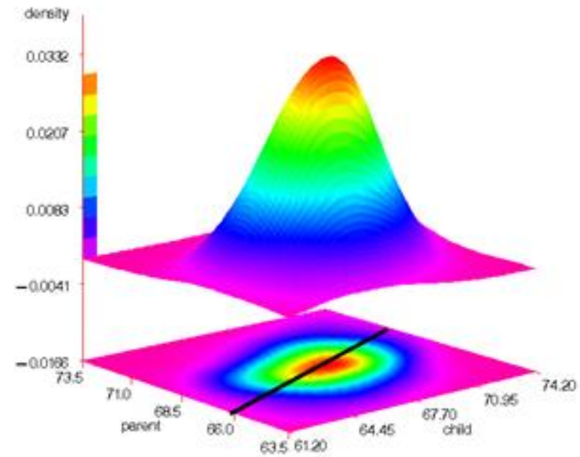


A gleam in the mind’s eye

Stories & lessons from the history of data visualization

Société statistique du Canada Statistical Society of Canada

Michael Friendly

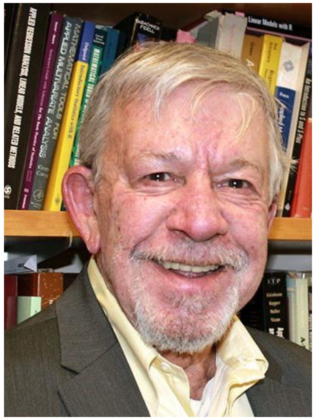
SSC 2021 June 11, 2021

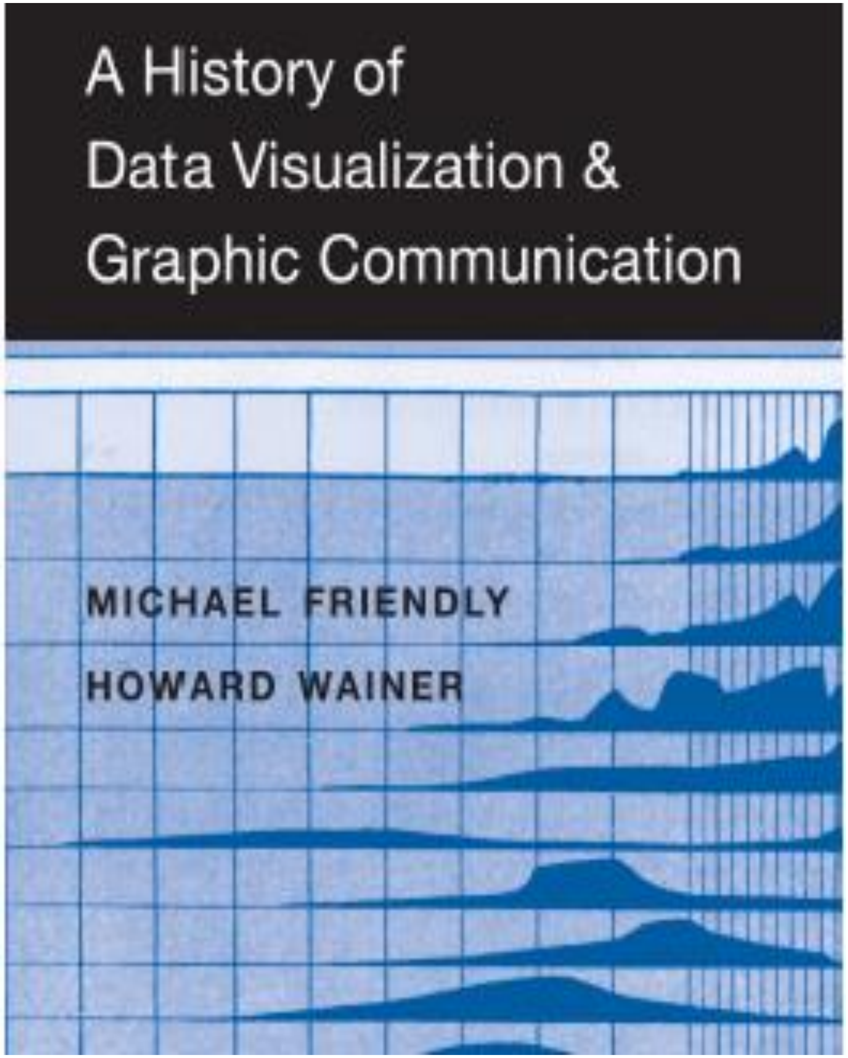
YORK UNIVERSITÉ UNIVERSITY

Obligatory shameless plug

This talk is based on our new book, Harvard University Press,

June, 2021





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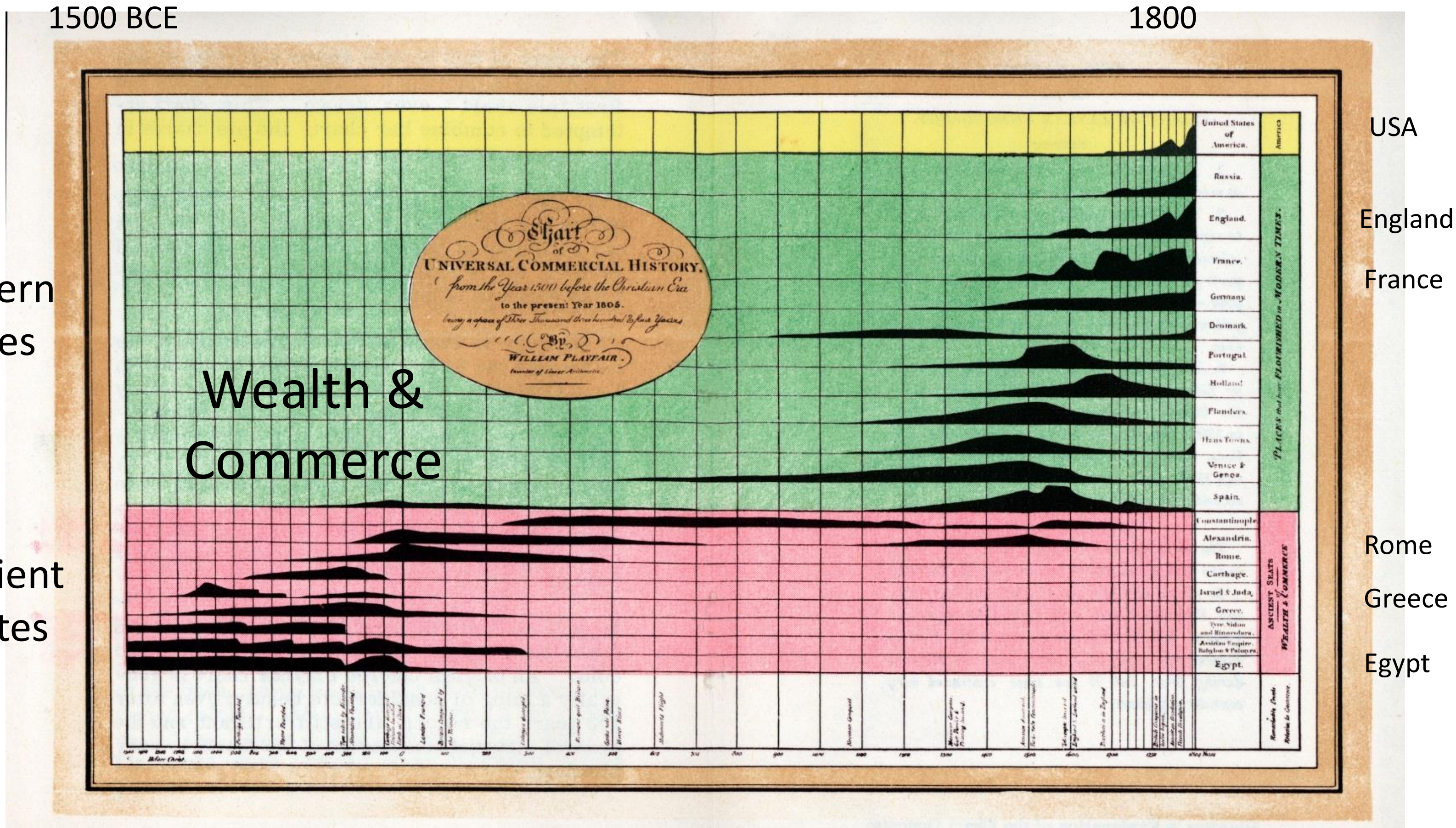


Cover image: William Playfair (1805), *Chart of Universal Commercial History*.
Q1: How and when did civilizations rise and fall from 1500 BCE to 1800 AD?
Q2: Why? How to explain?

Larger Q: How to visualize history?
Why is this a remarkable graph?

A long view of history

Main arguments: Elevator pitch

Much of the history of data visualization can be seen as a combination of:

- important scientific & social questions of the day
- rise of empiricism for understanding natural phenomena
  - a developing abundance of data
  - need/desire to find regularities, discover laws
- cognitive abilities of some heroes to conceive of solutions by visual imagination & reasoning
  - visual thinking
  - a "gleam in the mind's eye"

Plan for today

- Introduction: Context for history of data vis
  - Data visualization today: problems & challenges
  - Orienting Qs: When & why did visualization arise?
- Prehistory of visualization
- Some stories of the rise of visual thinking

Datavis today: Problems & challenges

- Today: Immersed in a sea of data
  - COVID, fitness trackers, election polls, economic forecasts, what’s trending on Twitter
- Big data, complex, high-dimensional problems
  - Personal:
    - how to monitor my heart health? blood sugar?
    - how to manage my investment portfolio?
  - Societal:
    - Tracking disease outbreaks of COVID, measles, Ebola, etc.
    - Understanding crime, gun violence, poverty, etc.
    - Effects of climate change on extreme weather, forest fires, etc.
- How can data vis help?
  - Role of graphics in communication & persuasion?

Powerful graphs: Measels and vaccines

Visualizing the impact of health policy interventions

In 2015 Tynan DeBold & Dov Friedman in the *Wall Street Journal* show the effect of the introduction of vaccination programs in the US states on disease incidence, using color-coded heat maps for a variety of diseases

Before: 17.0 M cases, 1926--1963

After: 1.7 M cases, 1963--2015

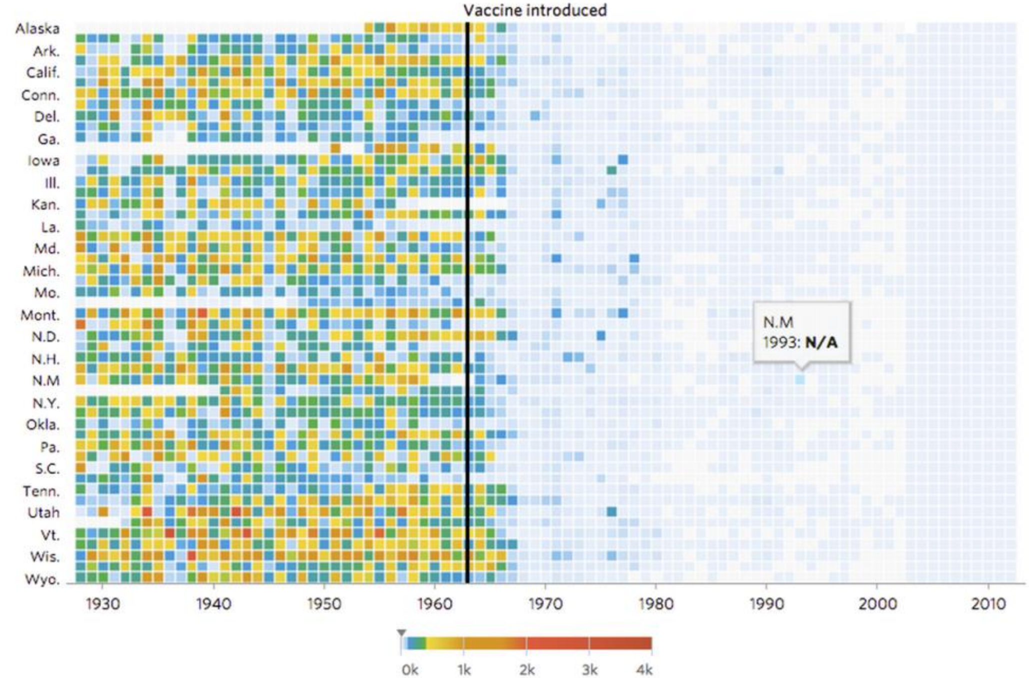
Measles was decimated!

The message hits you between the eyes!

Powerful graphs make comparison easy

In 2014, vaccination rates declined and measles re-emerged in those areas

Effective graphs can cure ignorance, but not stupidity.



Source: http://graphics.wsj.com/infectious-diseases-and-vaccines/

Orienting Questions

- Visualization in prehistory?
  - When did pictorial, symbolic representation arise?
  - Why? What purpose did it serve?
- How did graphic depiction of numbers ("data") arise?
- Why?
  - What purpose did it serve?
  - What were the scientific questions promoting this?
  - How did graphic inventions make a difference?

Prehistory of visualization

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

Lascaux II, Main chamber (Montignac, France)

Lascaux: What were they thinking?

