Cours 2024-2025:

La perception des graphiques: un nouvel exemple de recyclage neuronal
The perception of graphics : a new example of neuronal recycling

Stanislas Dehaene
Chaire de Psychologie Cognitive Expérimentale

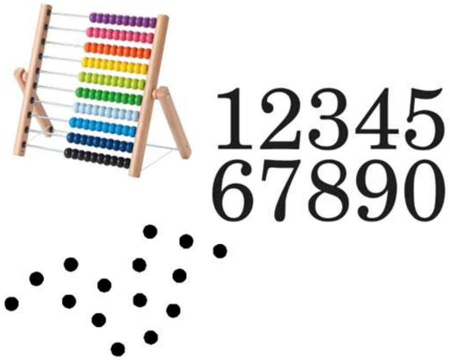
Cours n°1

Introduction : l'origine et l'évolution des graphiques
Introduction: Origins and evolution of graphics

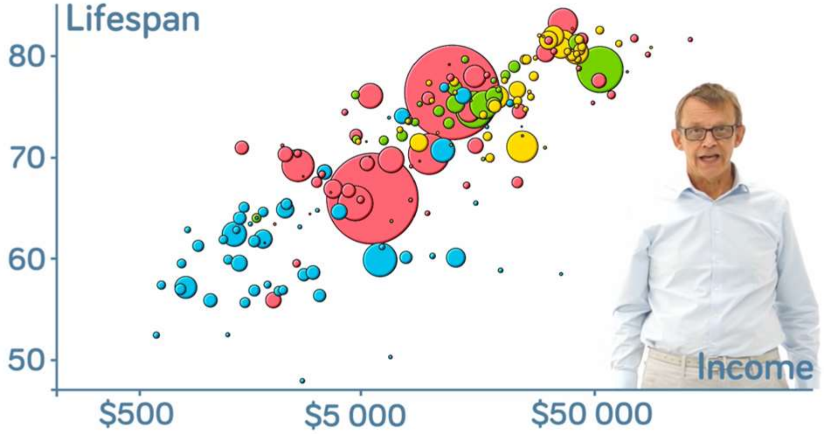
« Graphicacy » is a dramatically understudied cultural invention

LITERACY

NUMERACY

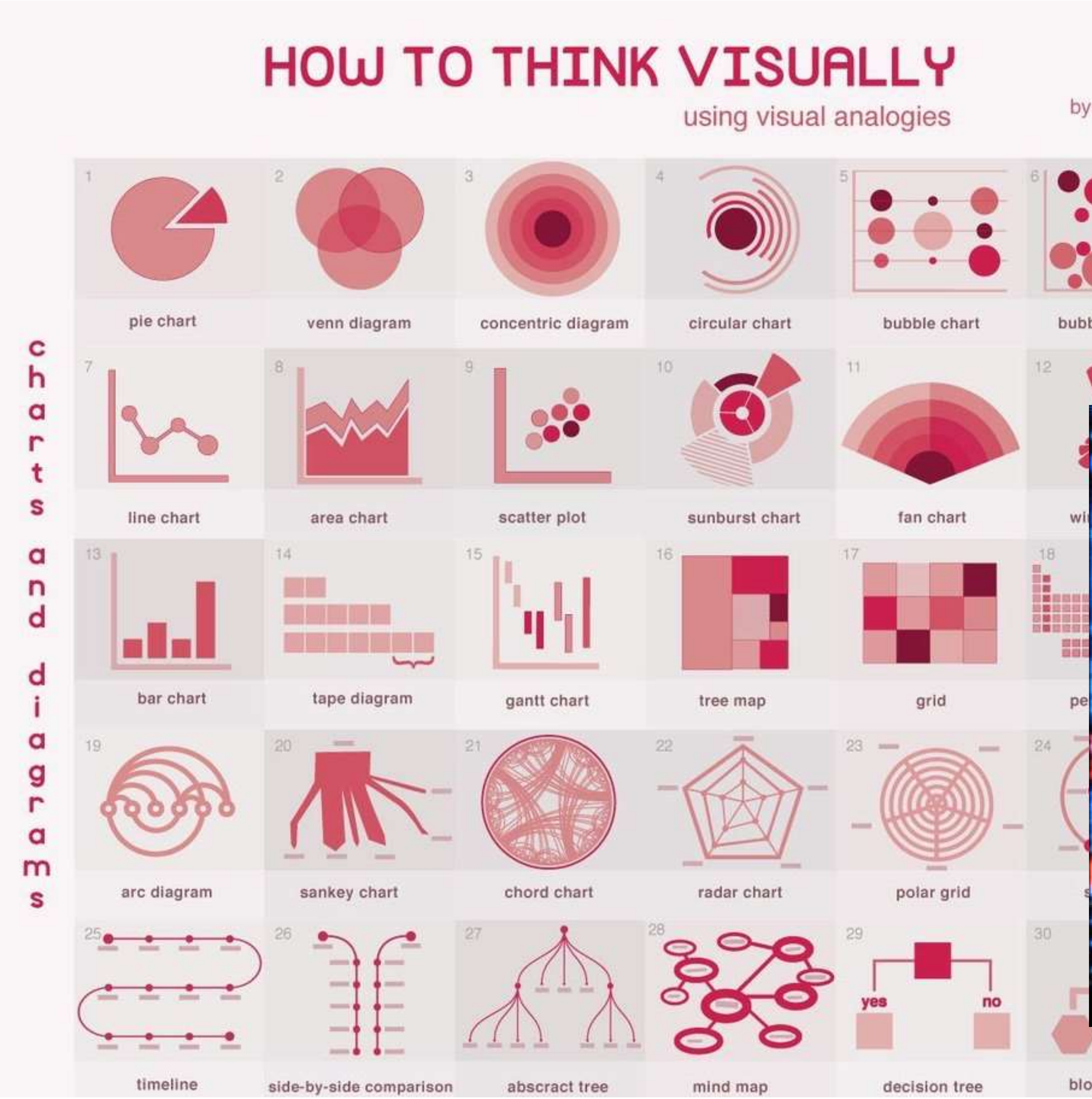


GRAPHICACY

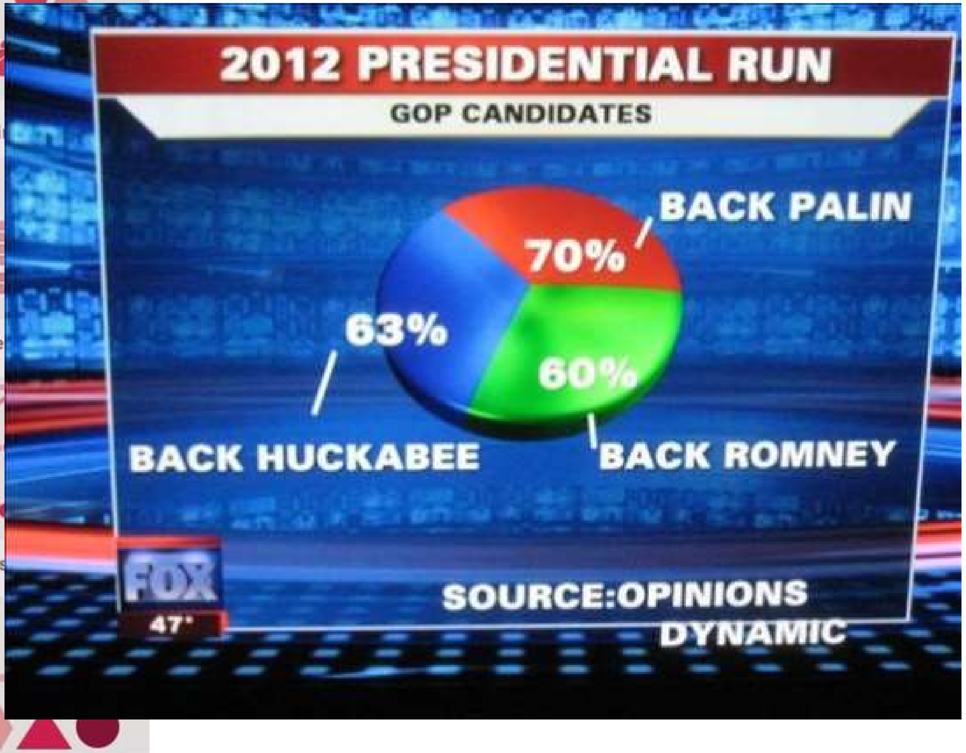


Graphics share many characteristics with words and numbers:

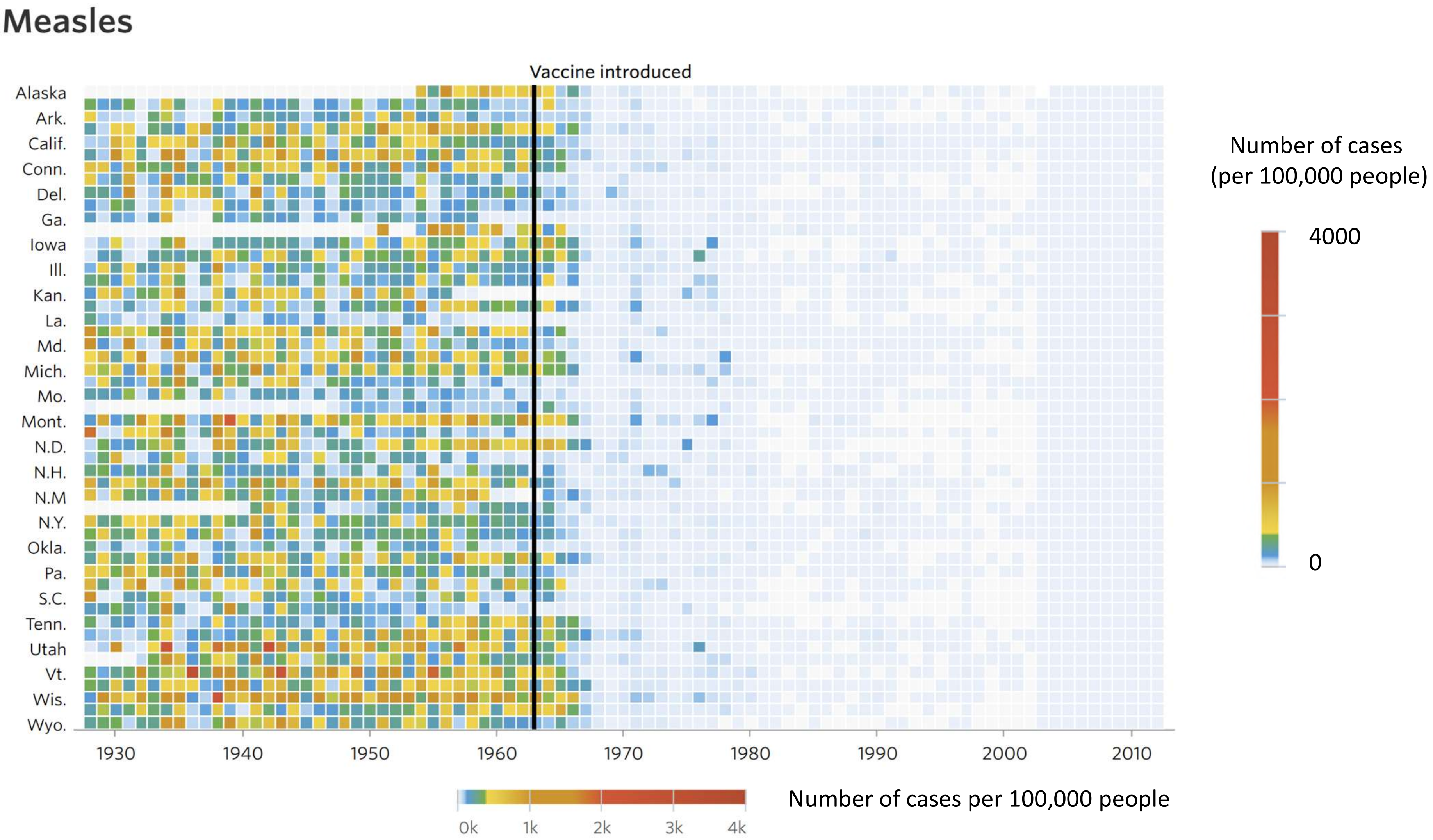
1) They are human **cultural inventions**
2) They are **symbolic** representations forming a graphic language
3) They are based on shared **conventions** (both in terms of semantics and syntax)
4) They require considerable **learning**
5) They are taught at **school** to a highly variable degree
6) They **recycle** the visual channel for efficient information transmission



