TO

THE WEATHER OF A LARGE PART OF EUROPE,

During the Month of December 1861.

BY FRANCIS GALTON, F.R.S.

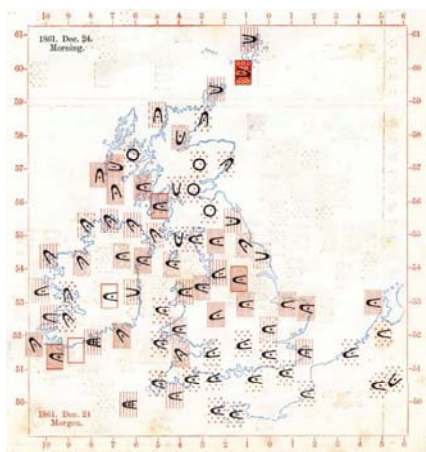
(Galton, 1863)

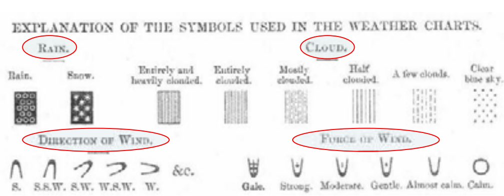
Method: All weather stations across Europe asked to record data 3x/day for all of Dec., 1861

Data: recordings of barometric pressure, wind dir/speed, rain, temp., cloud: 3x/day, 50 weather stations in Europe.

Graphic analysis: 3x31=93 maps, each with multivariate glyphs showing all variables

Visual ideas:
- Iconic symbols
- Multivariate glyphs (stamps!)

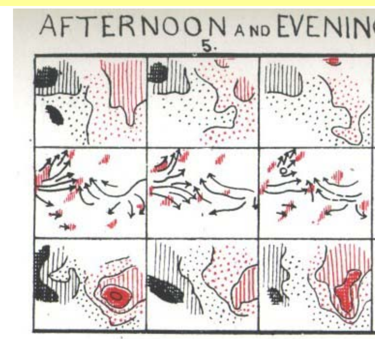




Visual abstraction → Patterns

What varies with what, over time and space?

- mini, abstract maps: vars x TOD
- iso-contours, shading to show equivalence
- arrows to show wind direction



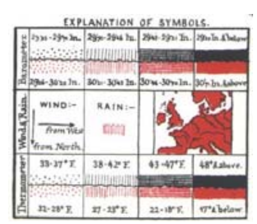
pressure

wind, rain

temperature

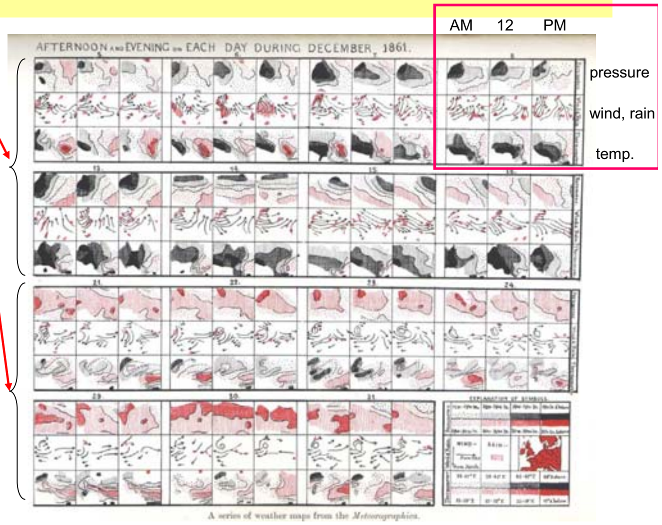
AM noon PM

Data for Dec 5, 1861



The large picture → Insight

Pattern:
Low pressure (black) in early Dec. → CCW wind
High pressure (red) in late Dec. → CW wind



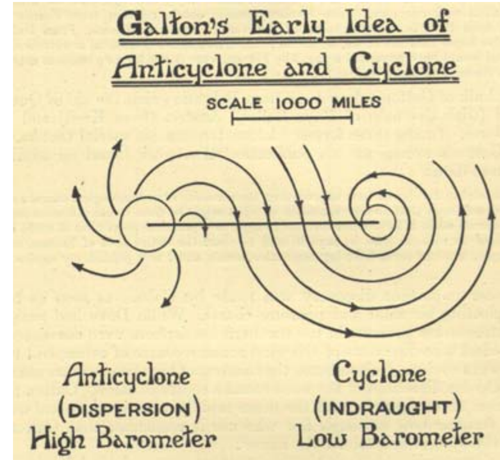
Graphic: 3x3x31 grid, mapping {pressure, wind/ rain, temperature} x {AM, 12, PM} x day {1:31}

(try this with your software!)