Lascaux II, Chamber of the Bulls

- Visual features:
  - shows 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

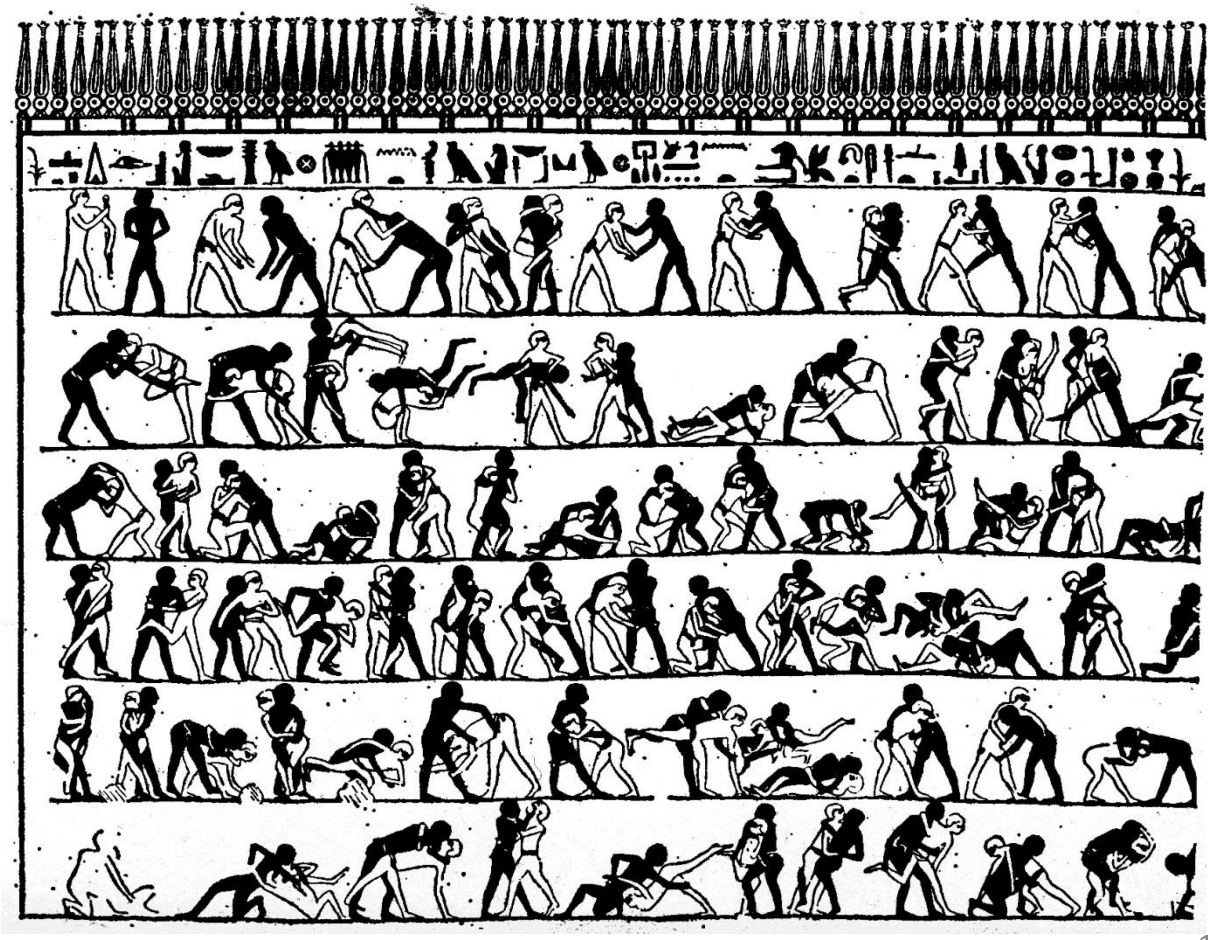
Early Egyptian animated graphic diagram

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



Visualizing the known world

A next step in visual thinking was to visualize **space** beyond what the eye could see.
How to show visually what we know about the known world?
This was the origin of maps.

The epic poems of Homer, the *Iliad* and the *Odyssey* told stories of the Mycenaean Greeks, ~1600-1100 BCE: The siege of Troy, return of Odysseus to Ithaca & Penelope.

But only in words.

This early Babylonian world map, from ~ 600 BCE showed the known world in a circular form that would become the commonplace representation.

Stories of the rise of visual thinking

Stories:

- M.F van Langren & the "secret" of Longitude
- A.-M. Guerry & the rise of social science
- Graphic vision of Minard
- Galton's graphical discoveries

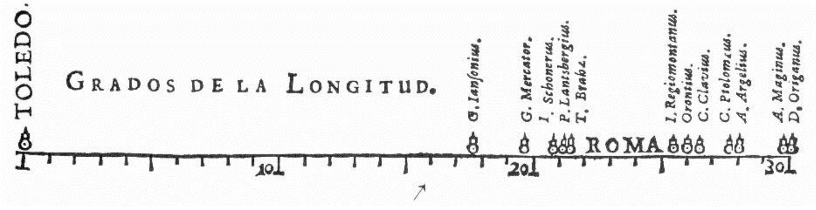
Themes:

- The idea of a GRAPH
- The birth of DATA
- Visual solutions to practical & scientific problems
- Visualization → Theory (graphic discovery)
- Data → Theory → Practice
- Escaping Flatland: 2D→ 3D

1. The IDEA of the Graph

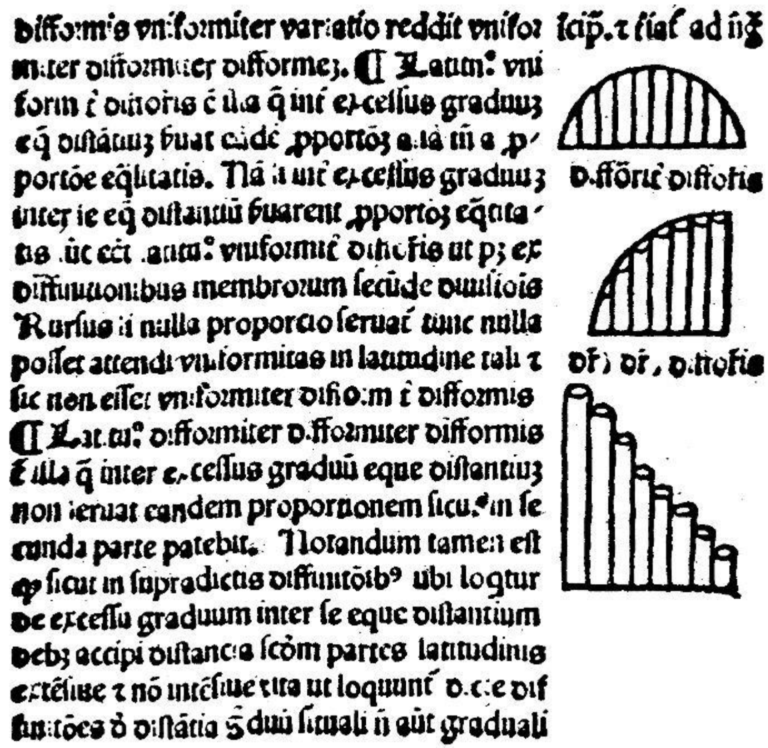
- When did the idea of an abstract visual representation of statistical data arise?
  - What made this special, as distinct from earlier graphical forms?
- What was the first instance of something we can call a graph of data?
  - What does this tell us about the rise of visual thinking?

Hero of this story:
Michael Florent van Langren
- B: Apr. 1598 (Amsterdam)
- D: May 1675 (Brussels)



Early things called "graphs"

- Oresme (~1360): functional relations (e.g., time, velocity, distance)
  - Illustrates various functions
  - He even anticipates bad 3D graphs available in excel!
  - What's not to like?
- Not based on data
  - *"If Oresme had data, we might have had statistical graphs 400 years before Playfair"* (Funkhouser, 1937)

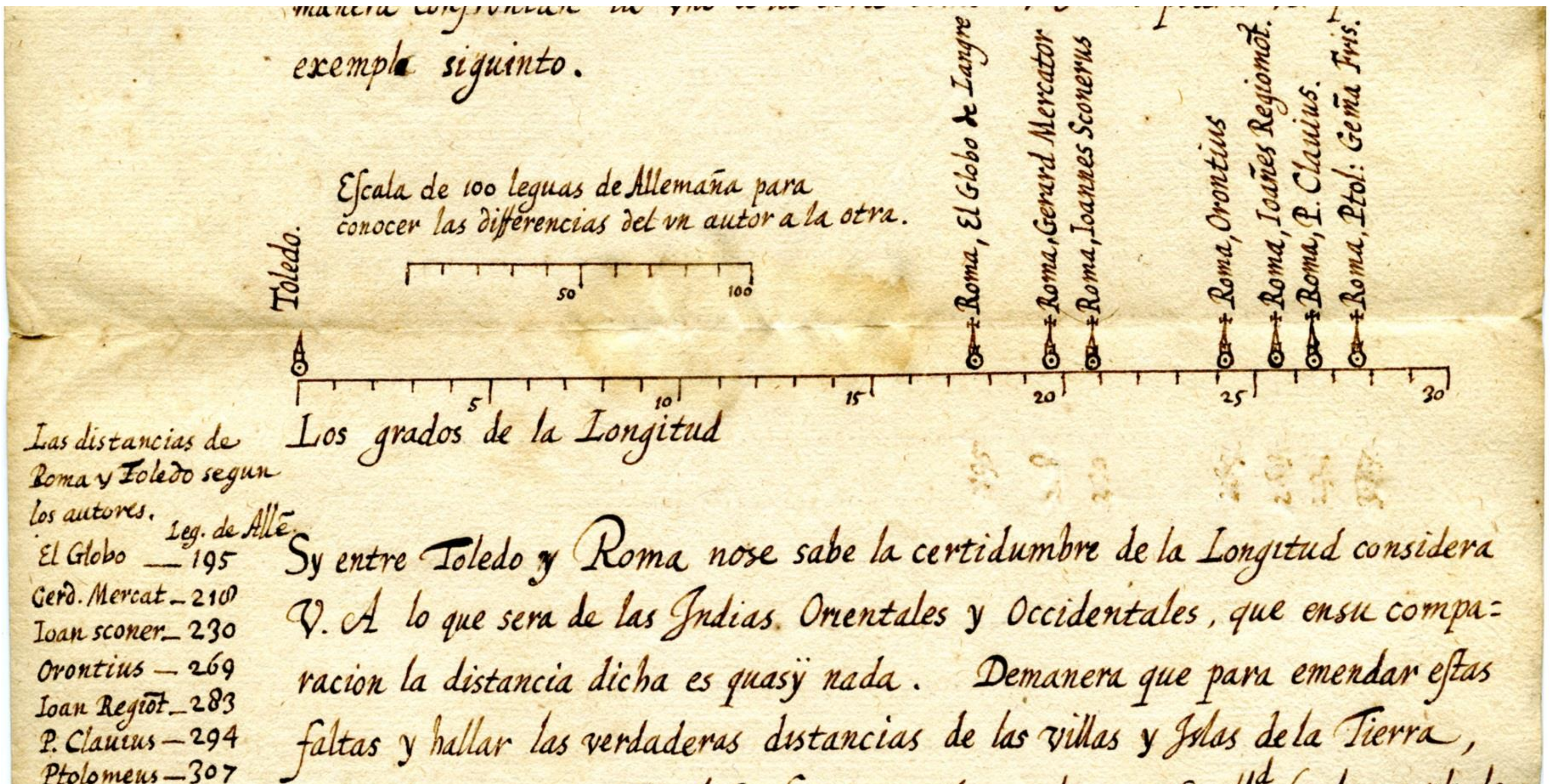


Page from *Tractatus de Latitudinibus Formarum* (Oresme, ~ 1360). Often called "Oresme's pipes"