Data graphics have become an integral part of our symbolic world

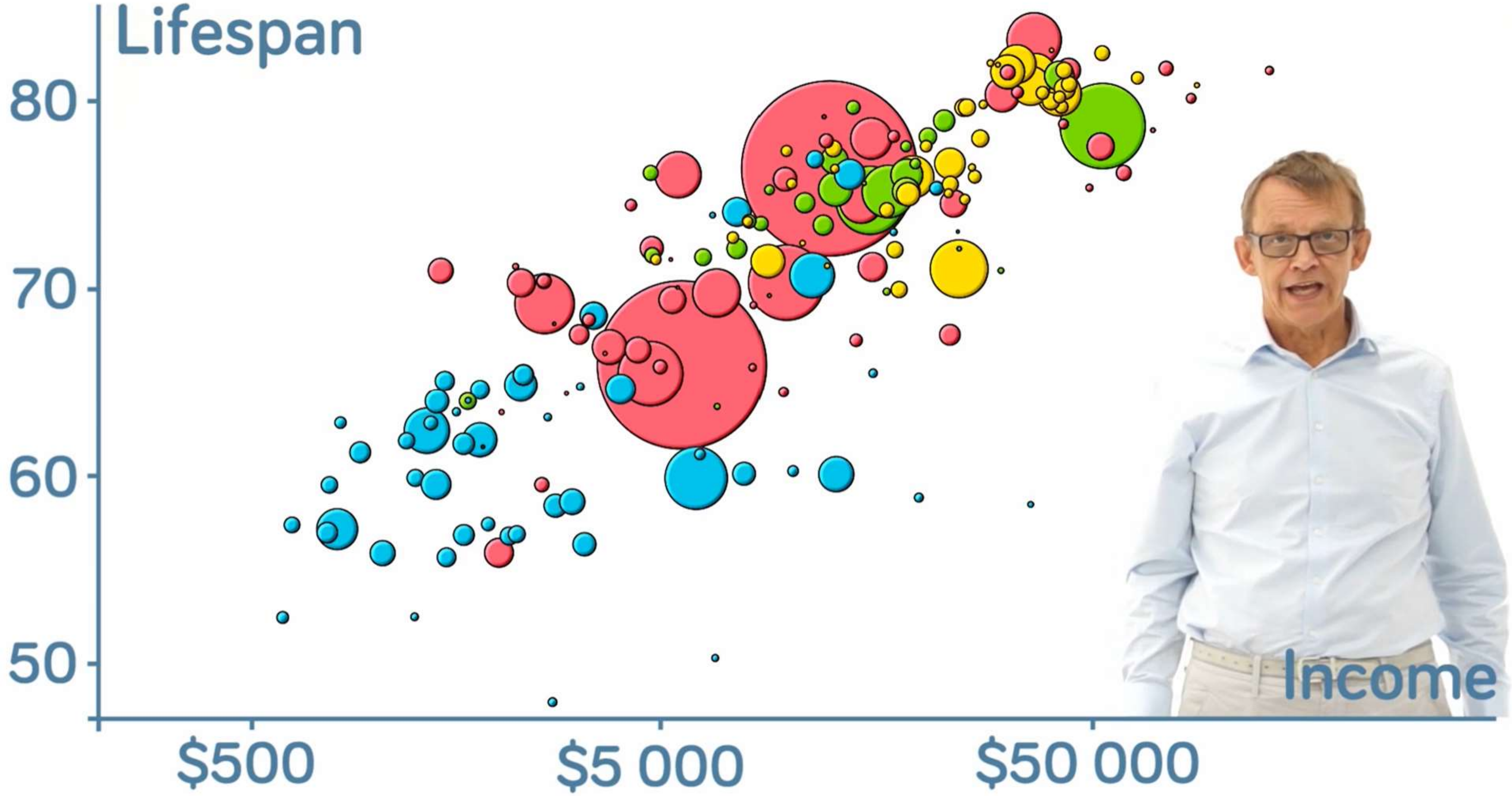


Data graphics can be enormously impactful and easy to read



[Battling Infectious Diseases in the 20th Century: The Impact of Vaccines - WSJ.com]

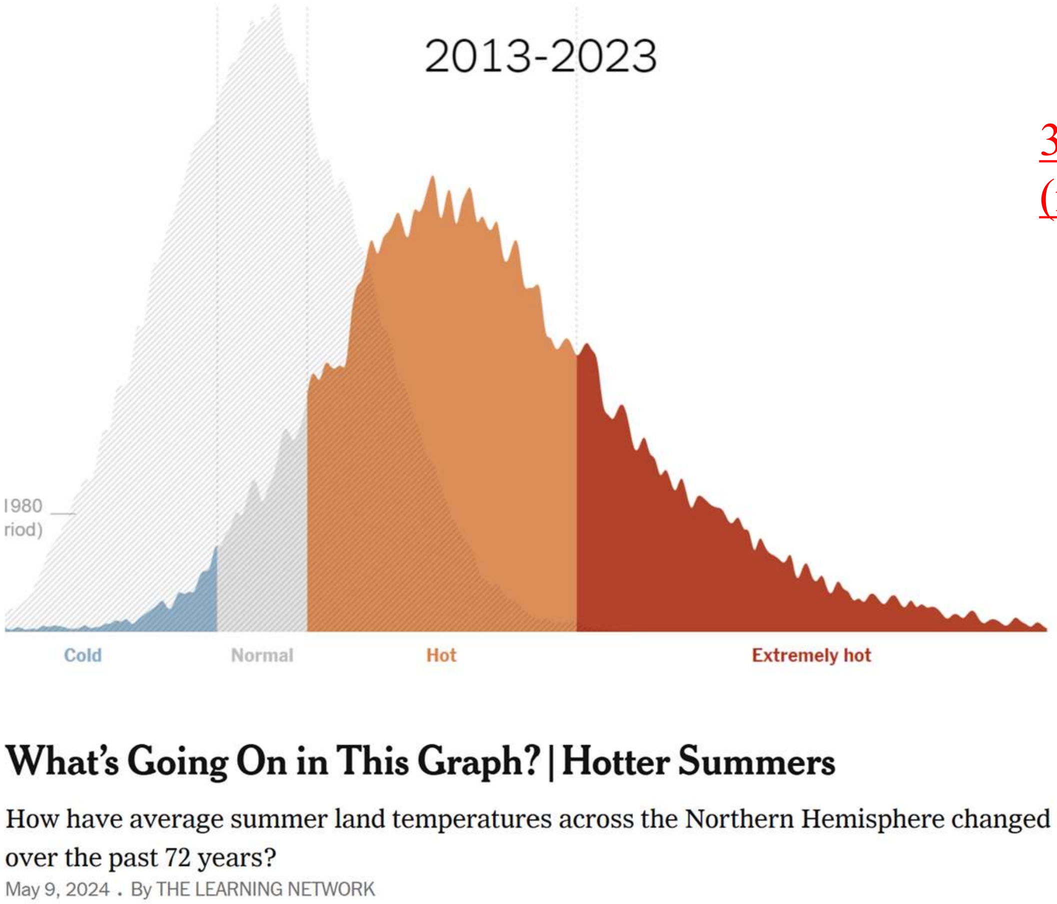
Interactive graphics software makes data visualization even easier to perceive



World Health Chart | Gapminder

Hans Rosling, physician and data scientist, author of *Factfulness*

Beautiful websites explain how graphics work



What's Going On in This Graph? | Hotter Summers

How have average summer land temperatures across the Northern Hemisphere changed over the past 72 years?

May 9, 2024 . By THE LEARNING NETWORK

[30 Climate Change Graphs - The New York Times (nytimes.com)]

[What's Going On in This Graph? | Hotter Summers - The New York Times (nytimes.com)]

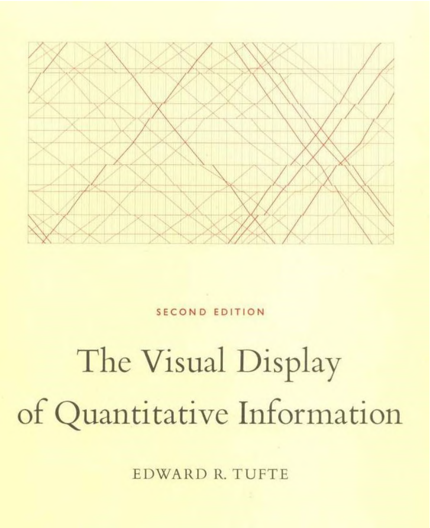
Plan of the course

1. Origins and evolution of graphics
2. Parsing the cognitive stages of graphics perception, comprehension and design

Four cognitive processes needed for graphics comprehension

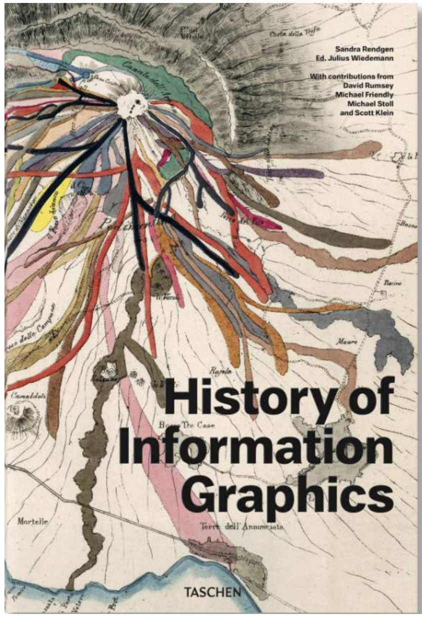
3. Understanding the mapping between numbers and space
4. Perceiving trends and curves
5. Understanding the compositionality of curves and graphics : the grammar of graphics
6. Accessing the meaning of graphics – and how education might improve graphic comprehension

Today : Origins and evolution of graphics



To prepare this course, I used many sources, notably

- Friendly, M., & Wainer, H. (2021). *A History of Data Visualization and Graphic Communication*. Harvard University Press.
- Michael Friendly's Website: Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization
- Kosslyn, S. M. (2006). *Graph Design for the Eye and Mind*. Oxford University Press, USA.
- Munzner, T. (2014). *Visualization Analysis and Design*. A K Peters/CRC Press.
- Rendgen, S., & Wiedemann, J. (2019). *History of Information Graphics* (Multilingual édition). Evergreen.
- Tufte, E. R. (2001). *The Visual Display of Quantitative Information, 2nd Ed.* (2e édition). Graphics Press USA.
- Wilkinson, L., Wills, D., Rope, D., Norton, A., & Dubbs, R. (2005). *The Grammar Of Graphics* (2nd ed. 2005 édition). Springer-Verlag New York Inc.



A very ancient “language of geometry”

See my 2023-2024 course at Collège de France

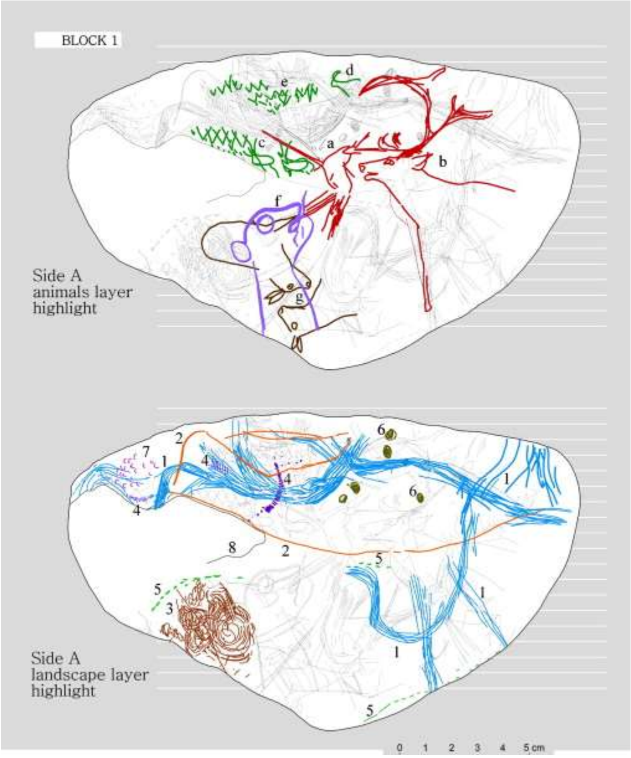
18,000 years ago

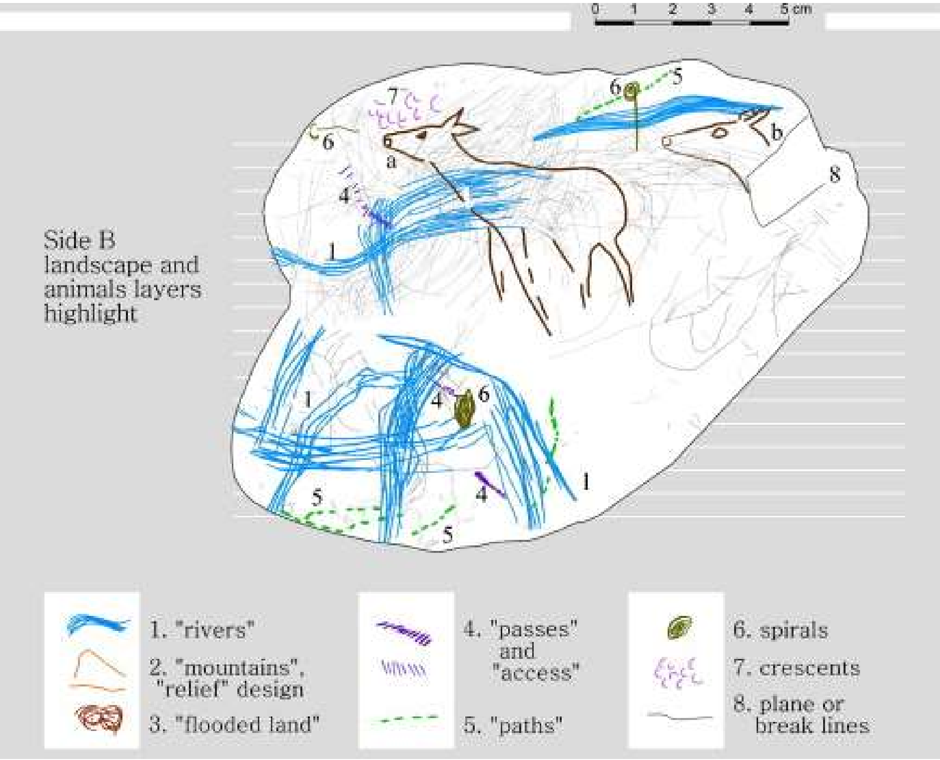
540,000 years ago

70,000-100,000 years ago

2-dimensional representation of the world: maps

The idea of using etchings to produce a conceptual map of the environment may already have occurred during prehistory.
E.g. some researchers have proposed, without solid proof, that Lascaux marks include a map of the night sky, or that an engraved stone block from 13,600 BP contains a map of the surroundings of the cave where it was found.