Visual insight → Theory

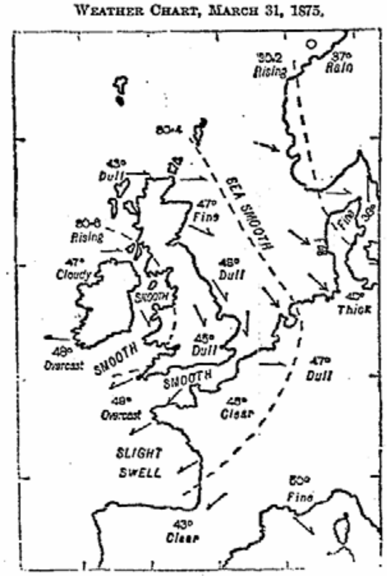
Visual insight from 93 (3x31) high-D graphs:
- Changes in wind dir w/ pressure over time
- → Winds revolve inwardly (CCW) in low pressure areas– as in a cyclone;
- → revolve outwardly (CW) in high pressure areas– "anti-cyclone"

Theory:
- Explained by Dove's 'Law of Gyration'
- Prediction: reversed pattern (CW/CCW) in southern hemisphere – confirmed!



Theory → Practice

WEATHER CHART, MARCH 31, 1875.



The dotted lines indicate the gradations of barometric pressure. The variations of the temperature are marked by figures, the state of the sea and sky by descriptive words, and the direction of the wind by arrows—barbed and feathered according to its force. ⊙ denotes calm.

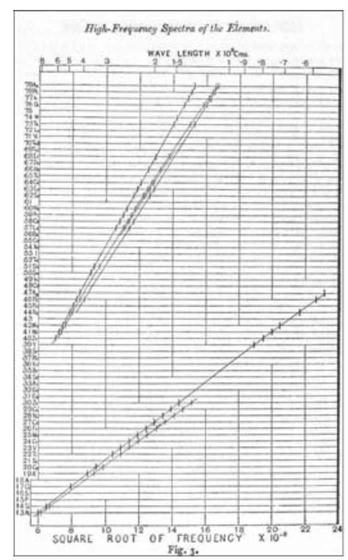
The first modern weather map, *London Times*, Apr. 1, 1875

Galton did for weathermen what Kepler did for Tycho Brahe. This is no small accomplishment. (Wainer 2005)

Moseley's discovery of atomic number

1913: Henry Moseley
Plot of serial numbers of elements vs. square root of frequencies from X-ray spectra:

- linear relations → periodic table better explained by atomic number than weight (serial # must have a physical basis).
- gaps in series → predicted existence of several undiscovered elements!
- multiple lines later explained with discovery of the spin of electrons.



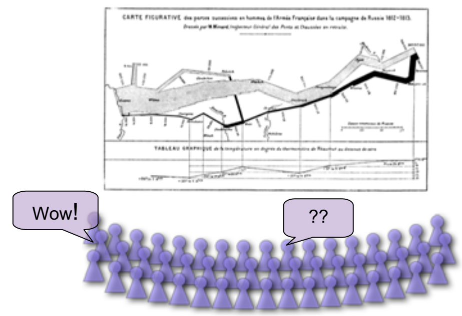
The hallmark of good science is the discovery of laws that unify & simplify findings, and allow prediction of yet unobserved phenomena.

Conclusions

- In the history of science, visualization often:
  - … proved crucial in discovery
  - … provided simple explanations for complex phenomena
- Notable examples in this history illustrate …
  - Importance of **visual thinking**
  - **Interoccularity**: message hits you between the eyes
  - Role of **smoothing** in seeing patterns, gaining insight
  - Necessity to **escape flatland**:
    - Progress in display of increasingly rich and complex data
  - Data → Visual abstraction → Theory → Practice

Graphs: Different strokes for different folks

Two roles for data visualization in science



Presentation

Goal: the Wow! experience
Single image for a large audience

Exploration & analysis

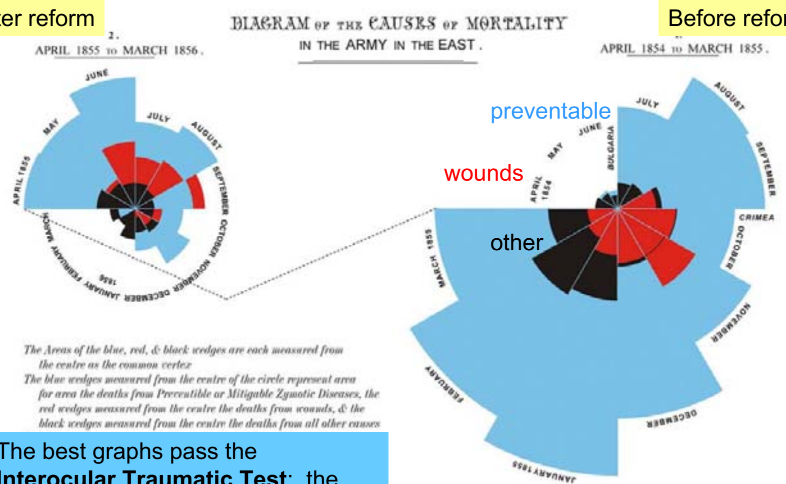
Goal: the Ah ha! Experience

Many images, for a narrow audience (you!), linked to analysis

Presentation graph: Nightingale (1857)

After reform

Before reform



The best graphs pass the **Interocular Traumatic Test**: the message hits you between the eyes!