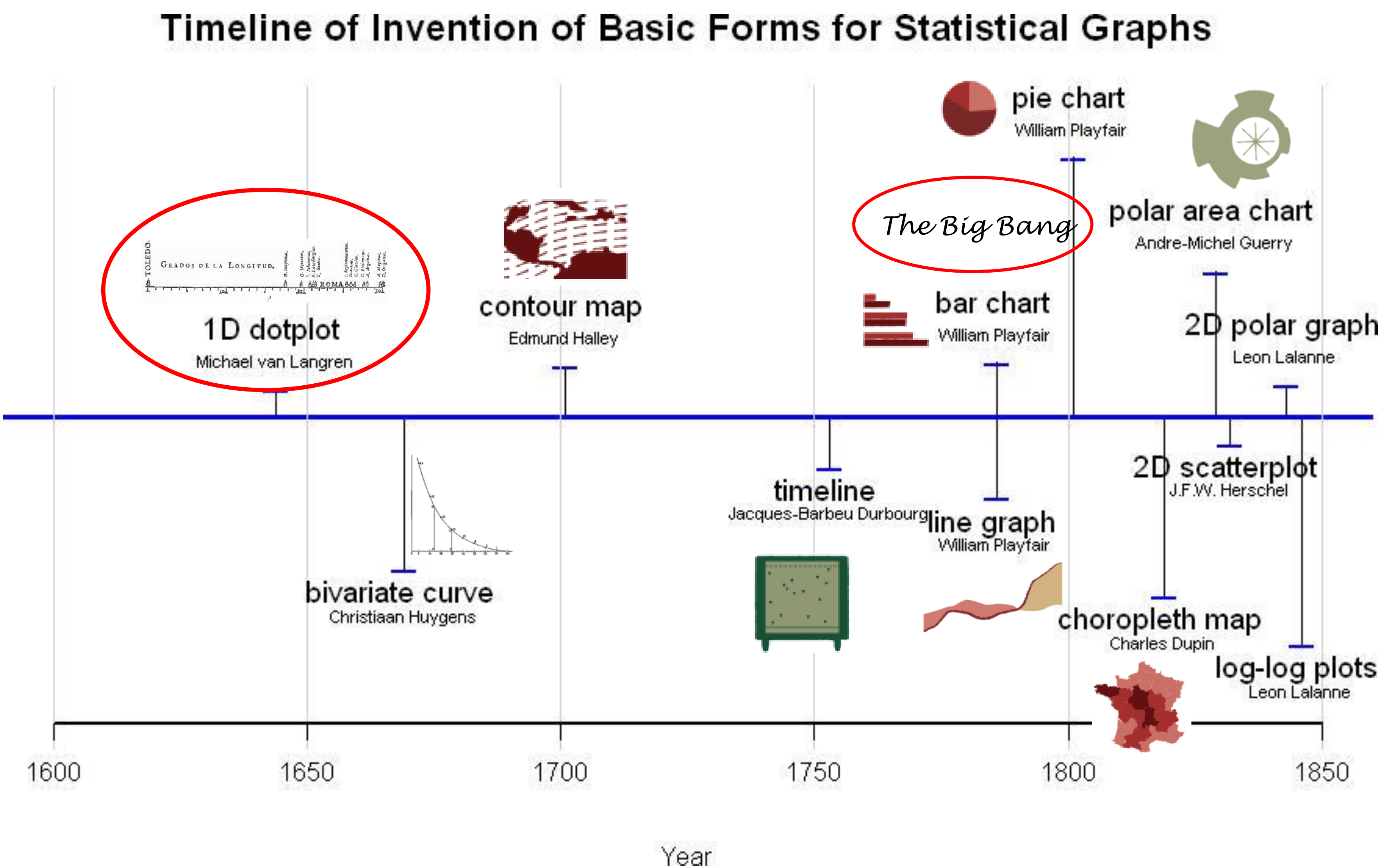
The first *real* graph of data

Michael Florent van Langren (1628) in a letter to the Infanta Isabella, regent for the Spanish court in the Netherlands

- Determinations of the longitude distance from Toledo to Rome

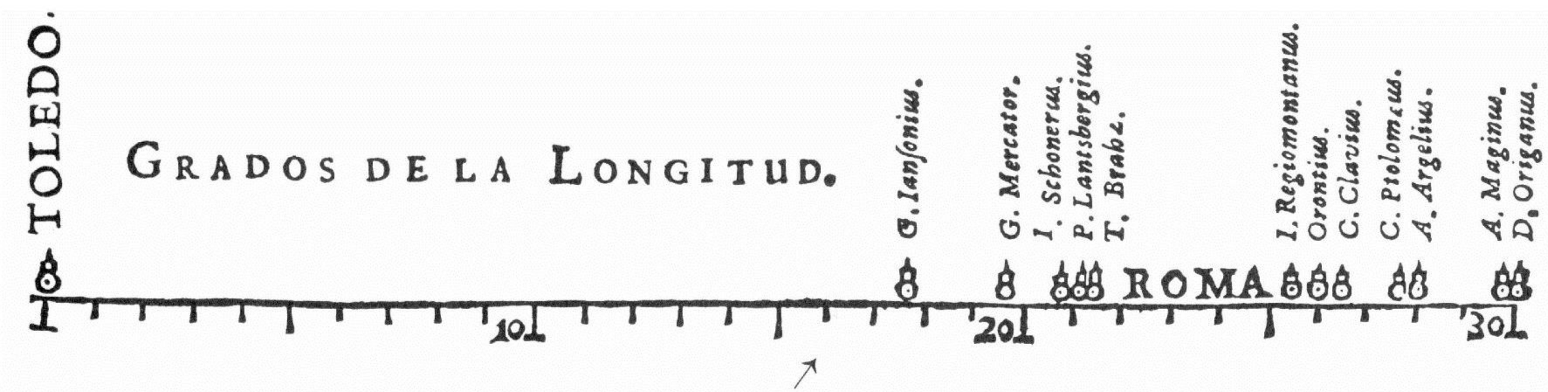


Why is MFvL's graph important?



Why the first graph got it right

- What was van Langren's communication goal?
- What else could he have done?
- Why did the idea of a graph occur to him?



M. F. van Langren (1644), *La Verdadera Longitud por Mar y Tierra* (The Truth about Longitude for Sea and Land)

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
1463	Regiomontanus,	25.4	Germany
1530	Lantsbergius, P.	21.1	Belgium
1536	Schonerus, I.	20.8	Germany
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	Germany
1605	Iansonius, G.	17.7	Flanders
1610	Argelius, A.	28.0	Italy

Answers: Who did it when?

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

Answers: How much did they vary?

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

Answers: What did XXX say?

Sorted by Longitude

Longitude	*Name*	*Year*	*Where*
17.7	G. Iansonius	1605	Flanders
19.6	G. Mercator	1567	Flanders
20.8	I. Schonerus	1536	Germany
21.1	P. Lantsbergius	1530	Belgium
21.5	T. Brahe	1578	Denmark
25.4	I. Regiomontanus	1463	Germany
26.0	Orontius	1542	France
26.5	C. Clavius	1567	Germany
27.7	C. Ptolomeus	150	Egypt
28.0	A. Argelius	1610	Italy
29.8	A. Maginus	1582	Italy
30.1	D. Organus	1601	Germany

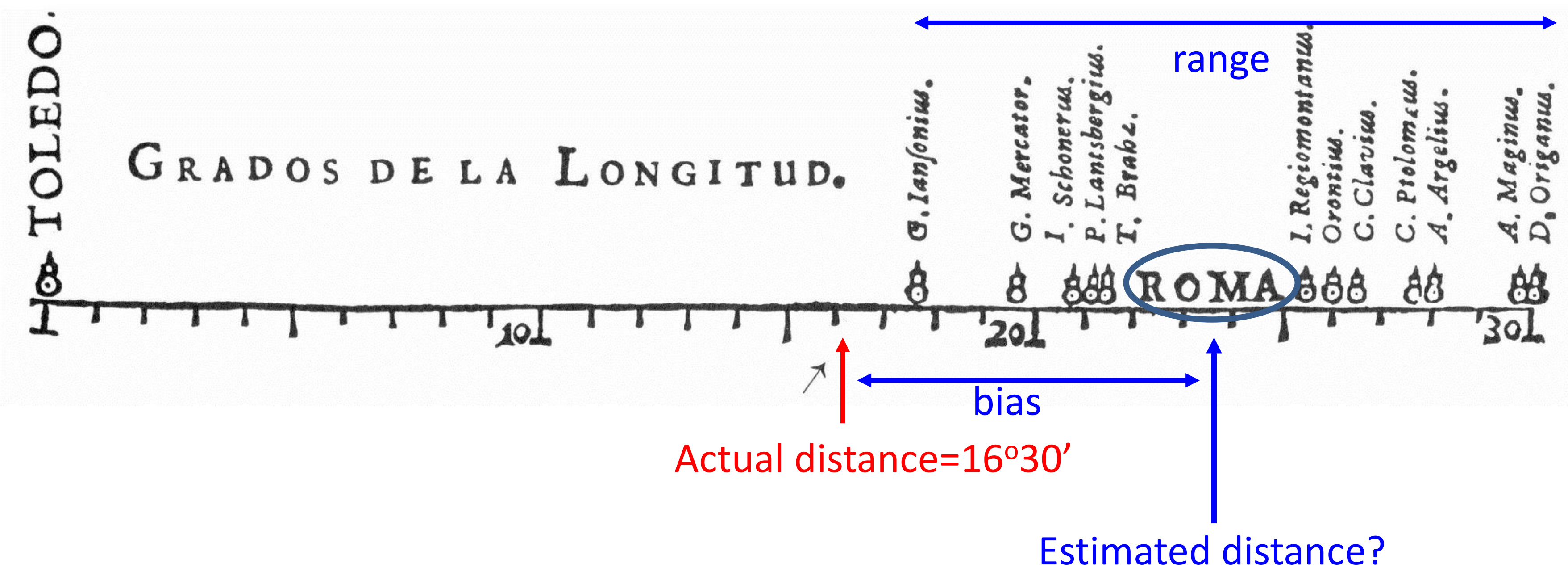
Sorted by Authority

Name	*Longitude*	*Year*	*Where*
Argelius, A.	28.0	1610	Italy
Brahe, T.	21.5	1578	Denmark
Clavius, C.	26.5	1567	Germany
Iansonius, G.	17.7	1605	Flanders
Lantsbergius, P.	21.1	1530	Belgium
Maginus, A.	29.8	1582	Italy
Mercator, G.	19.6	1567	Flanders
Organus, D.	30.1	1601	Germany
Orontius	26.0	1542	France
Ptolomeus, C.	27.7	150	Egypt
Regiomontanus, I.	25.4	1463	Germany
Schonerus, I.	20.8	1536	Germany

Only a graph shows…

A+ for visual information design!

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



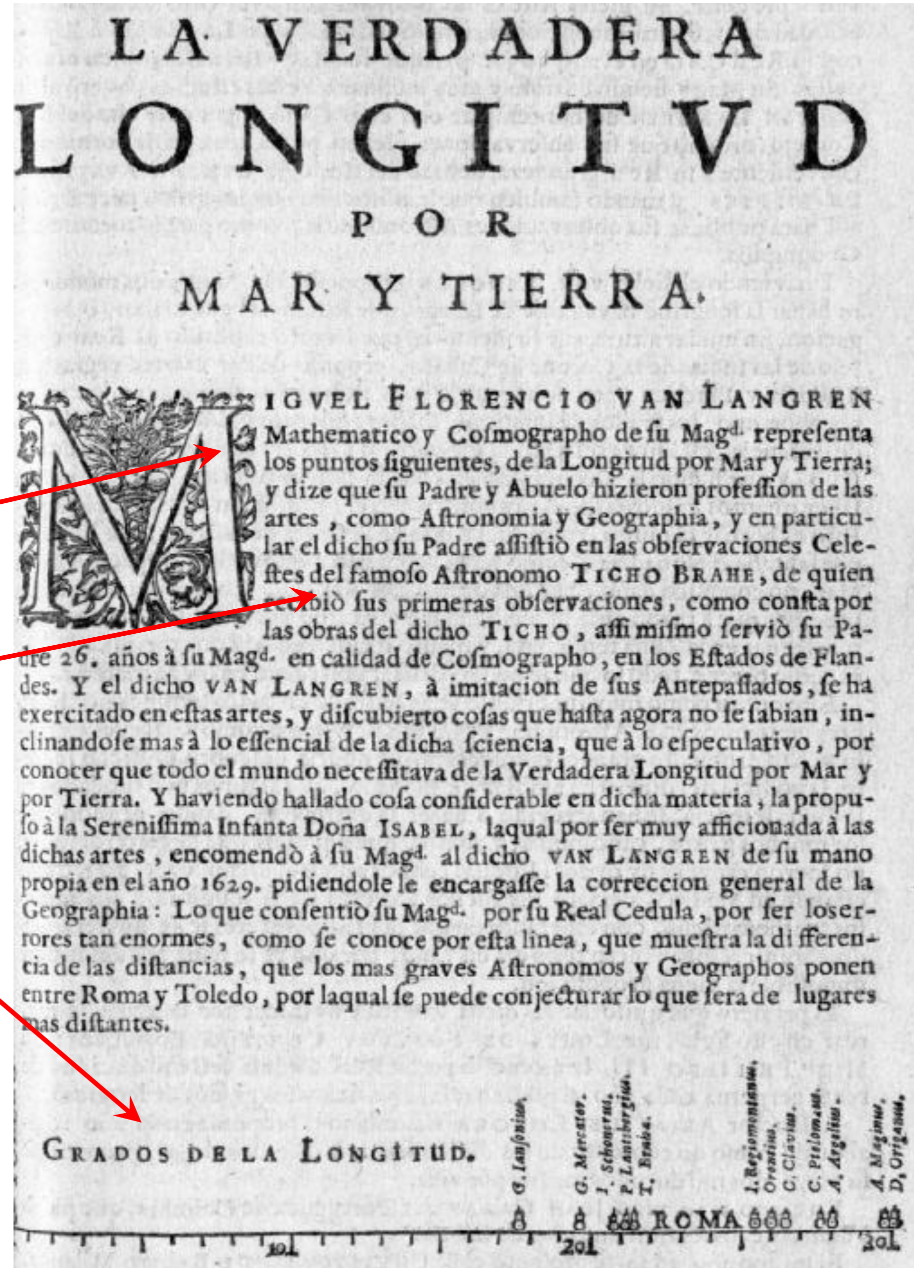
What was he thinking?