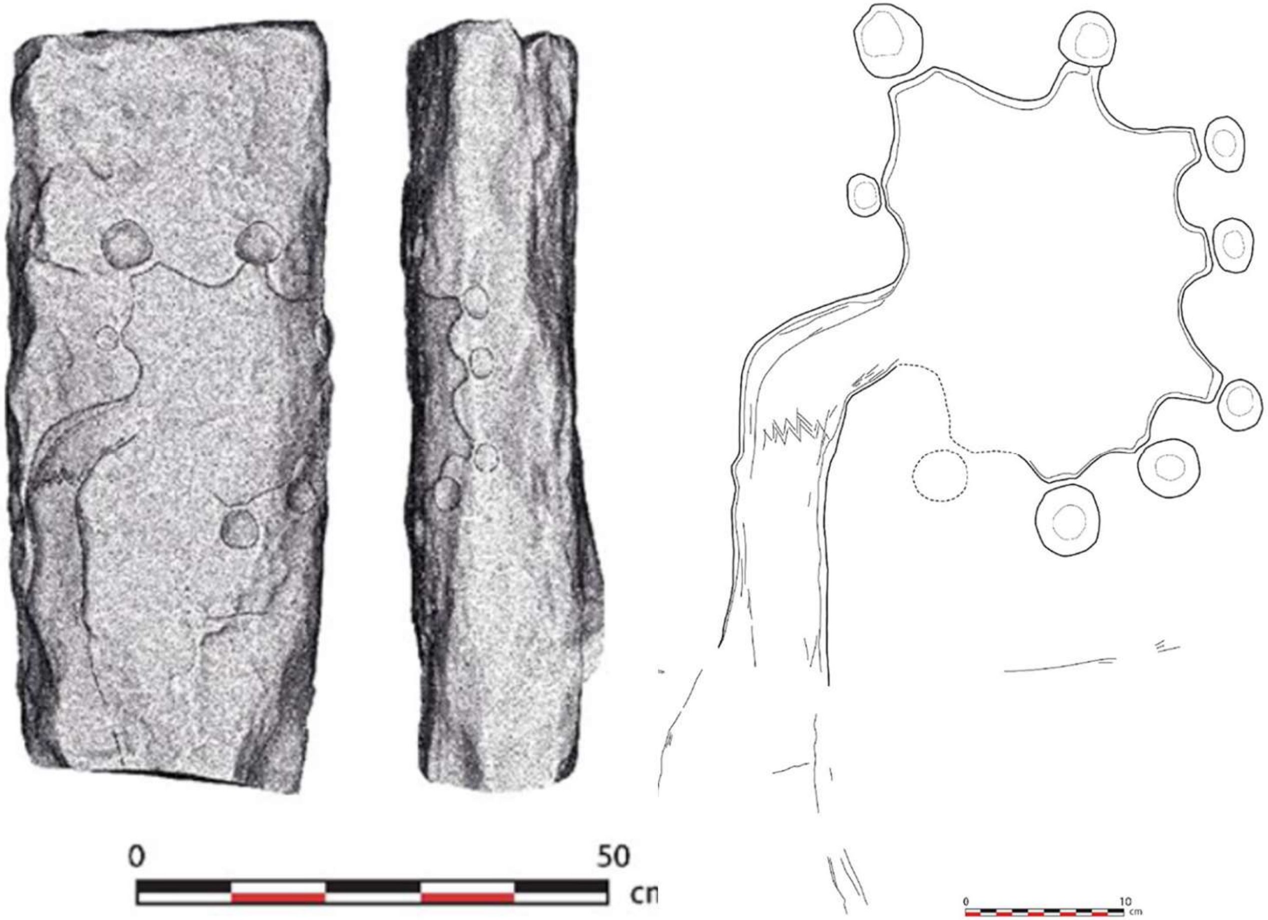
Utrilla, P., Mazo, C., Sopena, M. C., Martínez-Bea, M., & Domingo, R. (2009). A palaeolithic map from 13,660 calBP : Engraved stone blocks from the Late Magdalenian in Abauntz Cave (Navarra, Spain). *Journal of Human Evolution*, *57*(2), 99-111. https://doi.org/10.1016/j.jhevol.2009.05.005

See Michael Friendly's Website: Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization

A clearer example of a stone-age map: the case of desert kites

Crassard, R., Abu-Azizeh, W., Barge, O., Brochier, J. É., Preusser, F., Seba, H., Kiouche, A. E., Régagnon, E., Sánchez Priego, J. A., Almalki, T., & Tarawneh, M. (2023). The oldest plans to scale of humanmade mega-structures. *PLOS ONE*, *18*(5), e0277927. https://doi.org/10.1371/journal.pone.0277927

"Desert kites are gigantic archaeological structures made of stone alignments and walls. Kites are composed of driving lines (from hundreds of meters to 5km long) converging towards an enclosure (median size: 1ha), which is surrounded by up to 4-meter-deep pits (called 'pit-traps', from 1 to more than 20 in number per enclosure) where animals were trapped by hunters."
They are found in Jordan and Saudi Arabia, and some are thought to be 9000 years old.



Concepts of measurement and scale

The idea that number can be used to measure space probably emerged multiple times:

- Measuring distances by counting one’s steps (which even ants do!)

Spatial measurement probably led to the first concept of a graduated number line:

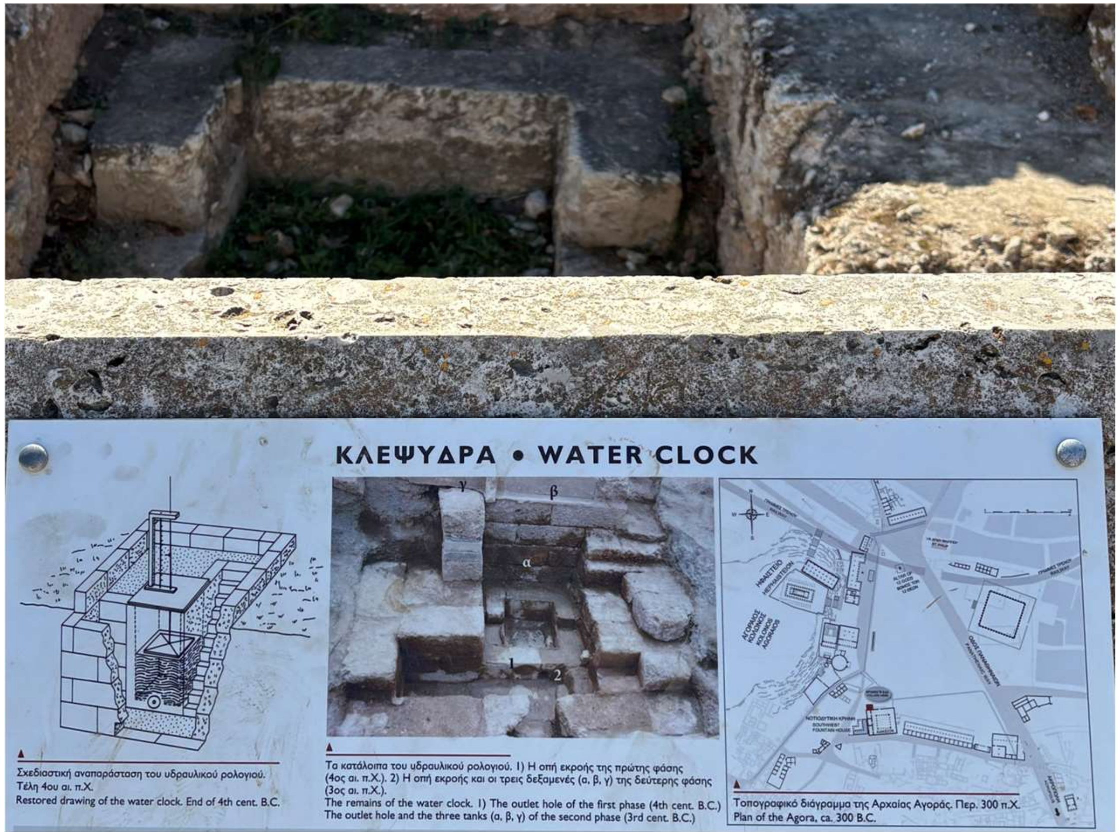
- The cubit (*coudée)* emerged in Ancient Egypt
- The nilometer

Nilometer in Elephantine island

The nilometer in Alexandria

Mapping non-spatial quantities onto space

A key aspect of graphics is the idea that space can be used to depict any non-spatial quantity, such as time.
Example: the Clepsydra or water clock, where time becomes inscribed with marks on a vertical scale.
The oldest one is probably from Egypt (Karnak), ~1400 BC.
The one show here is a reconstruction of Ktesibios’s (308-246 BCE).
Interesting, for a cylindrical vessel, the scale had to be non-linear – a first hint that scales can vary !
Clepsydras could be used to indicate hours, but also to limit the speech time of politicians!

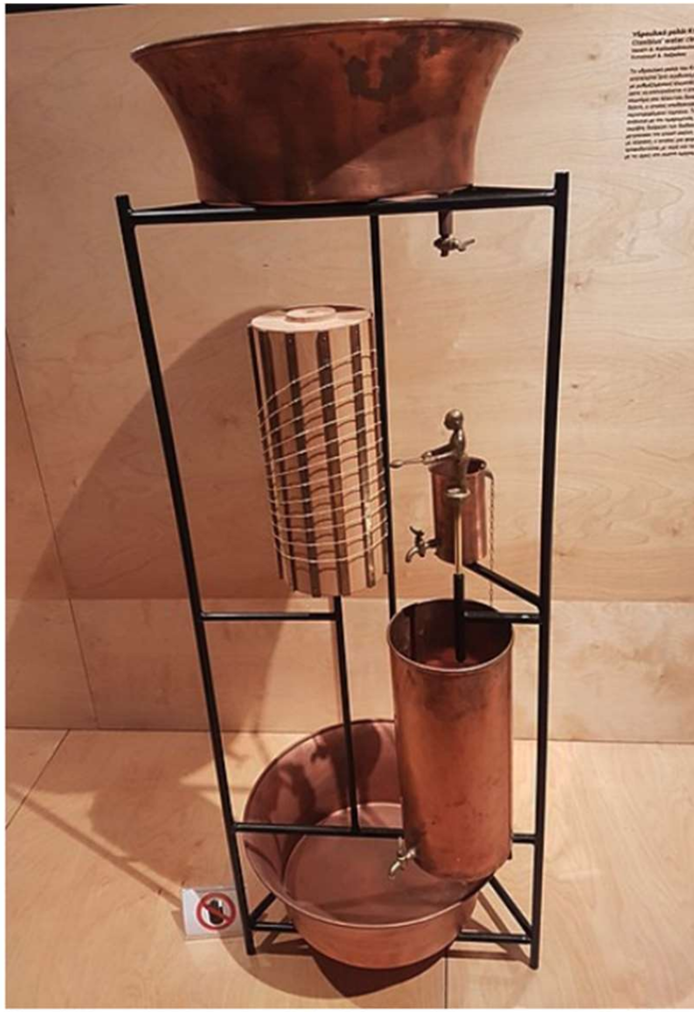


ΚΛΕΨΥΔΡΑ • WATER CLOCK

Σχεδιαστική αναπαράσταση του υδραυλικού ρολογιού.
Τέλη 4ου αι. π.Χ.
Restored drawing of the water clock. End of 4th cent. B.C.