The first graph in context

From van Langren (1644), *The Truth about Longitude for Sea and Land.*

Patronage:

- **Credentials**: I am your chief mathematician & cosmographer
- **Problem**: Navigation at sea is most important problem for you to prosper. Many others have studied this, without success.
- **Demonstration**: I show the great errors from all previous scholars.
- **Supplication**: I have a solution, if you will grant me the magnificent awards you have given to others, less worthy than I am.



LA VERDADERA
LONGITVD
POR
MAR Y TIERRA.

MIGVEL FLORENCIO VAN LANGREN Mathematico y Coſmographo de ſu Mag^d. repreſenta los puntos ſiguientes, de la Longitud por Mar y Tierra; y dize que ſu Padre y Abuelo hizieron profeſſion de las artes, como Aſtronomia y Geographia, y en particular el dicho ſu Padre aſſiſtiò en las obſervaciones Celeſtes del famoſo Aſtronomo TICHO BRAHE, de quien recibiò ſus primeras obſervaciones, como conſta por las obras del dicho TICHO, aſſi miſmo ſerviò ſu Padre 26. años à ſu Mag^d. en calidad de Coſmographo, en los Eſtados de Flandes. Y el dicho VAN LANGREN, à imitacion de ſus Antepaſſados, ſe ha exercitado en eſtas artes, y diſcubierto coſas que haſta agora no ſe ſabian, inclinandoſe mas à lo eſſencial de la dicha ſciencia, que à lo eſpeculativo, por conocer que todo el mundo neceſſitava de la Verdadera Longitud por Mar y por Tierra. Y haviendo hallado coſa conſiderable en dicha materia, la propuſo à la Sereniſſima Infanta Doña ISABEL, laqual por ſer muy aficionada à las dichas artes, encomendò à ſu Mag^d. al dicho VAN LANGREN de ſu mano propia en el año 1629. pidiendole le encargaſſe la correccion general de la Geographia: Lo que conſentiò ſu Mag^d. por ſu Real Cedula, por ſer los errores tan enormes, como ſe conoce por eſta linea, que mueſtra la differencia de las diſtancias, que los mas graves Aſtronomos y Geographos ponen entre Roma y Toledo, por laqual ſe puede conjecturar lo que ſera de lugares mas diſtantes.

2. The Birth of Data

- When & how did the idea of "data" arise?
- What do we mean by "data"?
  - Empirical observations ✓
  - Recorded ✓, quantified ✓, categorized ?
  - Suited to something that could be used to address some larger question or problem
  - More than just a collection of individual numbers

Hero of this story:
André-Michel Guerry
- B: Dec. 1802 (Tours)
- D: Apr. 1866 (Paris)


A.-M. Guerry

Early numbers, not quite "data"

Flooding of the Nile

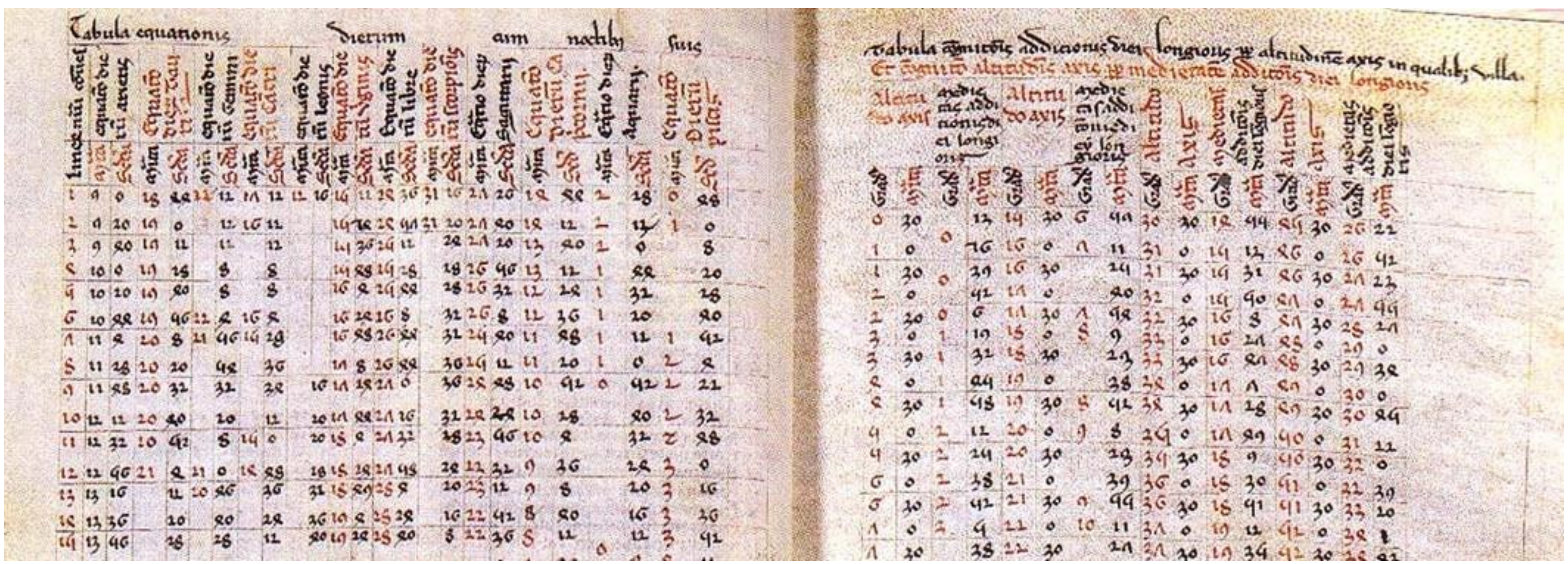
- Goes back 7000 years before construction of the Aswan Dam
- Dates & heights of flooding recorded
- Perhaps the longest time series data ever recorded
- Why is this not "data" in the narrow (modern) sense?

View of the pyramids in flood season

A nilometer was invented, ~ 700 AD

Ephemeris tables: not quite “data”

- Extensive tables of astronomical observations
  - Positions of planets, moon, etc. observed from given location
  - Tables of Toledo (~1150), Alfonsine Tables (~1260), Rudolphine tables (Kepler, 1627) using Tycho Brahe’s catalog: 1’ of arc
  - Included topgraphic tables – conversion to time in other cities
  - I still say not quite “data” as we understand this today?



Alfonsine tables, Toledo, ca.1260

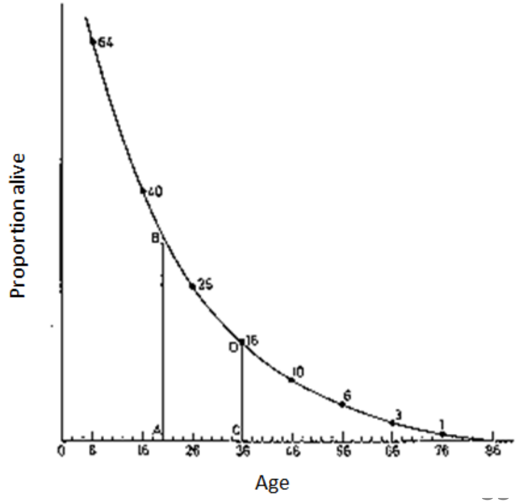
Political arithmetic

- The first inkling that "data" could be put to a larger use appeared in 1662, with John Graunt's *Natural & Political Observations Made upon the Bills of Mortality*
- It established a basis for numbers as **evidence for some proposition**.
- William Petty (1685-90) developed "political arithmetic" based on "the rule of three", allowing prediction & interpolation

a is to *b* as *c* is to *?*

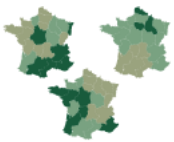
$$\frac{a}{b} = \frac{c}{?} \Rightarrow ? = \frac{bc}{a}$$

- This is what Huygens (1669) used to calculate life expectancy from Graunt's data
- Annuities & life insurance could now be calculated
- This was the beginning of what we now call "statistics" (term only coined in 1749)

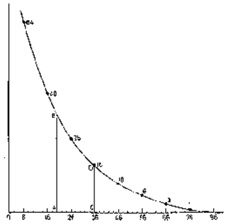


Big questions of the early 1800s

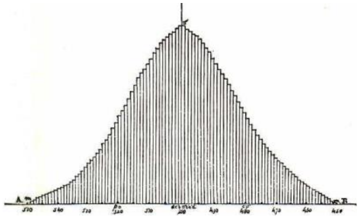
- Issues for European states
  - Demography: taxes, raising an army (Süssmilch, 1741)
  - “Statistik”: Numbers of the state (Achenwall, 1748)
  - **Social problems: crime, suicide, literacy, etc**.
  - Disease epidemics, e.g., cholera



- Anthropometry: the measure of Man
  - Distributions of human characteristics
  - Birth, mortality, lifespan



- Beginnings of statistical theory and application
  - Normal dist^n (de Moivre, 1733)
  - *L’homme moyen* (Quetelet, 1835)



Big data of the early 1800s: France

"An avalanche of social numbers"

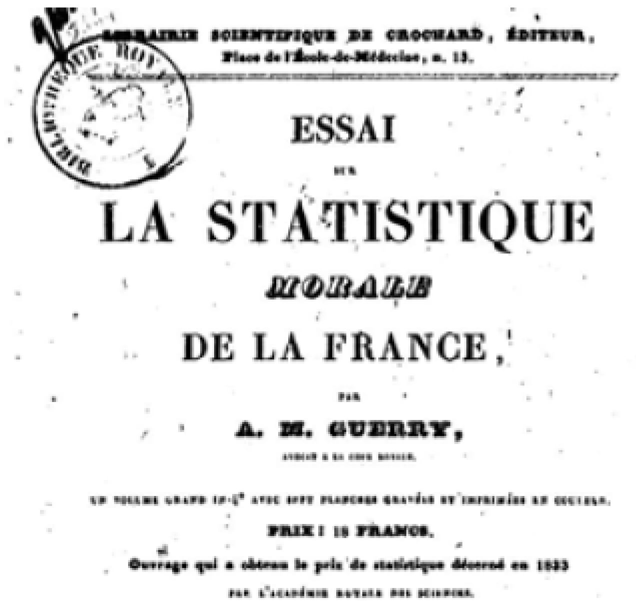
- J.-B.J. Fourier: *Recherches statistique sur la ville de Paris* (1821-1829)
  - Massive tabulations: births, deaths (by cause), admission to insane asylums (age, sex, affliction)
- Ministry of Justice: *Compte generale (1825--)*
  - First national compilation of criminal justice data
  - All charges & dispositions, quarterly, 86 departments
- Other sources:
  - Bureau de Longitudes (illegitimate births)
  - Parent-Duchâtelet (prostitution); Min. of War (desertions)
  - Suicide notes in Paris collected and analyzed for motives
- Social issues could now be addressed with **DATA**

3. A. M. Guerry and the rise of social science

Essai sur la statistique moral de la France

The launching pad of modern social science

- Presented to Academie des Sciences Français July 2, 1832
- First systematic analysis of comprehensive data on crime, suicide, and other social variables.
- Along with Quetelet (1831, 1835), established the study of “moral statistics” $\mapsto$ modern social science, criminology, sociology



Social context of crime in 1820s France

- Social upheaval following Napoleon's defeat
- Crime a serious concern:
  - Explosive growth in Paris
  - Widespread unemployment,
  - Emergence of "dangerous classes"
- Liberal ("philanthrope") view
  - Increase education
  - Better prison conditions, diet (bread ***and*** soup)
  - Religious instruction
- Conservative view
  - Build more prisons
  - Harsher treatment of recidivists
- Now, there was finally some DATA!

The discovery of "social facts"

Stability and Variation

Guerry's results were both compelling and startling:

- Rates of crime and suicide remained remarkably invariant over time, yet varied sytematically by region, sex of accused, type of crime, etc.
- In any given French city or department, almost the same number committed suicide, stole, gave birth out of wedlock, etc.

Year		1826	1827	1828	1829	1830	Avg
Sex		All accused (%)					
Male	OMG! ~ constant →	79	79	78	77	78	78
Female		21	21	22	23	22	22
Age		Accused of Theft (%)					
16–25	OMG! ~ constant →	37	35	38	37	37	37
25–25		31	32	30	31	32	31
Crime		Committed in summer (%)					
Indecent assault		.	36	36	35	38	36
Assault & battery		.	28	27	27	27	28

The discovery of “social facts”

Social laws á la physical laws

Do crime and other moral variables represent:

- structural, lawful characteristics of society, or are they
- simply indicants of individual behaviour?