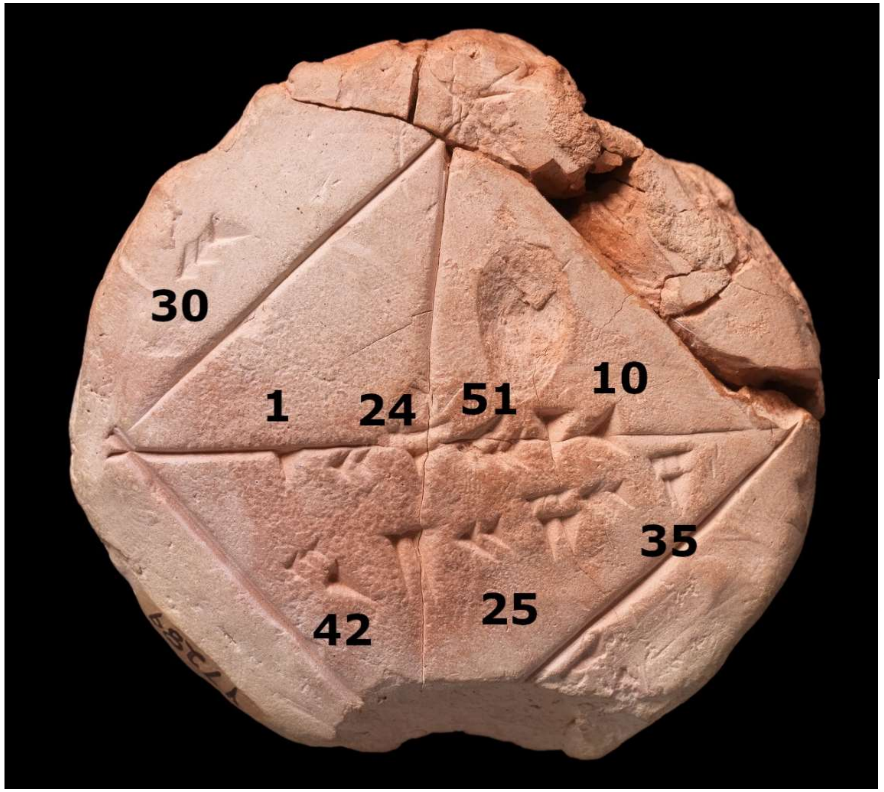
Τα κατάλοιπα του υδραυλικού ρολογιού. 1) Η οπή εκροής της πρώτης φάσης (4ος αι. π.Χ.). 2) Η οπή εκροής και οι τρεις δεξαμενές (α, β, γ) της δεύτερης φάσης (3ος αι. π.Χ.).
The remains of the water clock. 1) The outlet hole of the first phase (4th cent. B.C.) The outlet hole and the three tanks (α, β, γ) of the second phase (3rd cent. B.C.)

Τοπογραφικό διάγραμμα της Αρχαίας Αγοράς. Περ. 300 π.Χ.
Plan of the Agora, ca. 300 B.C.



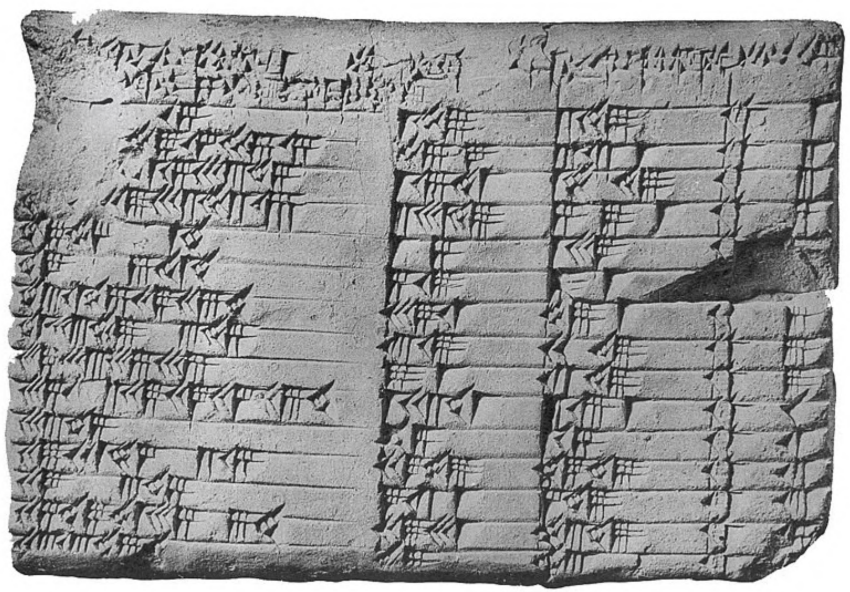
Orthogonal dimensions of space

The “Pythagorean” rule was in fact known much earlier, since Babylonian times (~2000-1600 BCE).



But this could also be 1/2 = 30/60, in which case the numbers indicate $\frac{1}{\sqrt{2}}$ -- the tablet gives a number and its inverse.

This fascinating tablet shows
- The square root of two, in sexagesimal notation 1 24 51 10, so up to 6 decimal places (1.41421296… instead of 1,41421356...).
- An application to a square of length 30, where the hypothenuse is 42 25 35 in sexagesimal notation.



The other side shows a rectangle with its hypothenuse.

This other tablet shows a Babylonian record of Pythagorean integer triples.

Coordinates : Claude Ptolemaius (Κλαύδιος Πτολεμαῖος; ~90-168 AD) and the systematic collection and mapping of numerical data

Ptolemy's ***Geography*** (whose title literally translates as "*Guide to Drawing the Earth")*, written around 150, aimed to collect all of the geographical **coordinates** of the time (the ancestor of today's big data!), in a form suitable to create a **map**.

The first book explains how to collect geographical data (longitudes and latitudes). It can be seen as a "manual" for the books II-VII, which consist entirely of tables of coordinates for more than 8000 places.

The end of book VII is a "**legend**" *(hypographe*, literally "what should be written under [each map]"*)*, while book VIII contains 26 other descriptions, thus suggesting that the *Geography* could have contained 27 maps (a whole map and some regional maps).

However, it is unclear whether the manual was actually accompanied by maps, or only contained the instructions to draw them. Versions with maps was recreated only much later, in the 13th century, when Maxime Planude discovered a manuscript without maps and, with great pains, redrew all the maps.

A latin translation was then published (1406) as *Cosmographia di Ptolomeo con la pictura* and became a huge success and a reference text.

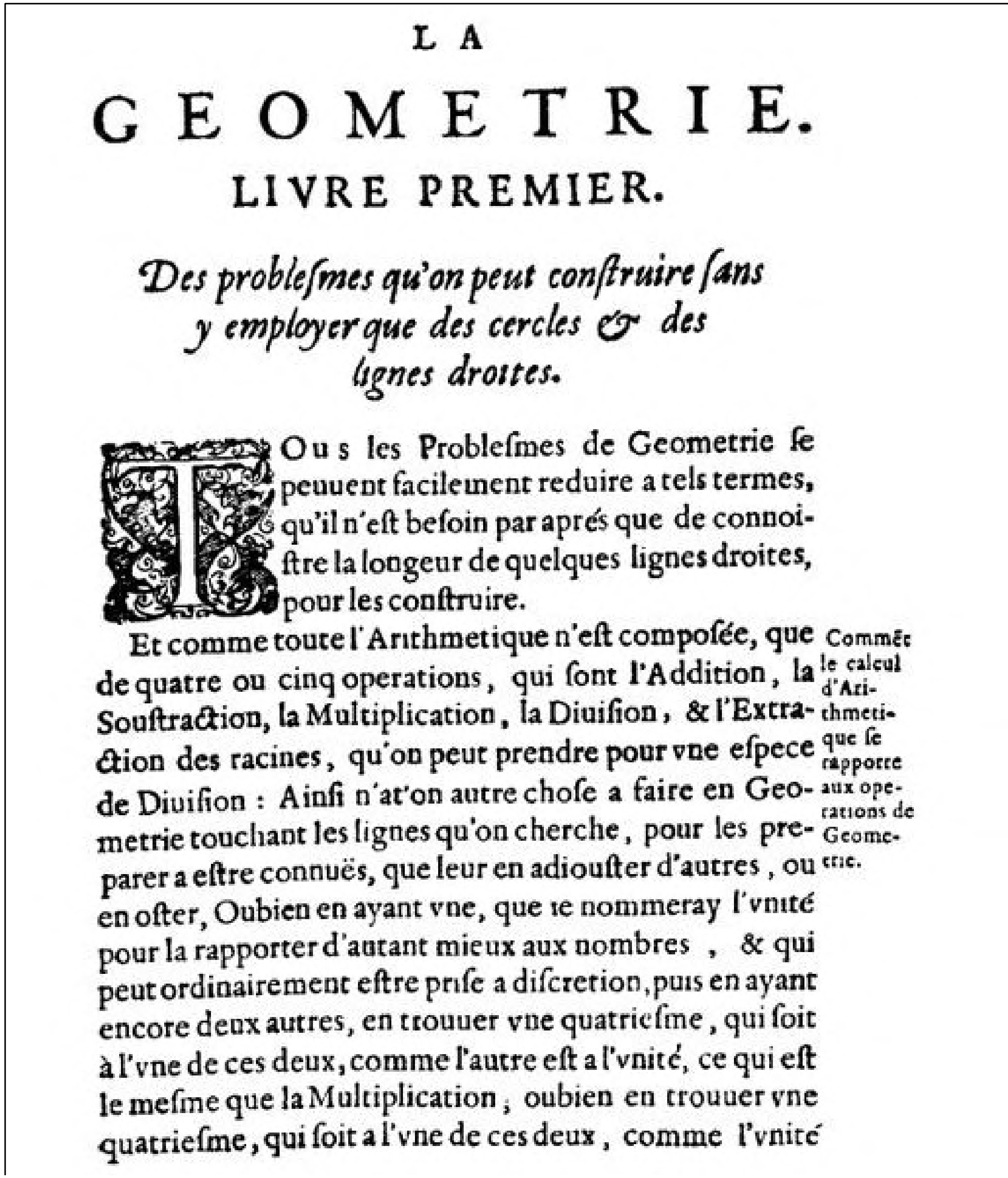
Cartesian coordinates

In La Géométrie, published in 1637, René Descartes shows how to solve some geometrical problems by representing points using numbers (and representing unknowns by x and y, and knowns by a, b,c, etc).

Before this idea (which was also shared by Pierre de Fermat), arithmetic/algebra and geometry were largely separate fields of mathematics.
His creation led to a fusion, *algebraic geometry.*

According to Encyclopedia Britannica: “According to legend, Descartes was inspired to devise his coordinate system by a fly he saw crawling on a tiled ceiling. He was curious how he might use numbers to describe the position of the fly and decided one way would be to choose a corner of the ceiling and count the tiles both horizontally and vertically from that corner to the fly. The result would be two numbers expressing exactly which tile the fly was on.”

Descartes never explicitly stated a 2D representation with an orthogonal coordinate system – but this was implicit in his work, and was made explicit by other mathematicians such as Frans van Schooten, a professor of mathematics at Leiden who published several extended versions in Latin.
The word “coordinates” itself is due to Leibniz.



LA

GEOMETRIE.

LIVRE PREMIER.

Des probleſmes qu'on peut conſtruire ſans y employer que des cercles & des lignes droites.

TOus les Probleſmes de Geometrie ſe peuuent facilement reduire a tels termes, qu'il n'eſt beſoin par aprés que de connoiſtre la longeur de quelques lignes droites, pour les conſtruire.

Et comme toute l'Arithmetique n'eſt compoſée, que de quatre ou cinq operations, qui ſont l'Addition, la Souſtraction, la Multiplication, la Diuiſion, & l'Extraction des racines, qu'on peut prendre pour vne eſpece de Diuiſion : Ainſi n'a-t'on autre choſe a faire en Geometrie touchant les lignes qu'on cherche, pour les preparer a eſtre connuës, que leur en adiouſter d'autres, ou en oſter, Oubien en ayant vne, que ie nommeray l'vnité pour la rapporter d'autant mieux aux nombres , & qui peut ordinairement eſtre priſe a diſcretion, puis en ayant encore deux autres, en trouuer vne quatrieſme, qui ſoit à l'vne de ces deux, comme l'autre eſt a l'vnité, ce qui eſt le meſme que la Multiplication ; oubien en trouuer vne quatrieſme, qui ſoit a l'vne de ces deux, comme l'vnité

Commẽt le calcul d'Arithmetique ſe rapporte aux operations de Geometrie.

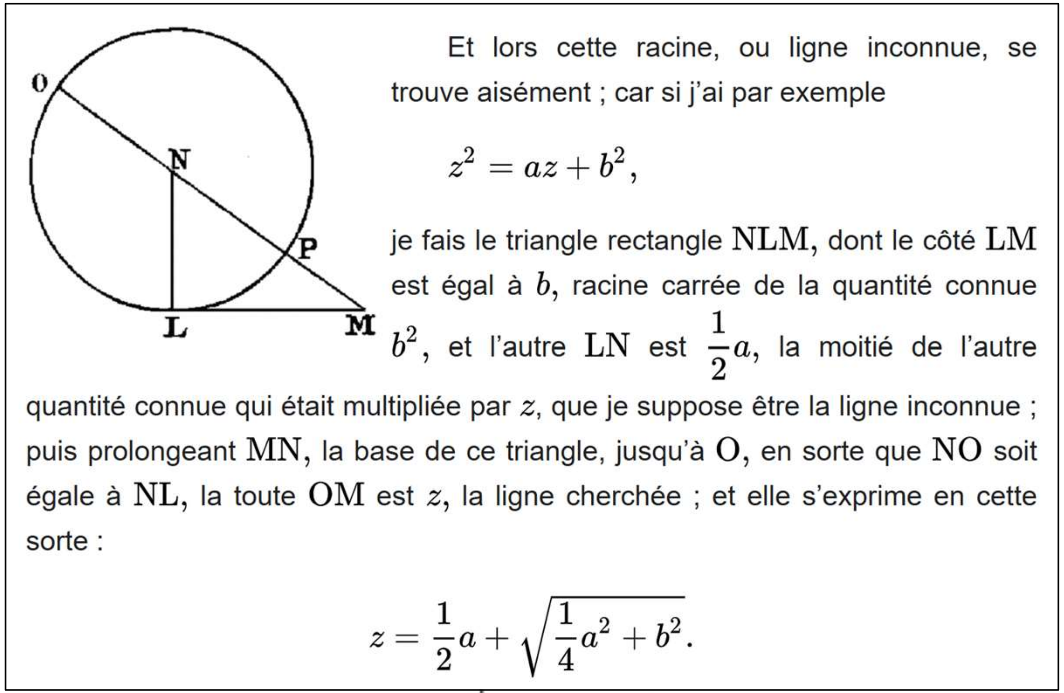
Cartesian coordinates

Close to the beginning is a paragraph entitled « Comment on peut user de chiffres en géométrie » :

« Mais souvent on n’a pas besoin de tracer ainsi ces lignes sur le papier, et il suffit de les désigner par quelques lettres, chacune par une seule. »

« Si [la question] peut être résolue par la géométrie ordinaire, c’est-à-dire en ne se servant que de lignes droites et circulaires tracées sur une superficie plate, lorsque la dernière équation aura été entièrement démêlée, il n’y restera tout au plus qu’un carré inconnu ».

« lorsque cette équation ne monte que jusqu’au rectangle de deux quantités indéterminées, ou bien au carré d’une même, la ligne courbe est du premier et plus simple genre, dans lequel il n’y a que le cercle, la parabole, l’hyperbole et l’ellipse qui soient compris. »

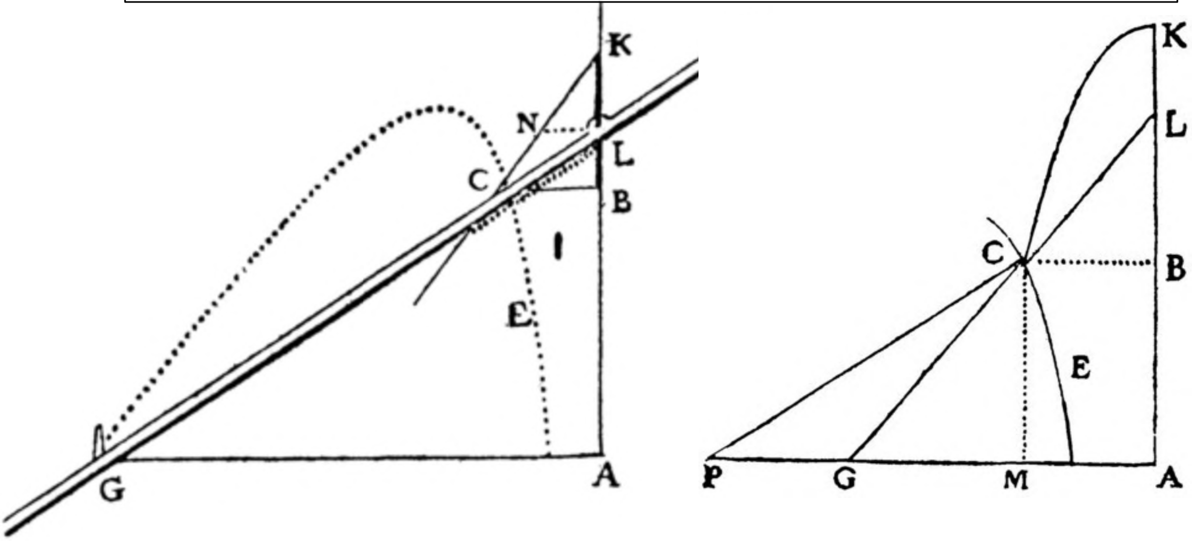


Et lors cette racine, ou ligne inconnue, se trouve aisément ; car si j’ai par exemple

$$z^2 = az + b^2,$$

je fais le triangle rectangle NLM, dont le côté LM est égal à b, racine carrée de la quantité connue b^2, et l’autre LN est $\frac{1}{2}a$, la moitié de l’autre quantité connue qui était multipliée par z, que je suppose être la ligne inconnue ; puis prolongeant MN, la base de ce triangle, jusqu’à O, en sorte que NO soit égale à NL, la toute OM est z, la ligne cherchée ; et elle s’exprime en cette sorte :

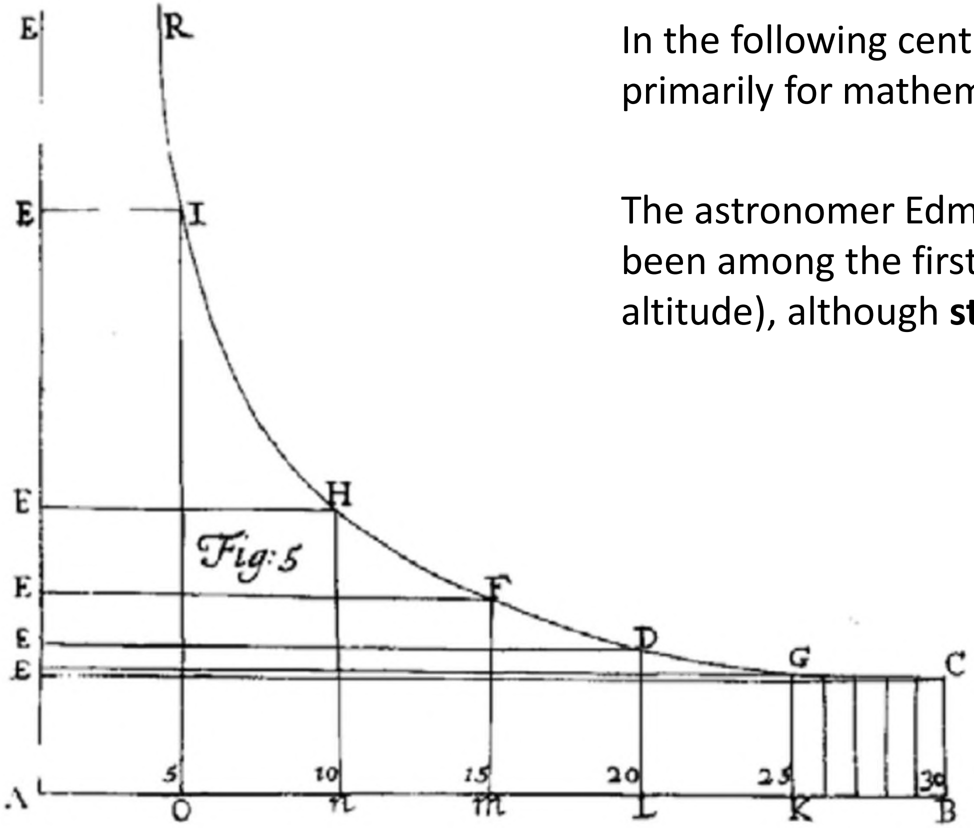
$$z = \frac{1}{2}a + \sqrt{\frac{1}{4}a^2 + b^2}.$$



From the mathematical use of graphics to the visualization of physical quantities

In the following centuries, graphics were rarely used, and primarily for mathematical purposes.

The astronomer Edmund Halley (1656-1742) seems to have been among the first to plot physical variables (pressure versus altitude), although **still in a theoretical form**.

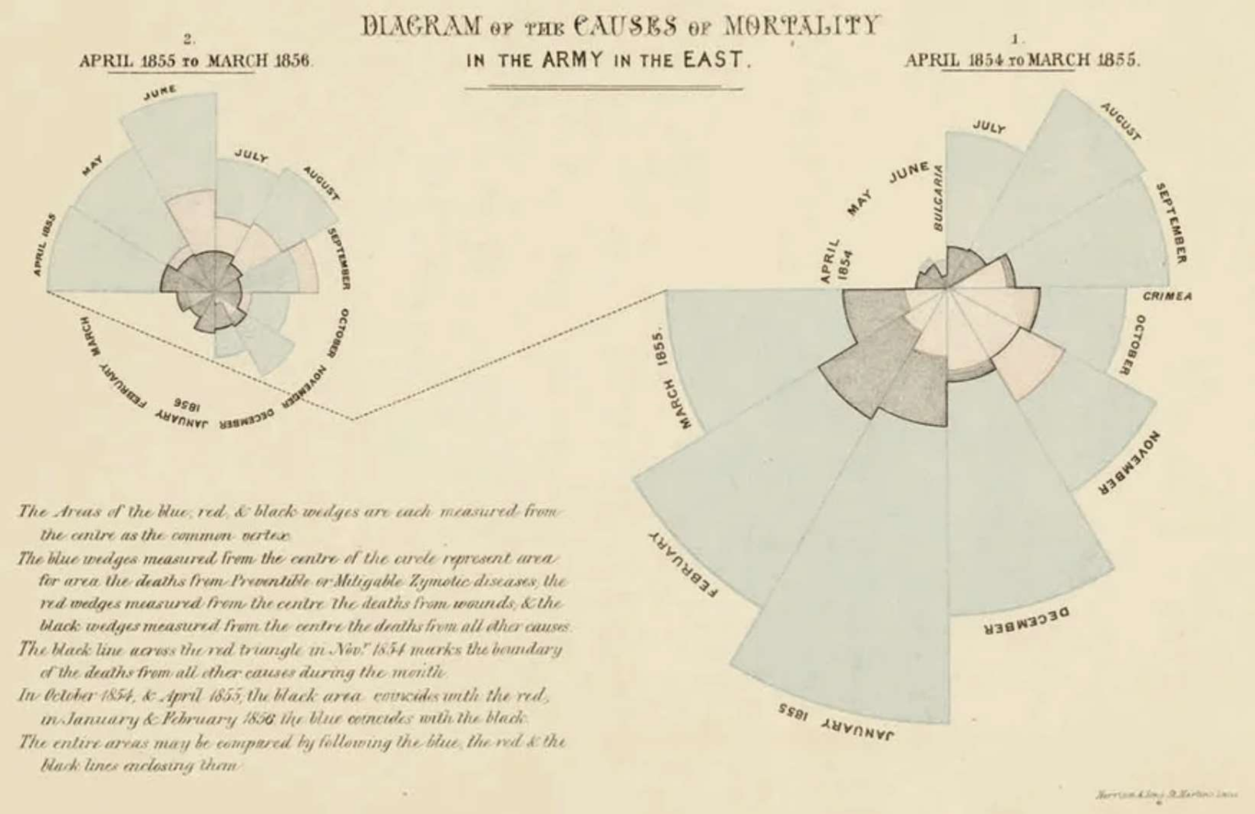


Halley, 1686

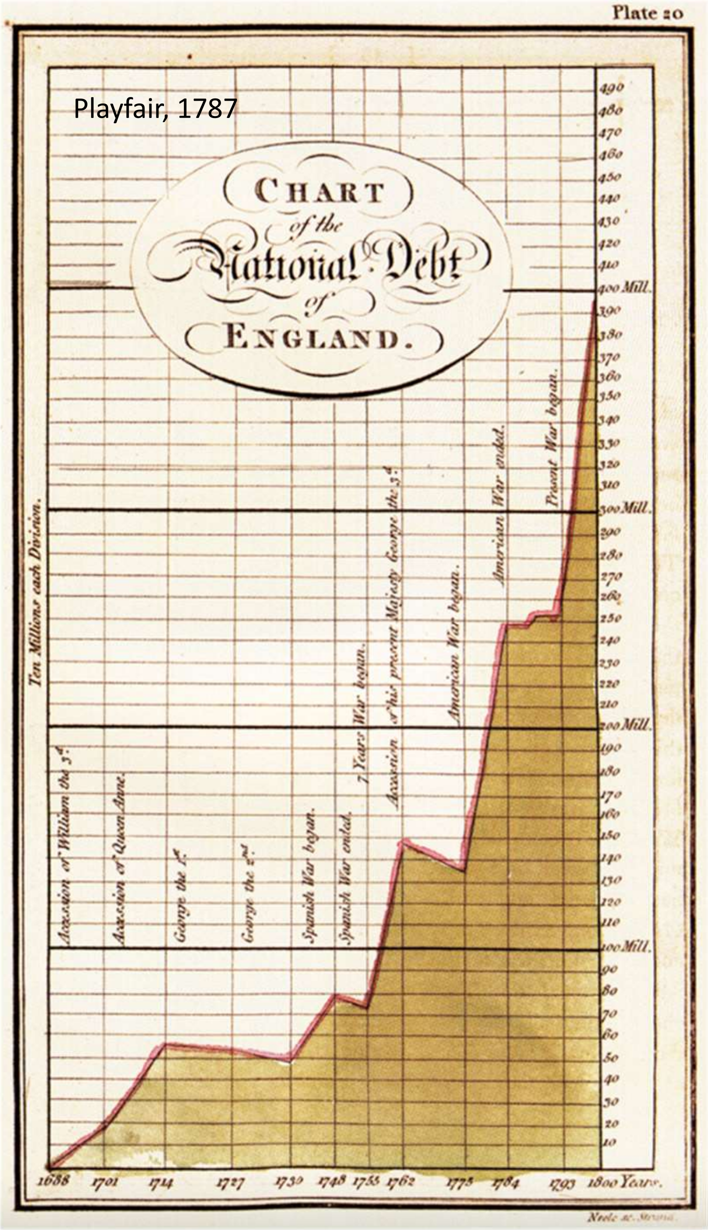
The statistical use of graphics for data science

Engineer and economist William Playfair (1759-1823) understood that the power of graphics lied in their ability to reveal patterns hidden in numbers and data – without having to struggle with tables, and in a striking manner that immediately appealed to readers.