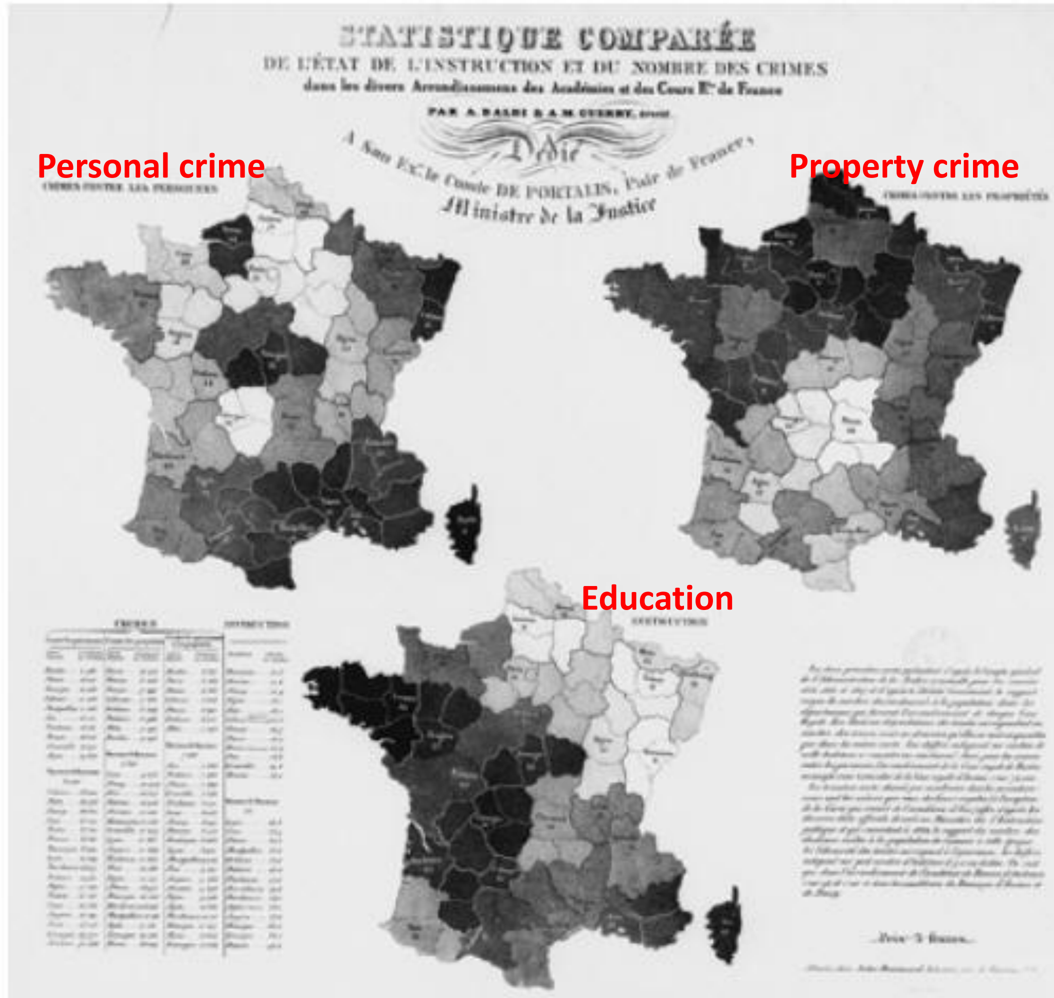
Guerry argued:

> *Each year sees the same number of crimes of the same degree reproduced in the same regions.(Guerry, 1833, p.10)*

> *... We are forced to recognize that the facts of the moral order are subject, like those of the physical order, to invariable laws (Guerry, 1833, p14)*

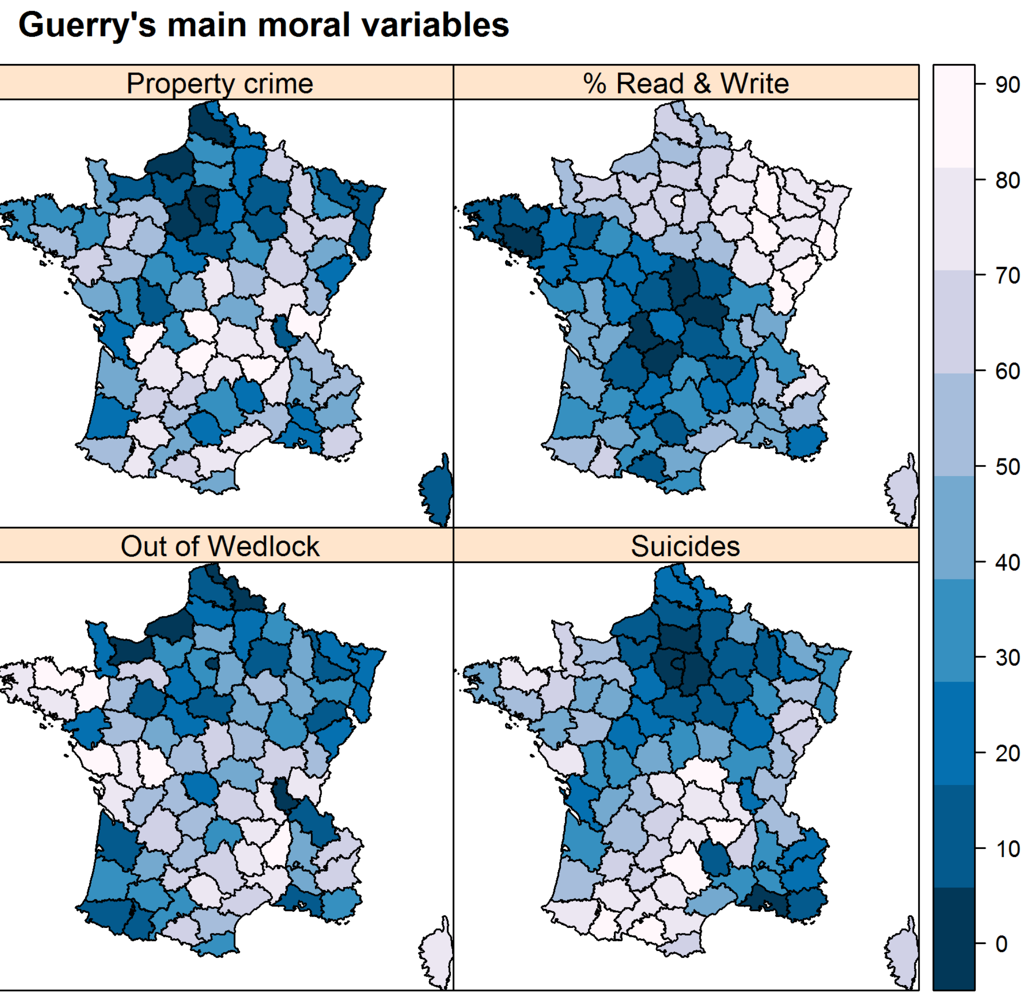
1829: *Statistique comparée de l'état de l'instruction...*

- First shaded thematic maps of crime data
- First comparative maps of social data
- ↦ crime against persons seemed inversely related to crime against property!
- Instruction: ↦ *France obscure* and *France éclairée* (Dupin, 1826)
- North of France highest in education, but also in property crime!

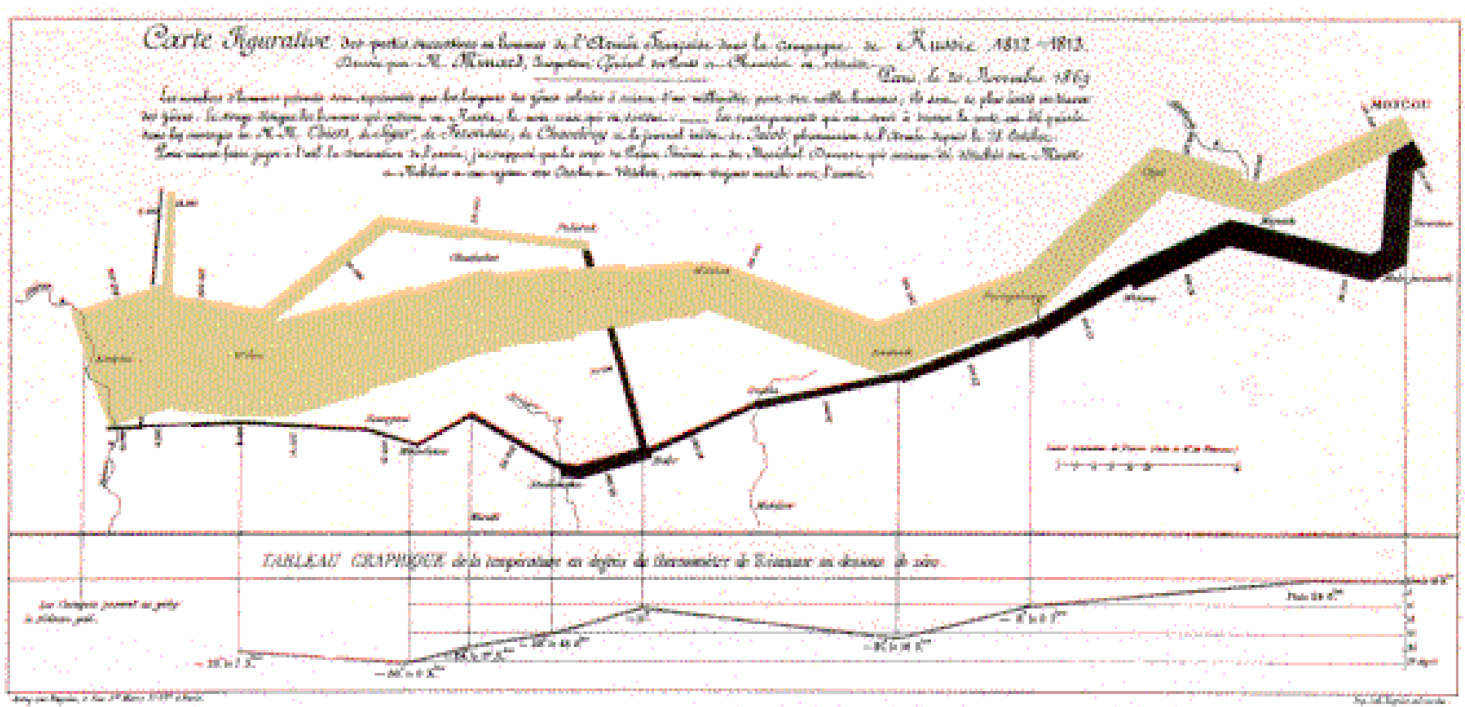


Multivariate comparisons

Before the invention of correlation, maps of different phenomena allowed thinking about relations among disparate social variables [Darker = WORSE]



4. The graphic vision of C. J. Minard



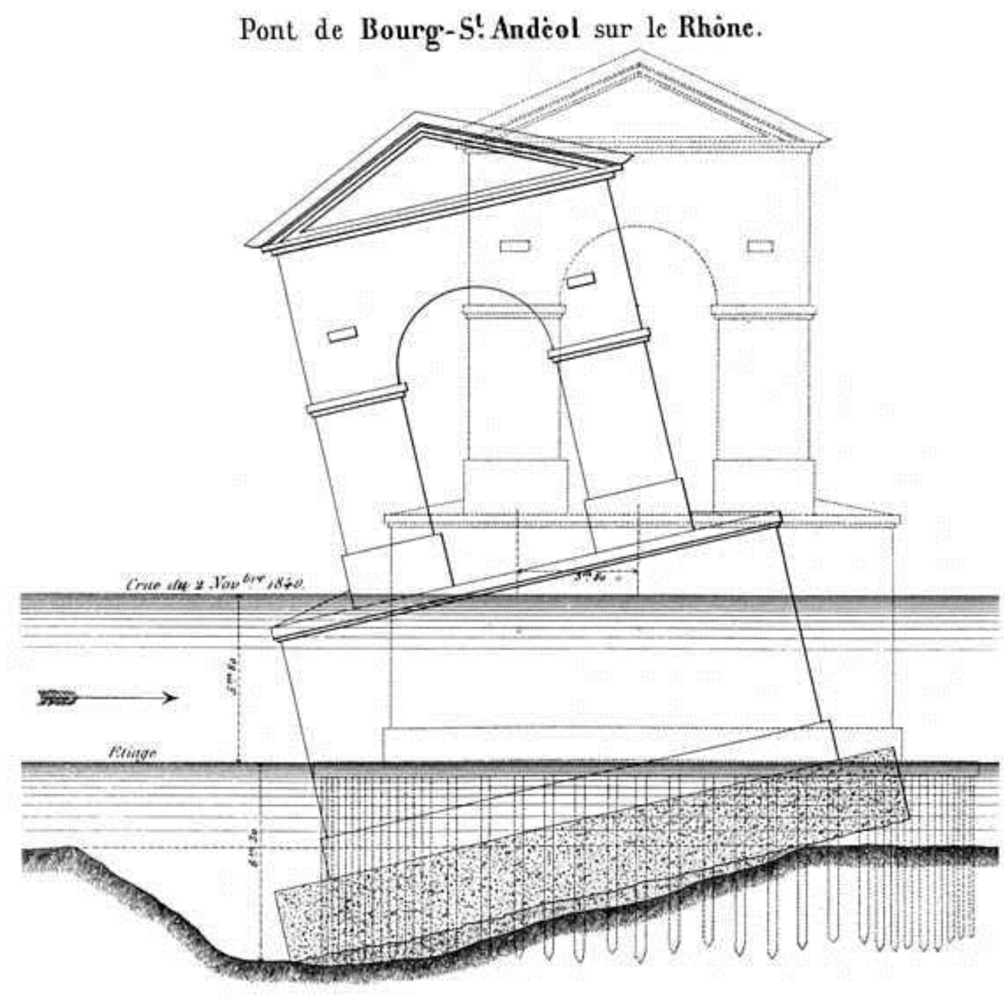
- Marey (1878): *"defies the pen of the historian in its brutal eloquence"*
- Tufte (1983): *"the best statistical graphic ever produced"*