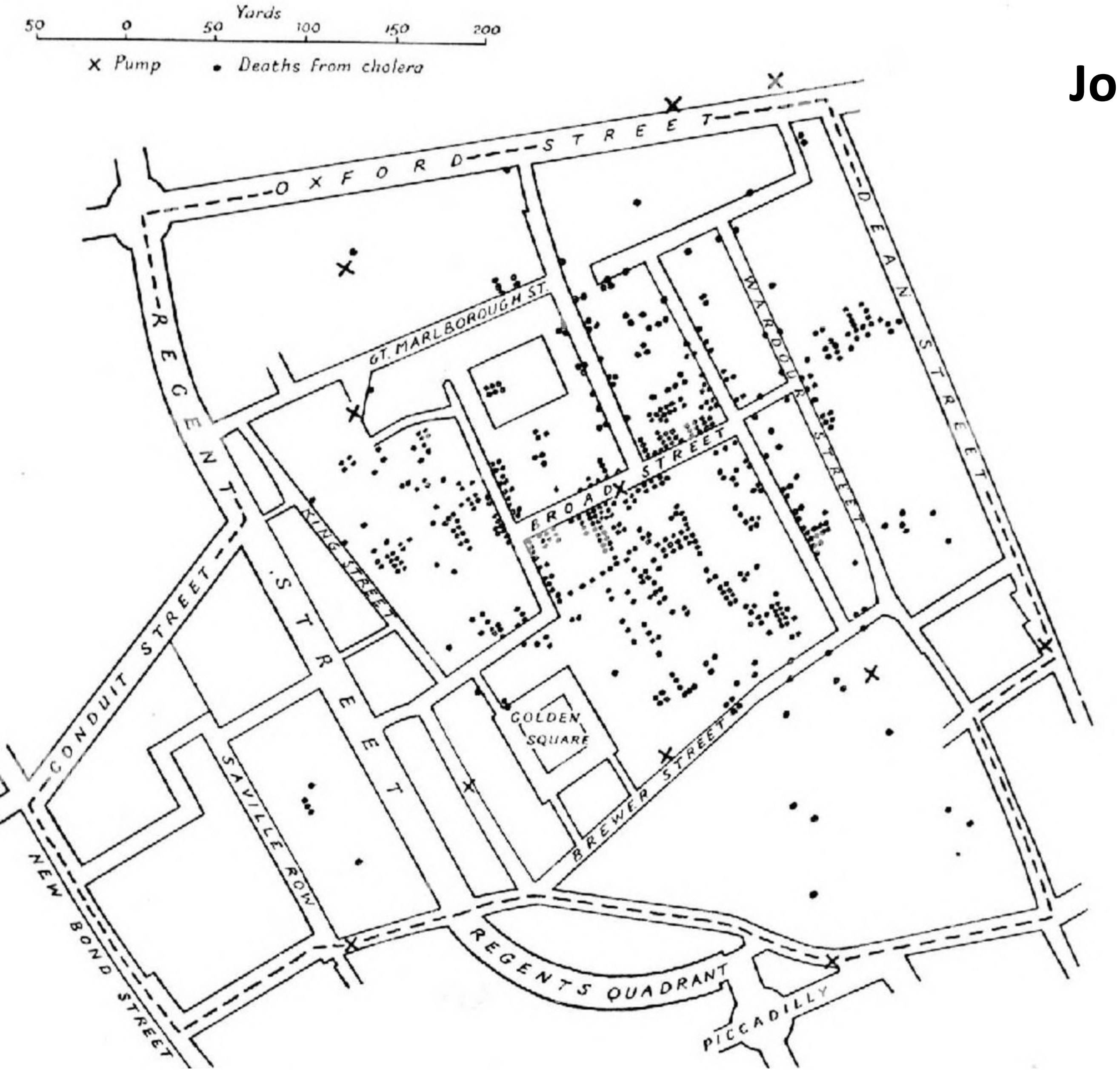
In another famous graph (circular and using area), nurse Florence Nightingale (1820-1910) revealed that most of the British deaths in the Crimean war were due to preventable disease (from poor sanitation and overcrowded barracks) rather than wounds.



The Areas of the blue, red, & black wedges are each measured from the centre as the common vertex.
The blue wedges measured from the centre of the circle represent area for area the deaths from Preventible or Mitigable Zymotic diseases, the red wedges measured from the centre the deaths from wounds, & the black wedges measured from the centre the deaths from all other causes.
The black line across the red triangle in Nov.r 1854 marks the boundary of the deaths from all other causes during the month.
In October 1854, & April 1855, the black area coincides with the red, in January & February 1856 the blue coincides with the black.
The entire areas may be compared by following the blue, the red & the black lines enclosing them.



Playfair, 1787

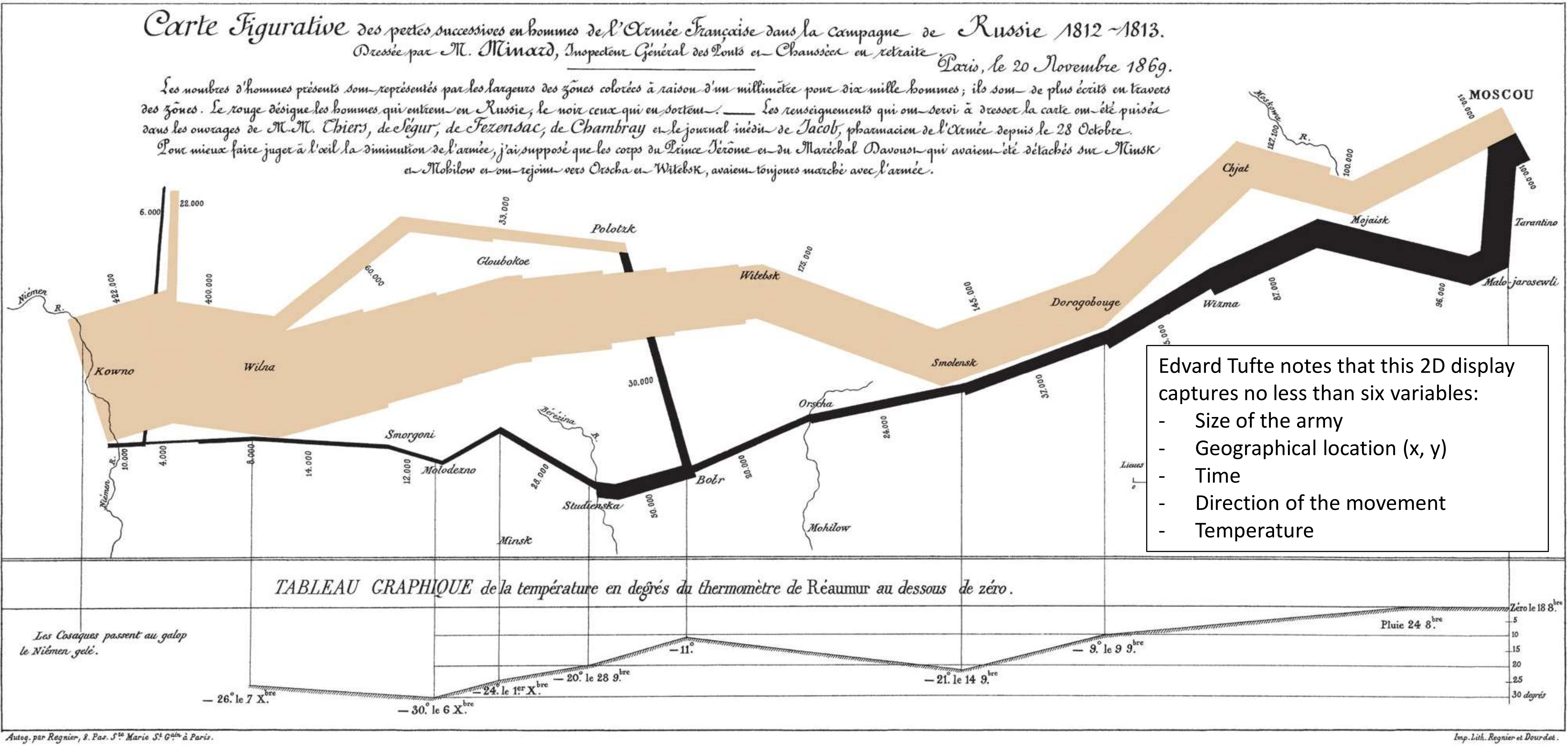


John Snow’s 1854 cholera map: cartography for statistics

John Snow (1813-1858) was an English physician and an early founder of epidemiology and medical hygiene.
He famously traced back a dramatic epidemy of cholera in London to the contamination of a specific water pump in Broad Street.
After he advised to remove the handle of the water pump, the epidemic stopped.
Snow’s map offers a unique combination of histogram and geographical information.
It would be very hard to convey the same information in numerical or tabular form – for the first time perhaps, the visual perception of a graphic provides a new way to analyze data.

Charles-Joseph Minard (1781-1870) and the golden age of data visualization

Admitted to Polytechnique at the age of 15, Minard worked as a civil engineer, but also produced 51 data maps considered as exemplary.



Edvard Tufte notes that this 2D display captures no less than six variables:

- Size of the army
- Geographical location (x, y)
- Time
- Direction of the movement
- Temperature

Etienne-Jules Marey (1830-1904) and *La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine (2nd edition, 1885)*

Marey, professor at Collège de France between 1869 and 1904, is best known for his studies of the physiology of locomotion, notably using chronophotography (a method that he invented, following up on Muybridge's studies).

However, he also published an extensive treatise on the use of graphics in experimental sciences, with hundreds of examples of data graphics and how to record data graphically.
He saw graphics as a way to compensate for the weaknesses of our sense and our language:

"La science a devant elle deux obstacles qui entravent sa marche: c'est d'abord la défectuosité de nos sens pour découvrir les vérités, et puis l'insuffisance du langage pour exprimer et pour transmettre celles que nous avons acquises. [..] la *méthode graphique* atteint mieux que tout autre ce double but."
"[Ces données expérimentales], la méthode graphique les traduit sous une forme saisissante que l'on pourrait appeler le langage des phénomènes eux-mêmes".

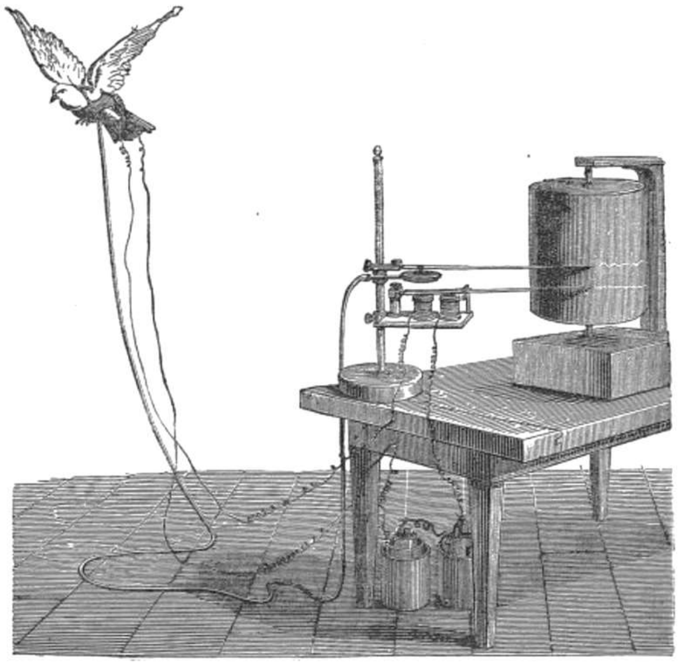


Fig. 70. Oiseau transmettant les battements de ses ailes à un signal électro-magnétique et à un myographe inscripteur.

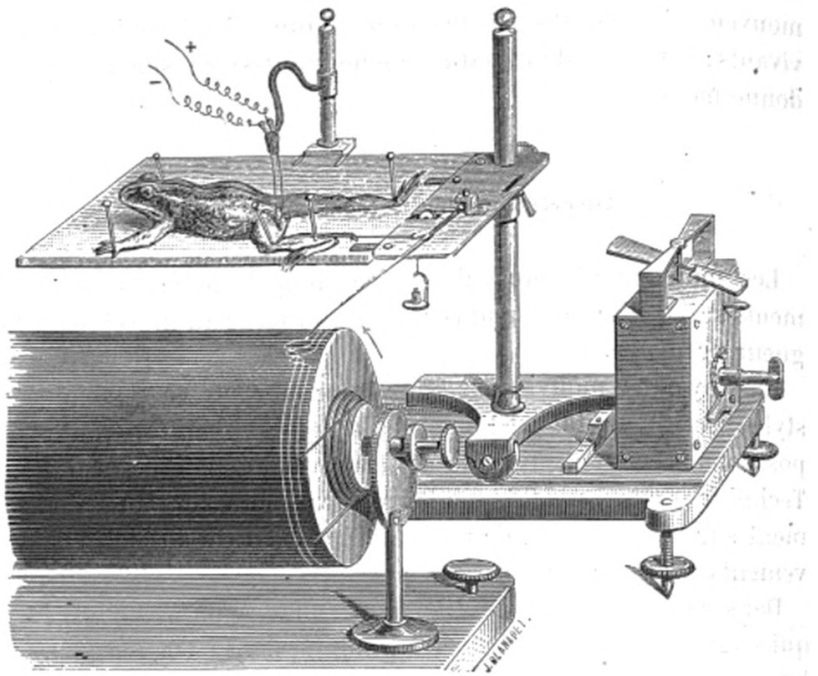


Fig. 97. Myographe simple.

Etienne-Jules Marey (1830-1904) and *La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine* (2nd edition, 1885)

« La méthode graphique exprime les phénomènes les plus variés, transforme d’obscures statistiques en une exposition lumineuse, condense sous le regard et fait embrasser d’un coup d’œil une quantité énorme de documents. »

This is a nice statement of the key properties of graphics:
- the capacity to plot in space a variety of data, whether spatial or not (time, quantities)
- their readability and interpretability (“une loi numérique apparaît, saisissante, lumineuse…”)
- their parallel processing, allowing to process thousands of data points in a single glance

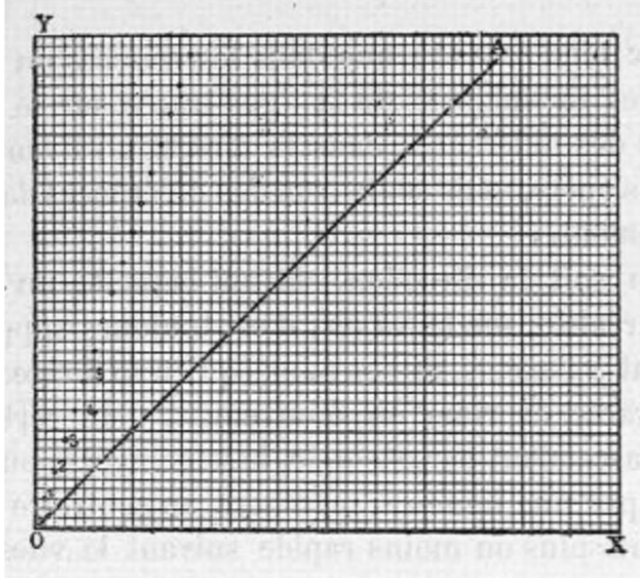
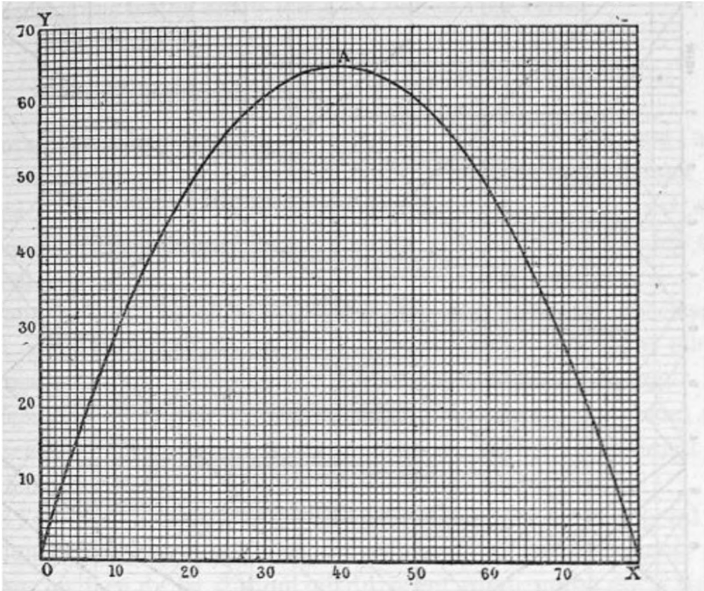


Fig. 5. Expressions graphiques du mouvement uniforme.



. 6. Expression graphique d'un mouvement varié (mouvement uniformément diminué OA ; mouvement uniformément accéléré AX).

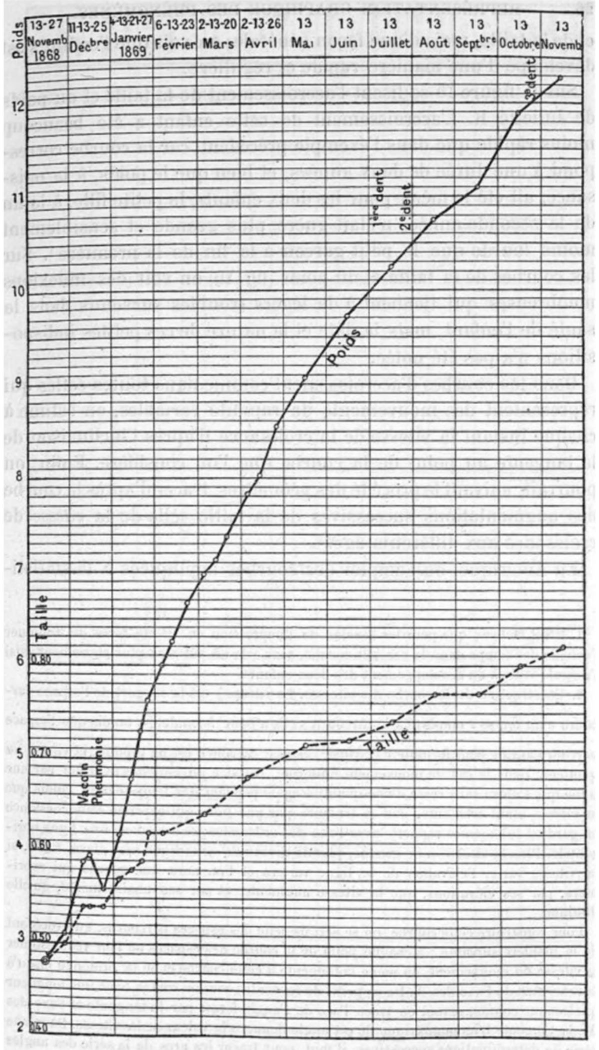


Fig. 9. Courbes de l'accroissement de la taille et du poids de Jean Lorain pendant sa première année.

Etienne-Jules Marey (1830-1904) and *La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine* (2nd edition, 1885)

The eye is sensitive to subtle properties, for instance the periodic growth and stopping of a plant with the night/day cycle.

« Il y a là un vaste champ à explorer. »

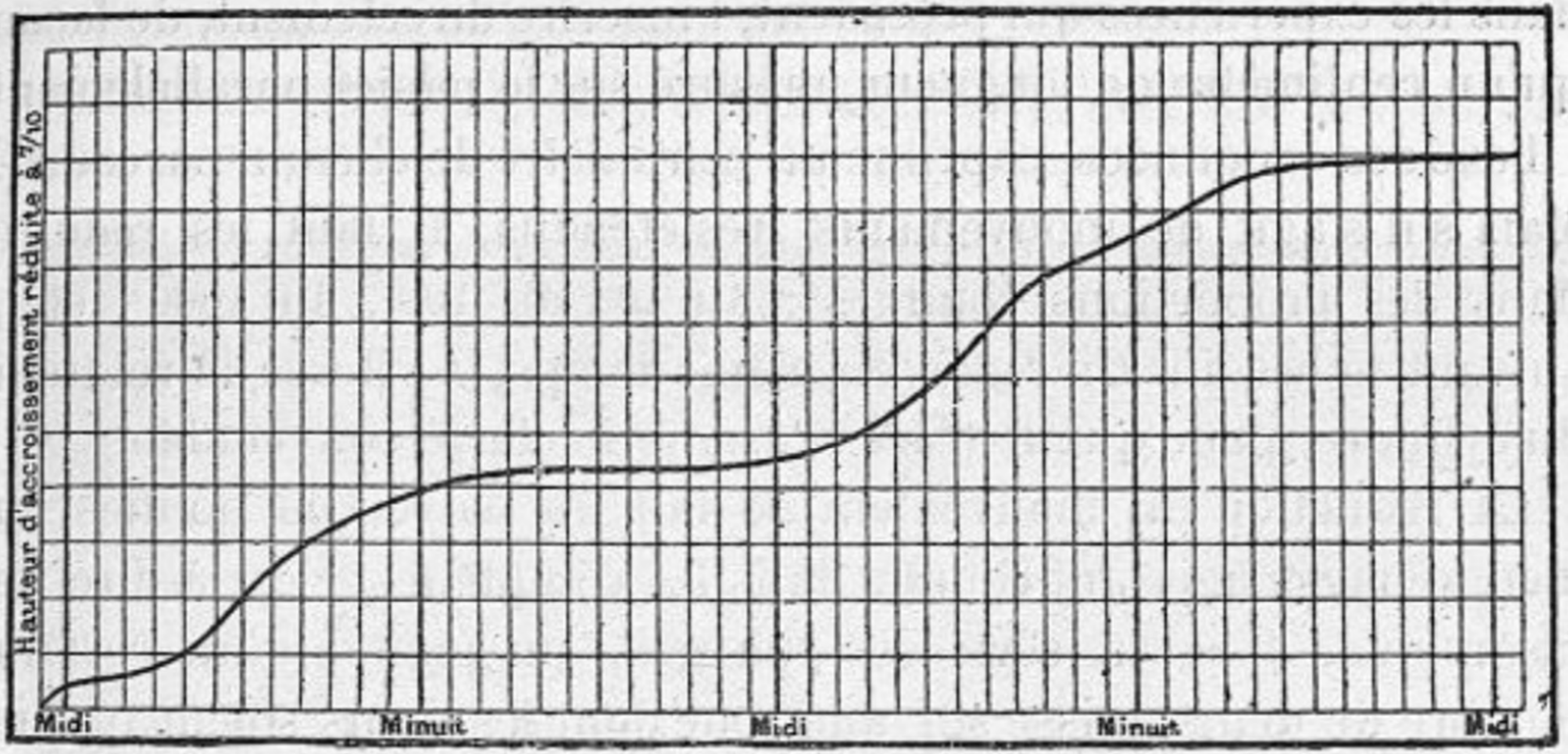


Fig. 92. Courbe de l'accroissement d'une tige de Paulownia, aux différentes heures du jour et de la nuit.

Etienne-Jules Marey (1830-1904) and *La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine* (2nd edition, 1885)