Visual thinking, visual explanation

Minard's main career was a as a civil engineer for the ENPC (bridges & roads)

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

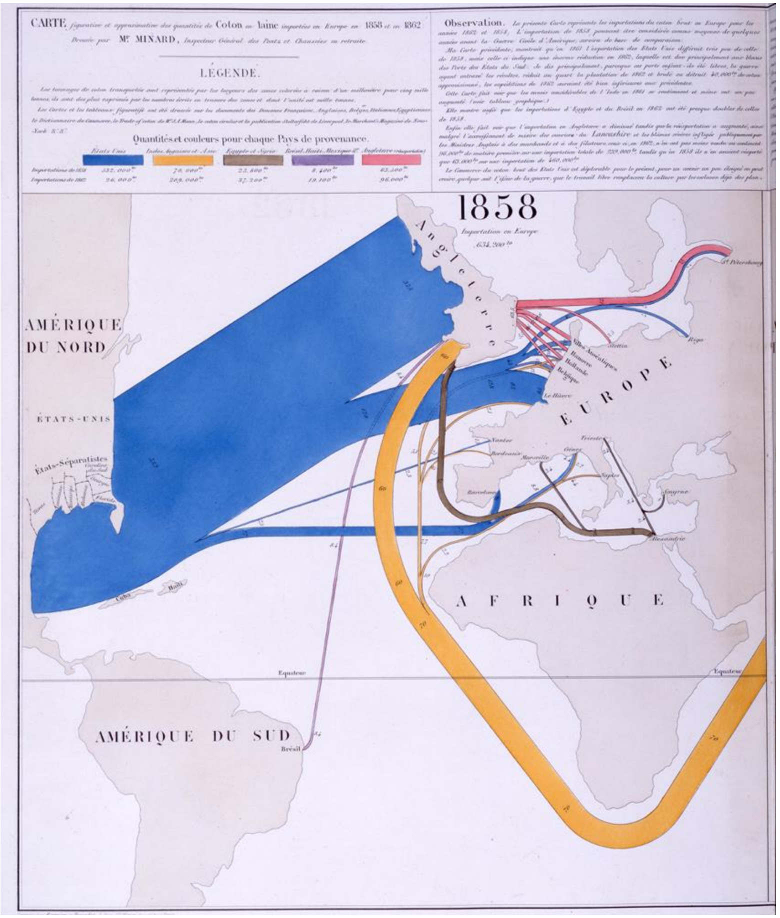
Minard's report consisted essentially of this self-explaining diagram.



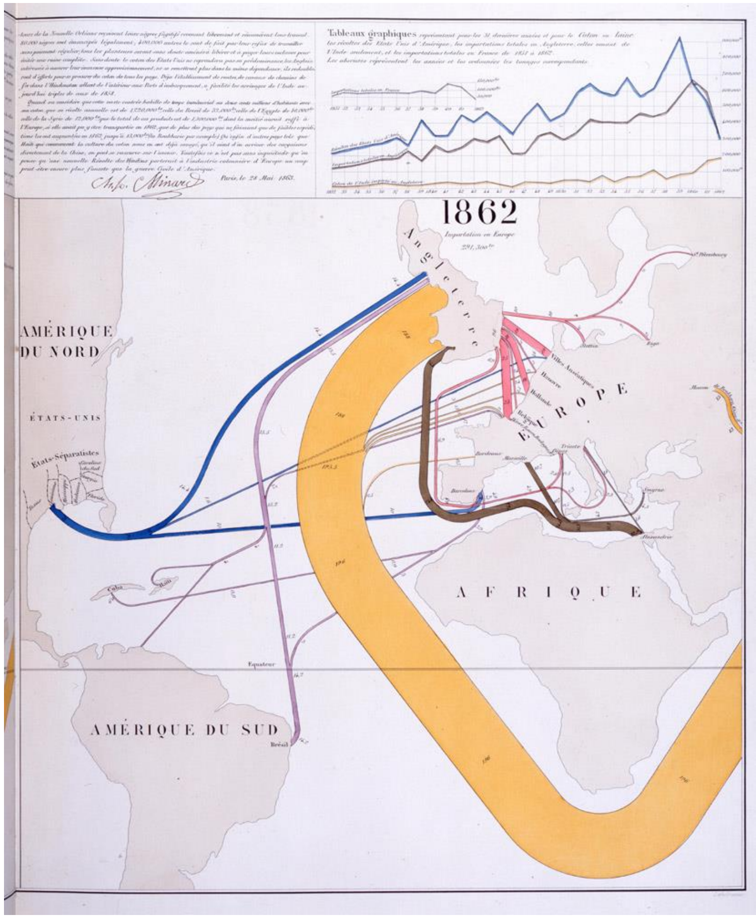
Effect of US Civil War on cotton trade

Visual explanation of the shift in cotton trade

Before



After



New graphic forms to answer questions

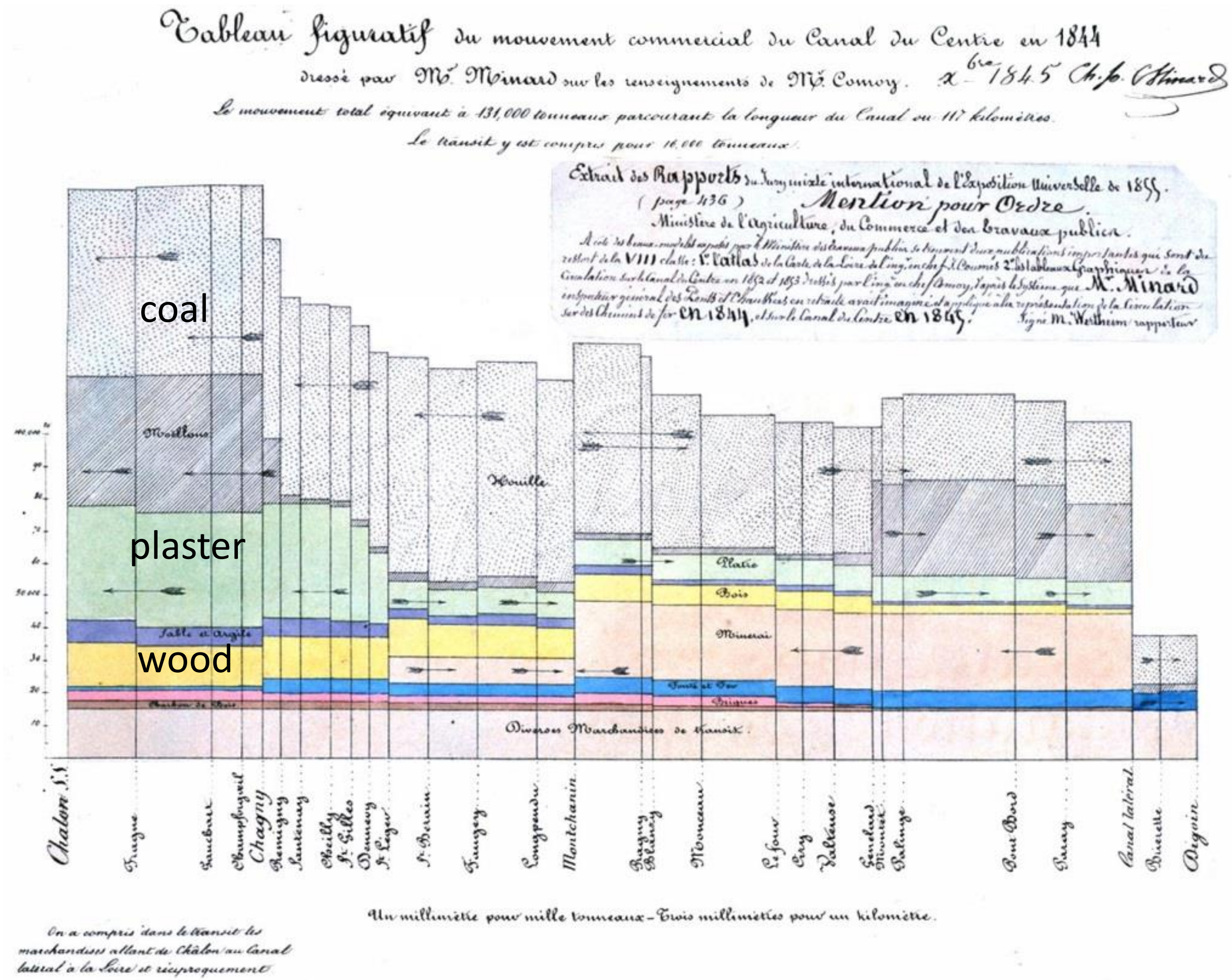
How to charge for the transportation of different goods on the Canal du Centre?

Visual answer:
Area ~ distance × amt
Show direction

This is an early ancestor of mosaic displays and related graphics

...Not only do my maps speak, but even more, they count, they calculate by the eye.

-- Minard (1862)

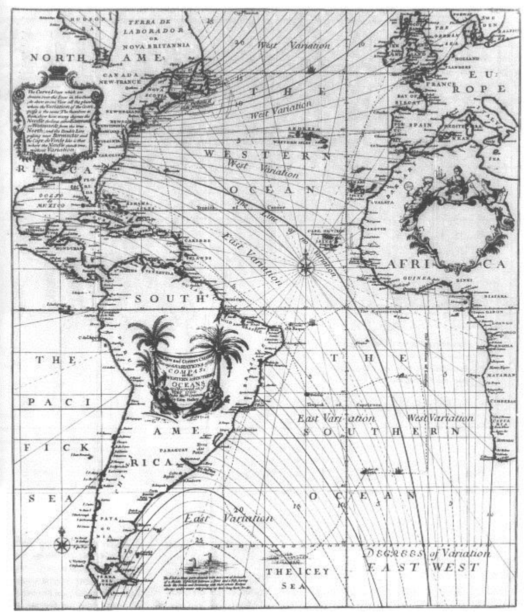


Escaping Flatland

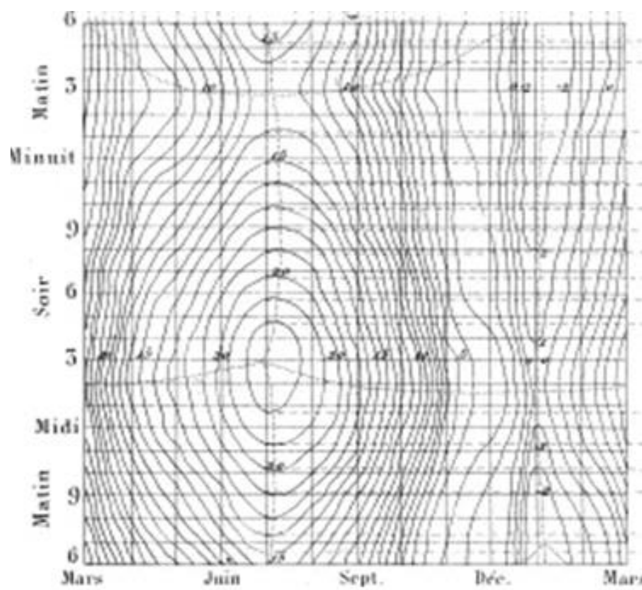
3D maps & graphs from Halley to Galton

A next step in visual thinking was the idea to show 3D+ phenomena on a 2D surface
This often involved (a) interpolation from scant data & (b) visual smoothing

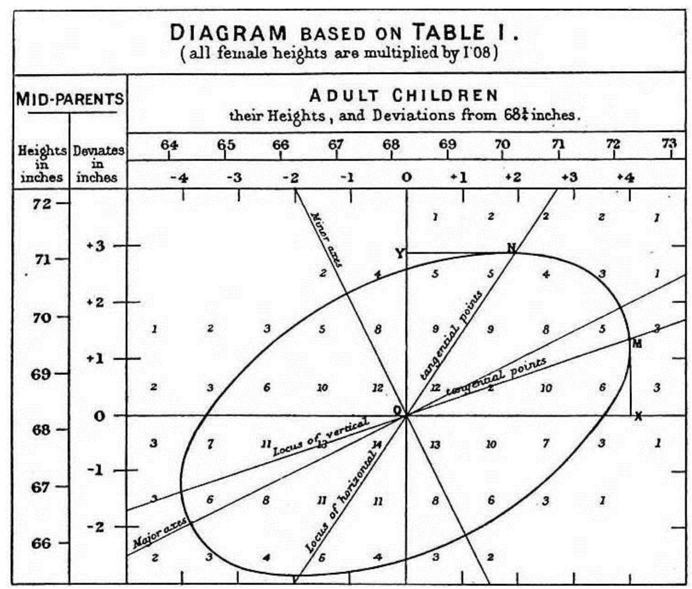
1701: Halley



1843: Lalanne

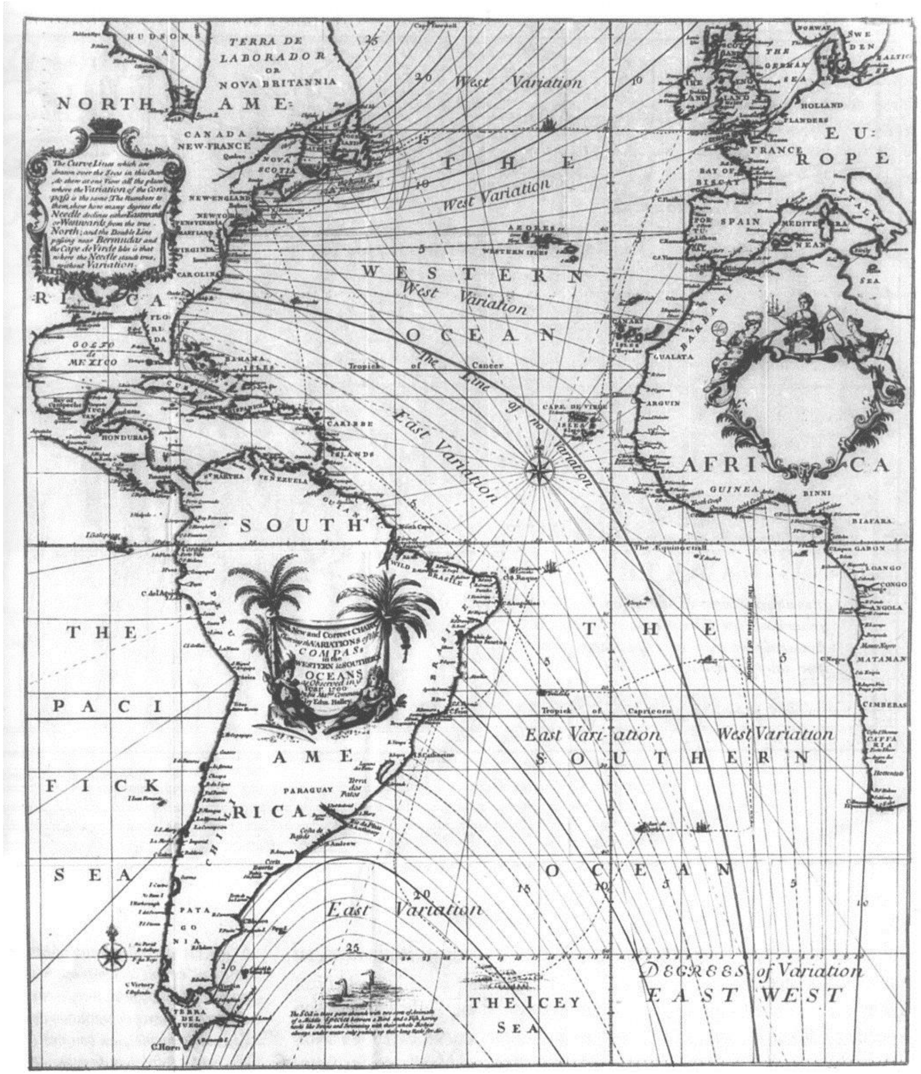


1866: Galton



Early 3D maps & graphs

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



Visual ideas:

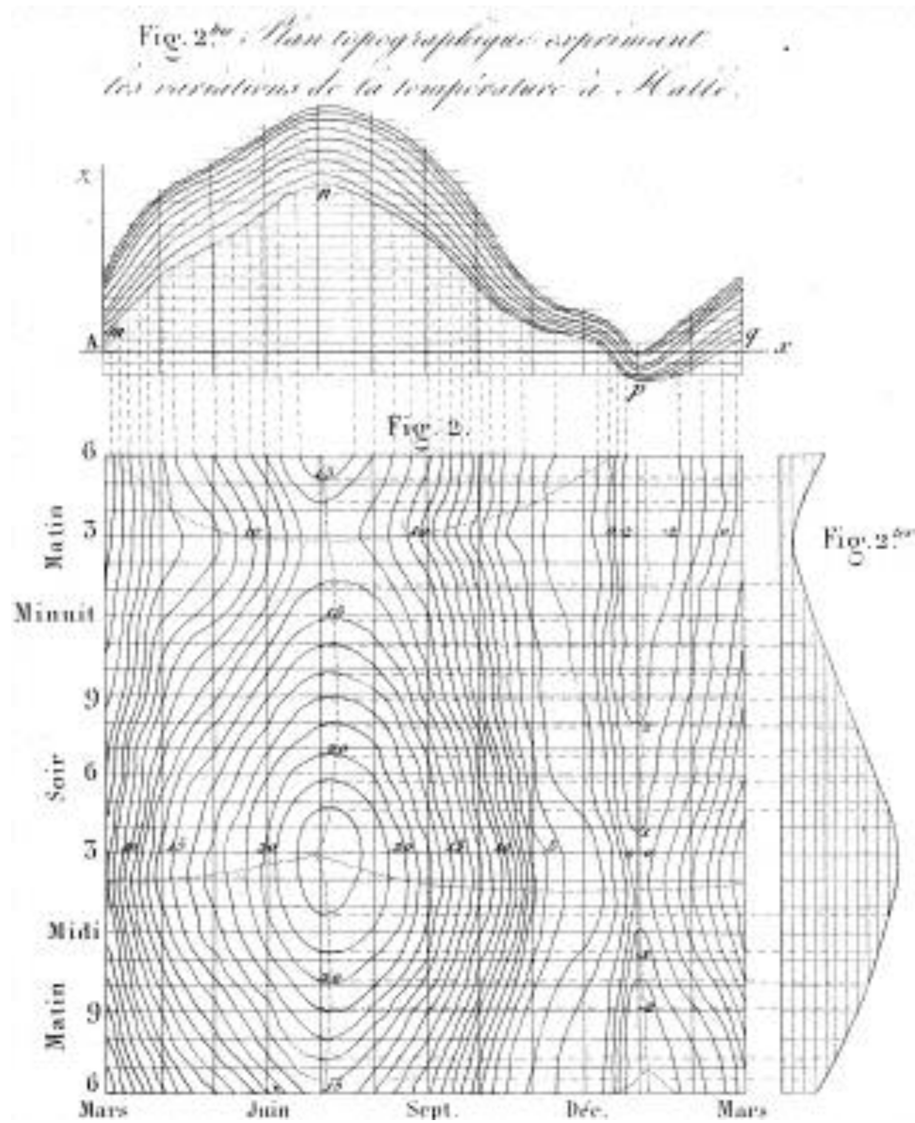
- curves showing equal value on a (lat, long) map.
- show a non-spatial variable
- Interpolation from observed data
- Regularity → smoothing

3D maps → Graphs

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

month

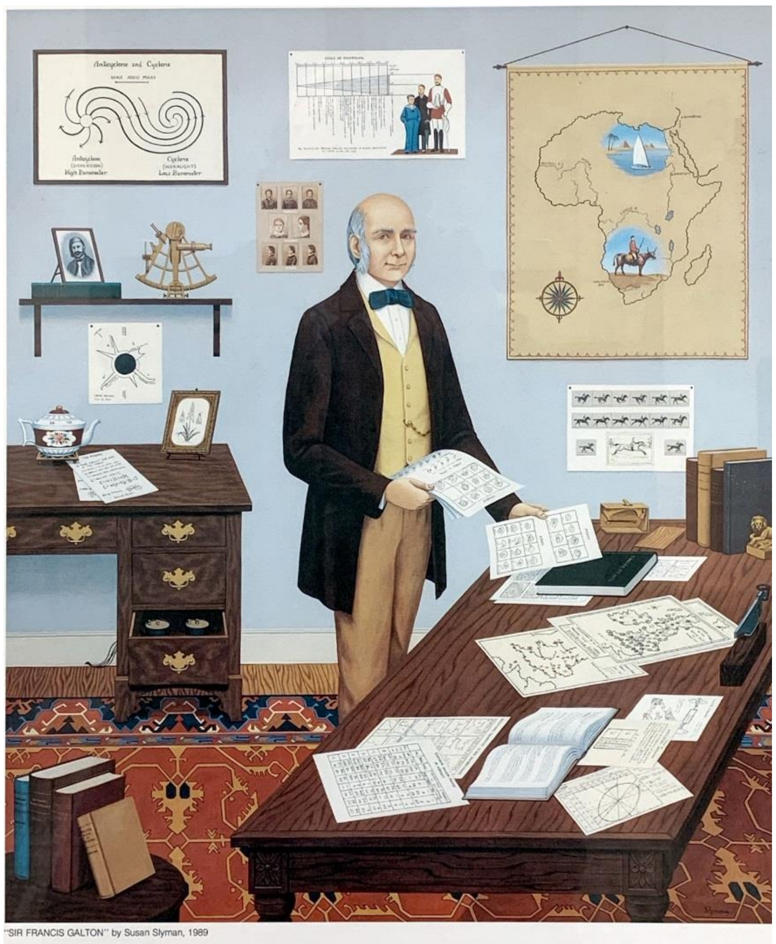
hour



Visual ideas:

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

Galton: Visual thinking & graphic discovery



Portrait of Galton in his study by Susan Slyman

Galton's contributions:

- Genetics (inheritance)
- Regression towards mean
- Forensics (fingerprints)
- Travel: Isochronic maps
- Weather maps
- Psychology: Mental imagery & word associations
- Standardized data forms & crowd-sourced collection

Galton's visual discoveries-

Bivariate normal correlation surface (1886)

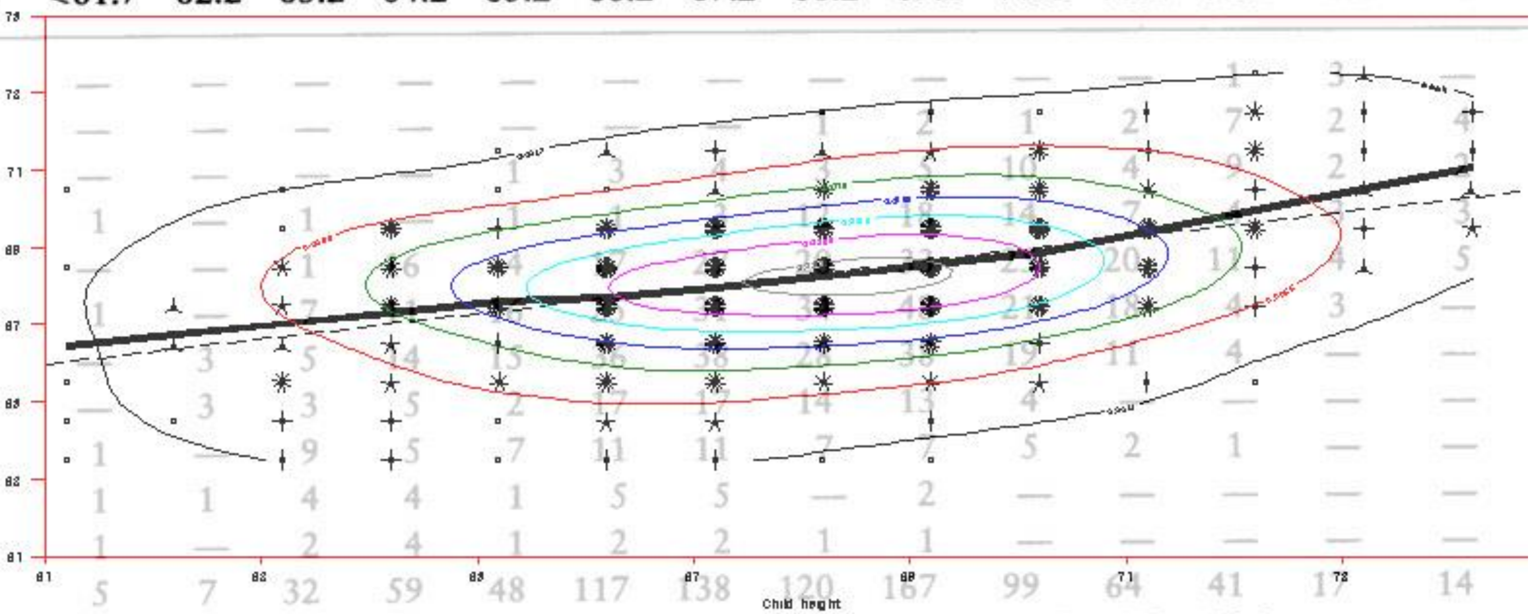
Table 9.1 One of Galton's correlation tables

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

Table 9.1 One of Galton's correlation tables



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>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	[illegible]	1	1	3	12	18	14	7	[illegible]	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	—	—	—	—	—
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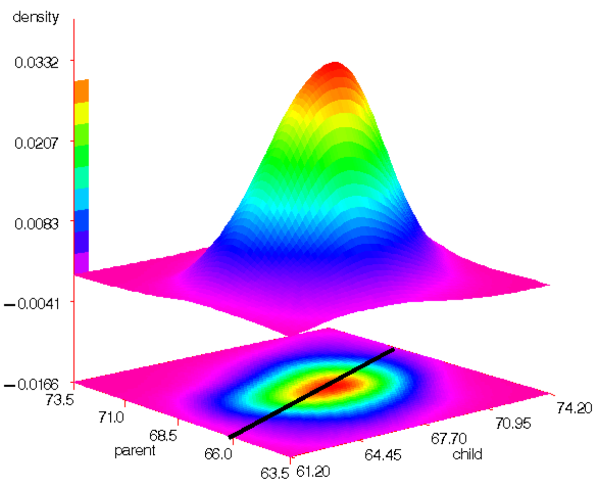
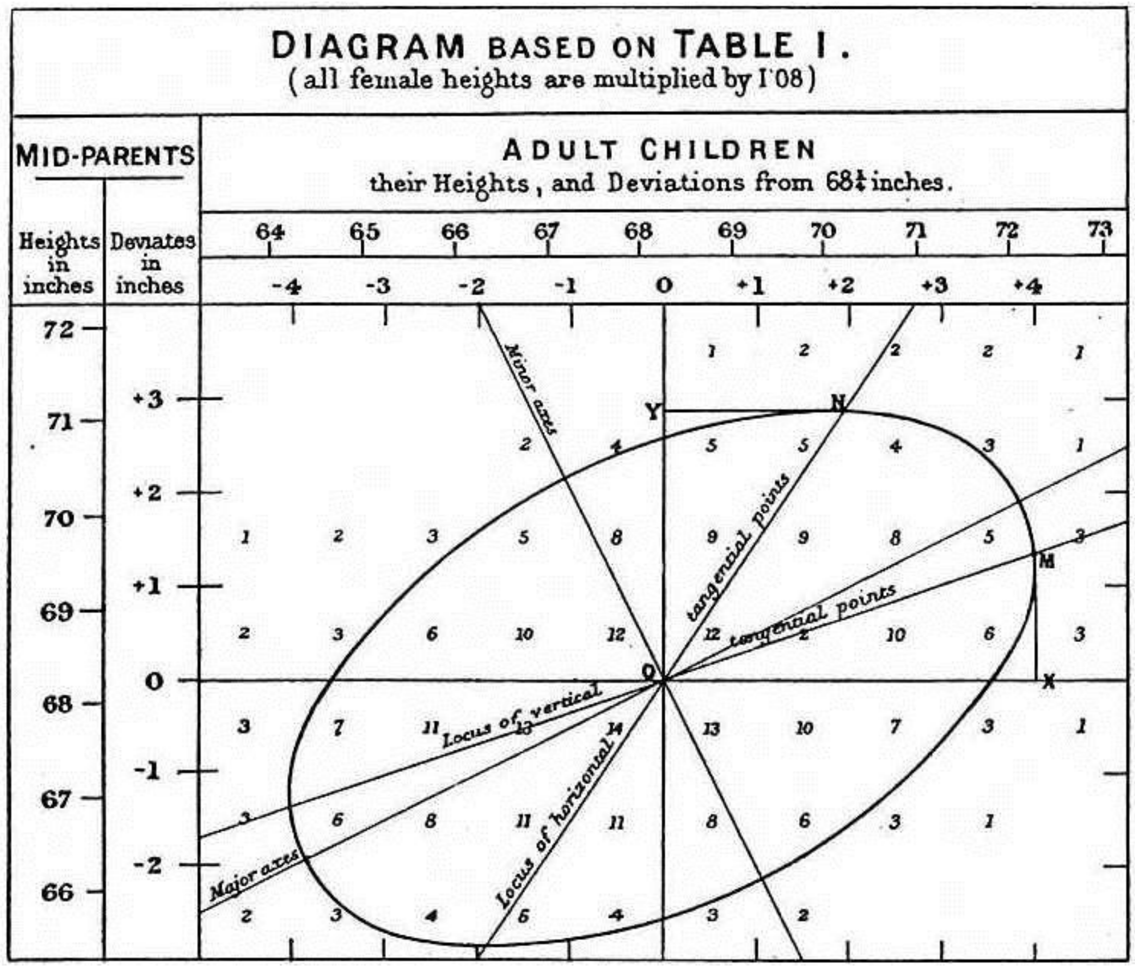
Source: Galton (1886), p. 68.

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)

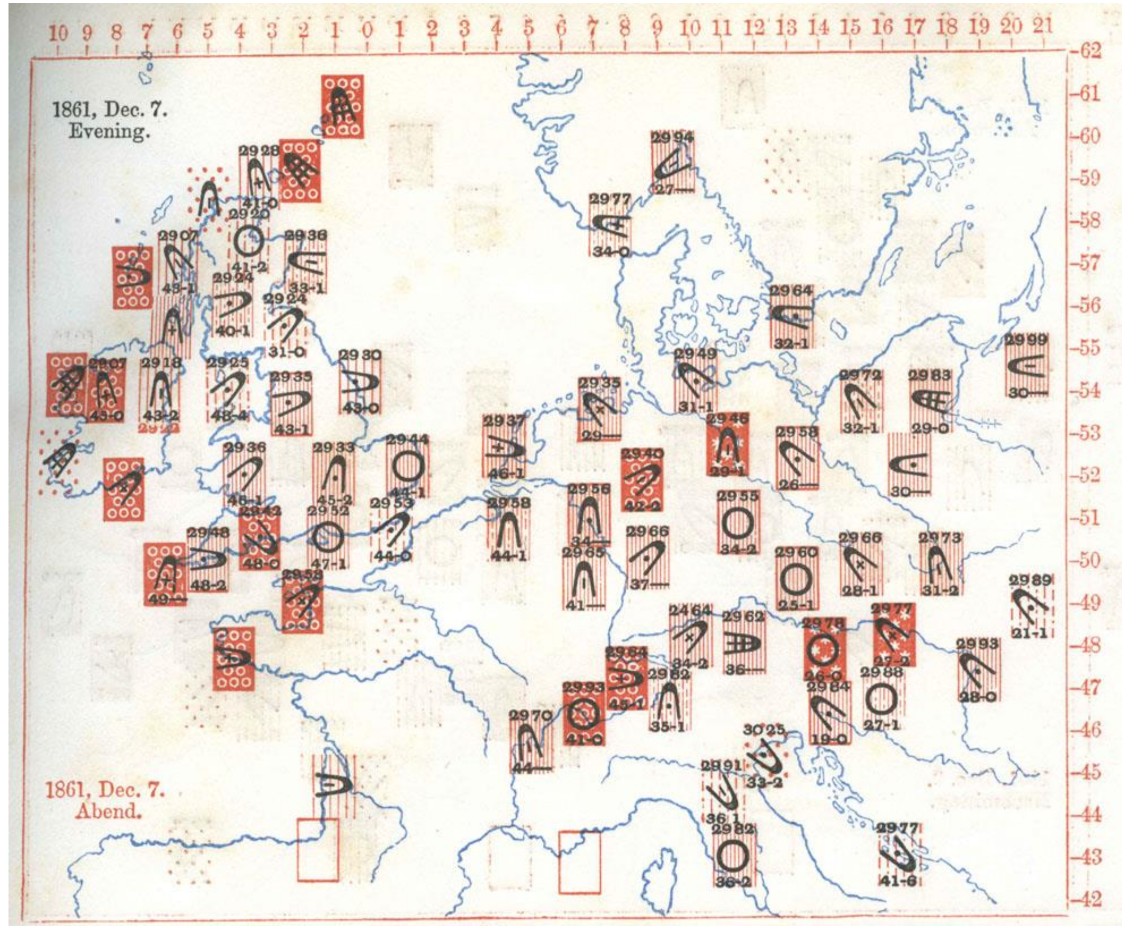
Images here courtesy of Stephen Stigler. Thx!

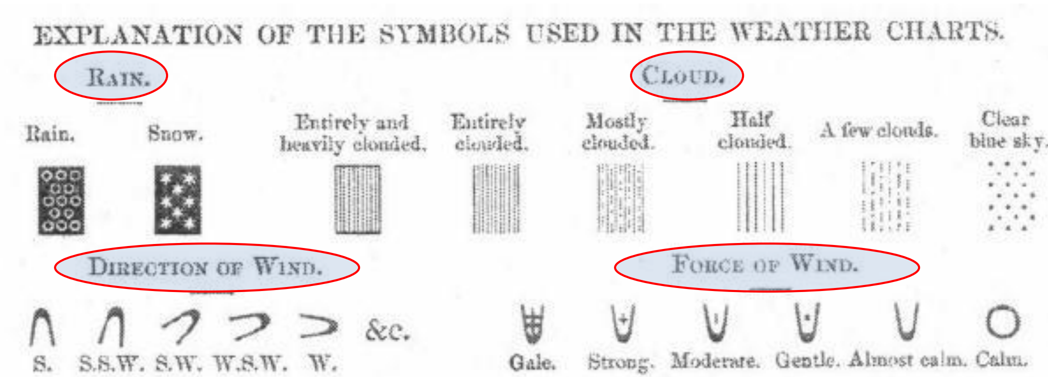
Method: All weather stations across Europe asked to record data 3x/day for all of Dec., 1861

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!)





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}

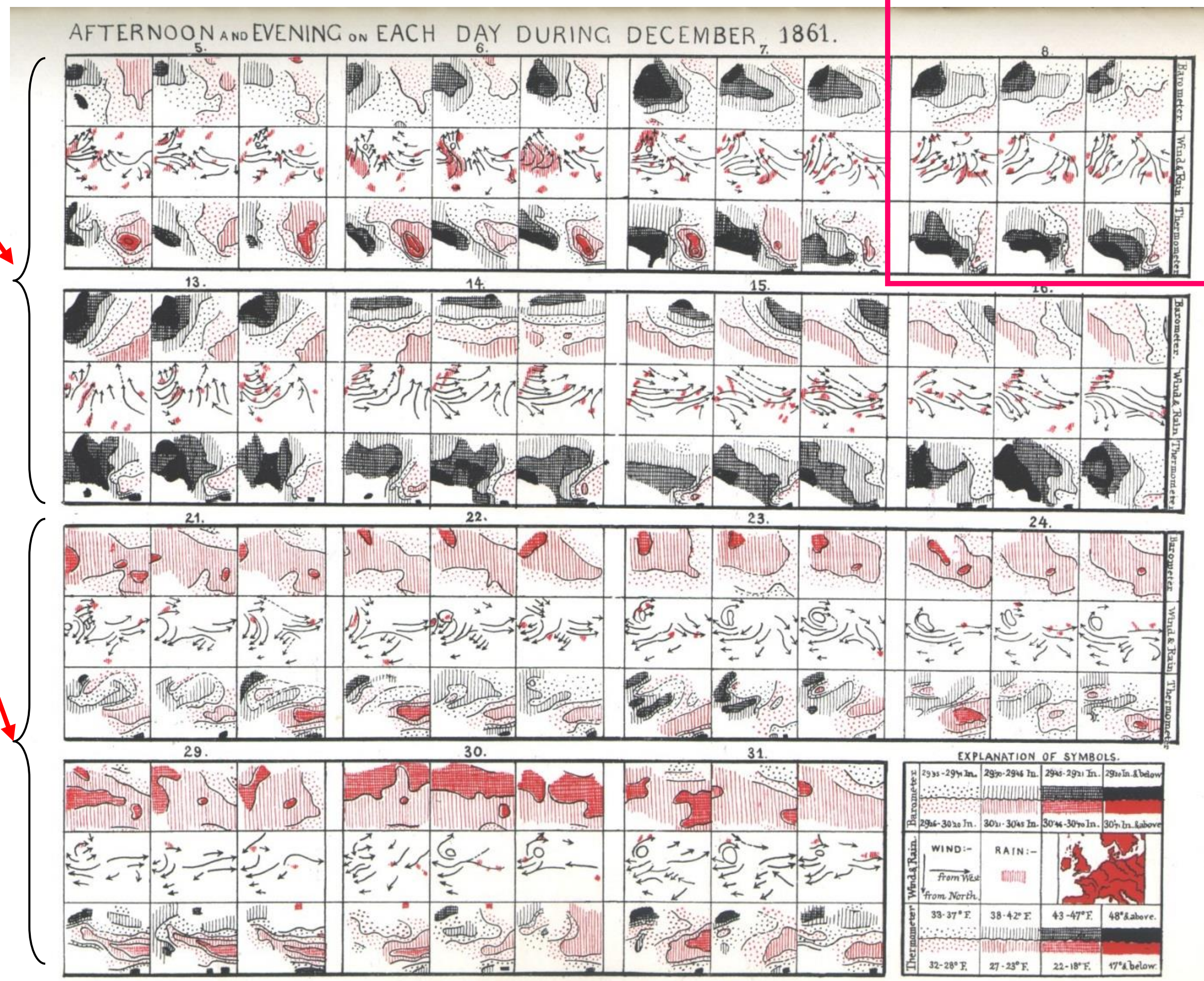
(try this with your software!)

AM 12 PM

pressure

wind, rain

temp.



A series of weather maps from the *Meteorographica.*

Galton's essential ideas

- DATA: Gather data from available sources
  - Crowd sourcing, create standardized forms
- Organize
  - tables, maps, …
  - look for patterns
- Find regularities
  - visual smoothing of observed data
  - zoom out: abstract version of a map or graph
- Explain with some general theory

An early example of modern data science

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 has been key to advances
  - geometry, smoothing, imagination, …
- **Problem driven**: developments often driven by practical and theoretical problems of the day
- **Communication driven**: developments often arose from a desire to communicate better

Thank you!

Questions?

Further info:

http://datavis.ca

@datavisFriendly

Photo mosaic of history of datavis