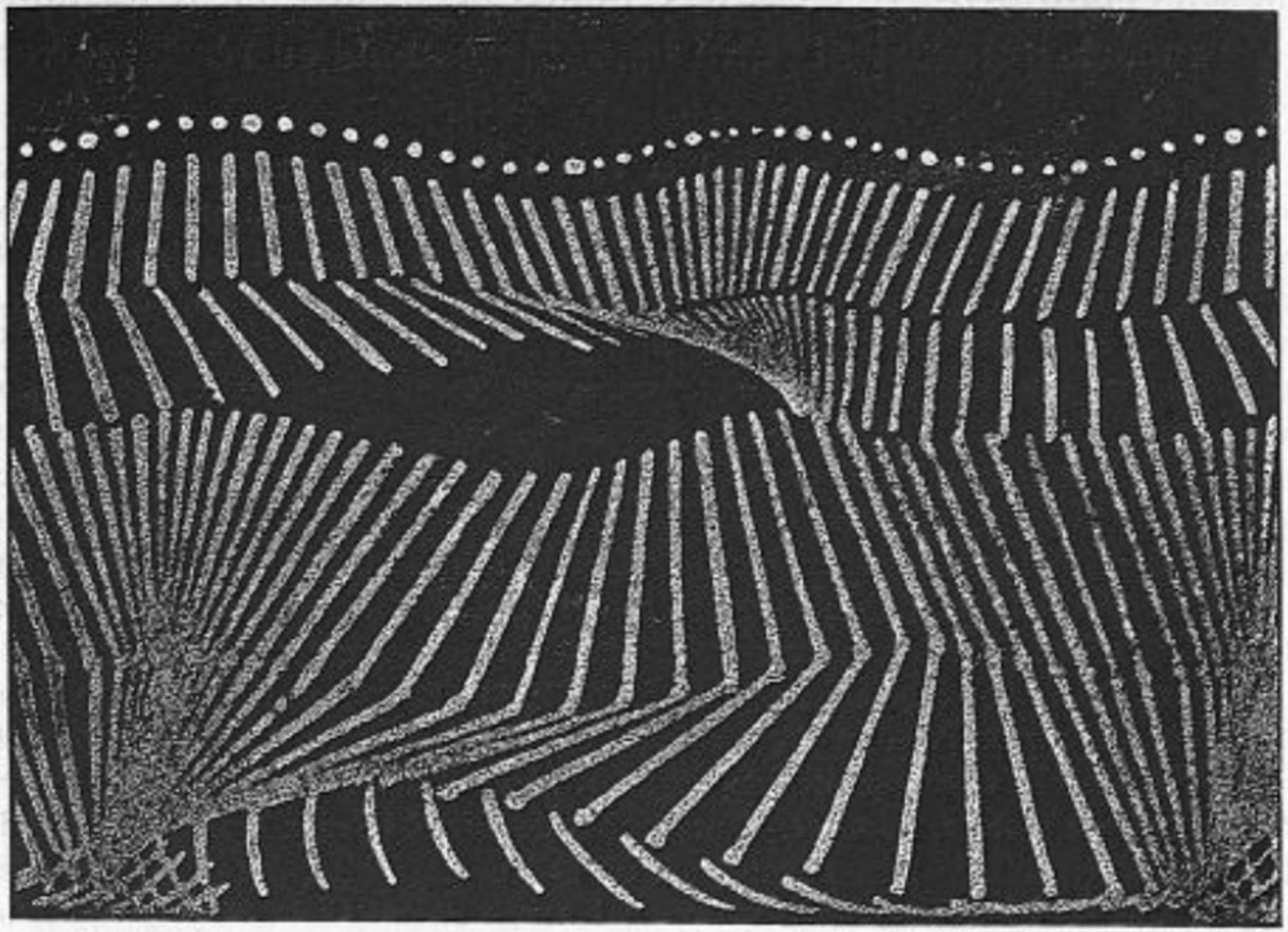
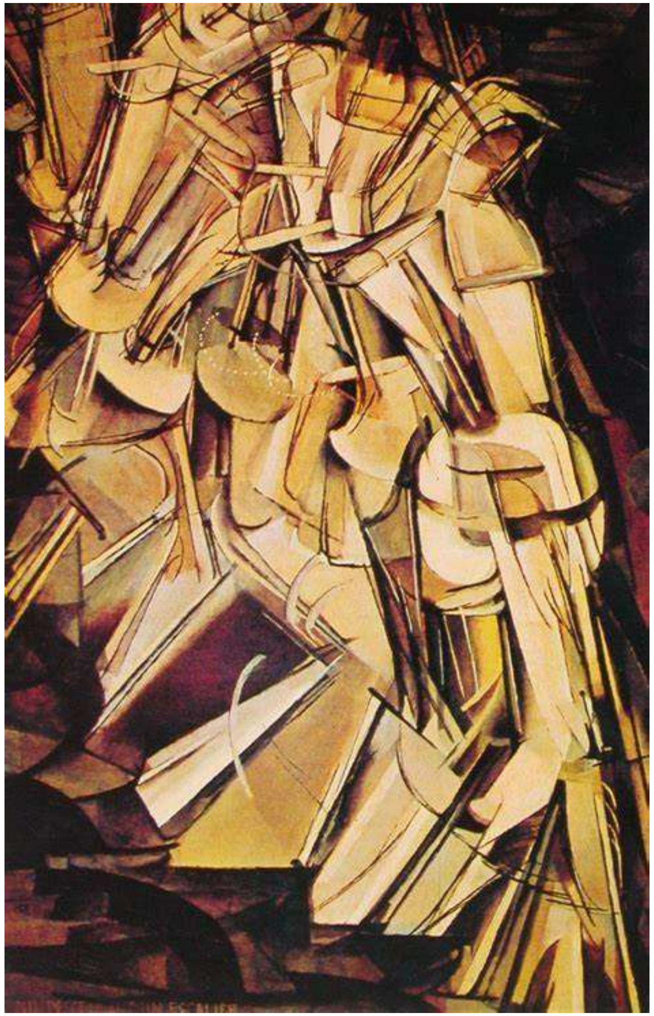
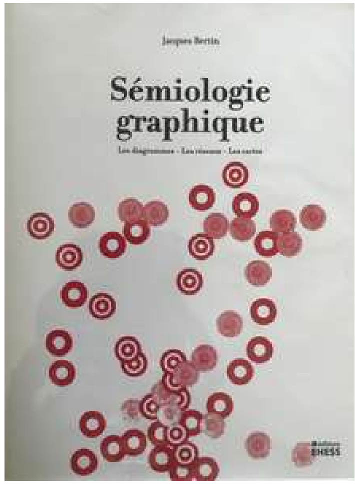


Fig. 34. Marche de l'homme. Trajectoire des différentes articulations; inclinaisons des divers rayons osseux. Les positions de la tête ne sont pas représentées dans la figure.



Marcel Duchamp, nu descendant un escalier (1912)

Jacques Bertin (1918-2010) and the semiology of graphics

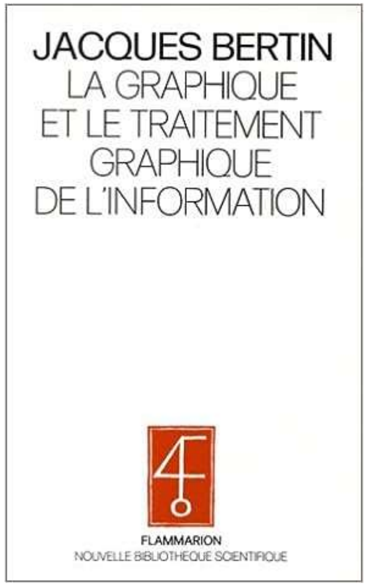


Jacques Bertin

Sémiologie graphique

Les diagrammes - Les réseaux - Les cartes

éditions EHESS



JACQUES BERTIN
LA GRAPHIQUE
ET LE TRAITEMENT
GRAPHIQUE
DE L'INFORMATION

FLAMMARION
NOUVELLE BIBLIOTHÈQUE SCIENTIFIQUE

Jacques Bertin was a cartographer, geographer and graphic analyst who theorized how graphics conveyed information and facilitated data analysis. He founded and directed the Cartographic Laboratory of the École pratique des hautes études (EPHE) and later EHESS.

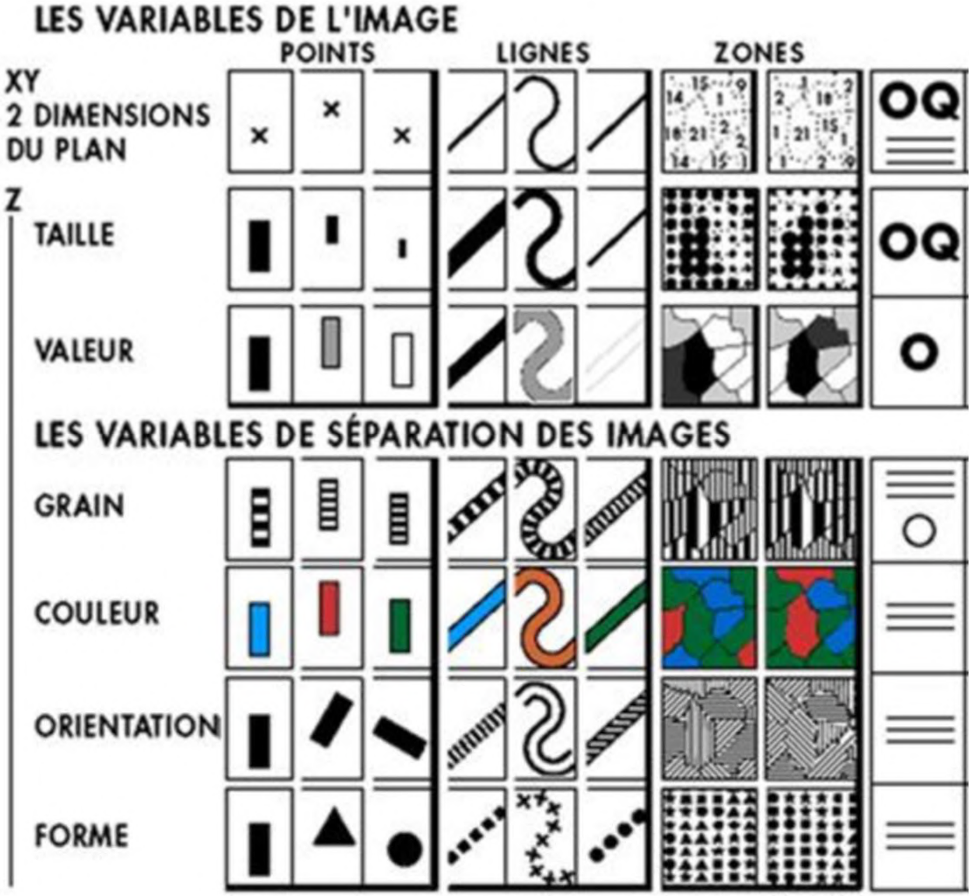
“La graphique est un moyen de communiquer avec les autres. C’est son emploi le plus connu. Elle sert aussi à poser et à résoudre un problème.”

“La graphique utilise les propriétés du plan pour faire apparaître les **relations** de ressemblance, d’ordre, ou de proportionalité entre des ensembles donnés”.

While signs can depict individual pieces of information, graphics [la graphique] provide a system of signs that make obvious the **relations** between several pieces of data.

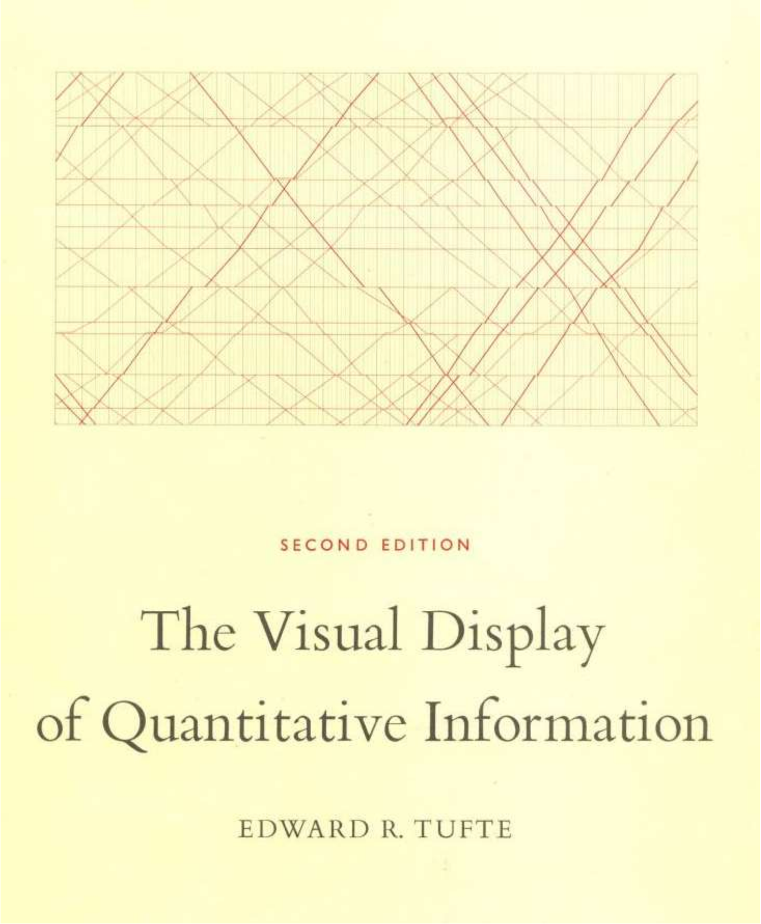
A few characteristics of his ideas:

- Graphics should maximize visual efficiency
- Mobility: the data can be moved, reordered, and plotted along various dimensions
- 8 visual variables can be used to convey different aspects of the data:
- Law of visibility: “any non-discriminative element is useless and reduces the visibility of the image.” Thus one must remove any such common element, and maximize the use of discriminant dimensions (e.g. scales, colors).



Edward Tufte (1942-), statistician and pionneer of data visualization

“At their best, graphics are **instruments for reasoning about quantitative information**.
Often, the most effective way to describe, explore and summarize a set of numbers – even a very large set –
is to look at pictures of those numbers.”

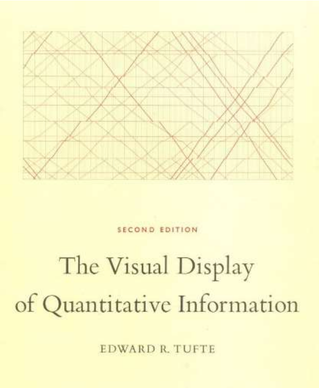


Tufte’s books introduce a number of ideas (or rather, hypotheses) :

- Graphical **integrity** : avoid graphical lies
- Maximization of the **data-ink ratio** : graphics can often be improved by removing uninformative elements, as Bertin also suggested.
- Maximization of **data density** : graphics should not be used when a small table suffices to convey the data, but should be as rich as possible (e.g. similar to a high-res map)
- Readability at **multiple spatial scales**: the eye/brain can see the global trend, but also focus on specific details of the data.
- **Small multiples** allow for a quick comparison of multiple series of similar data.
- **Sparklines**

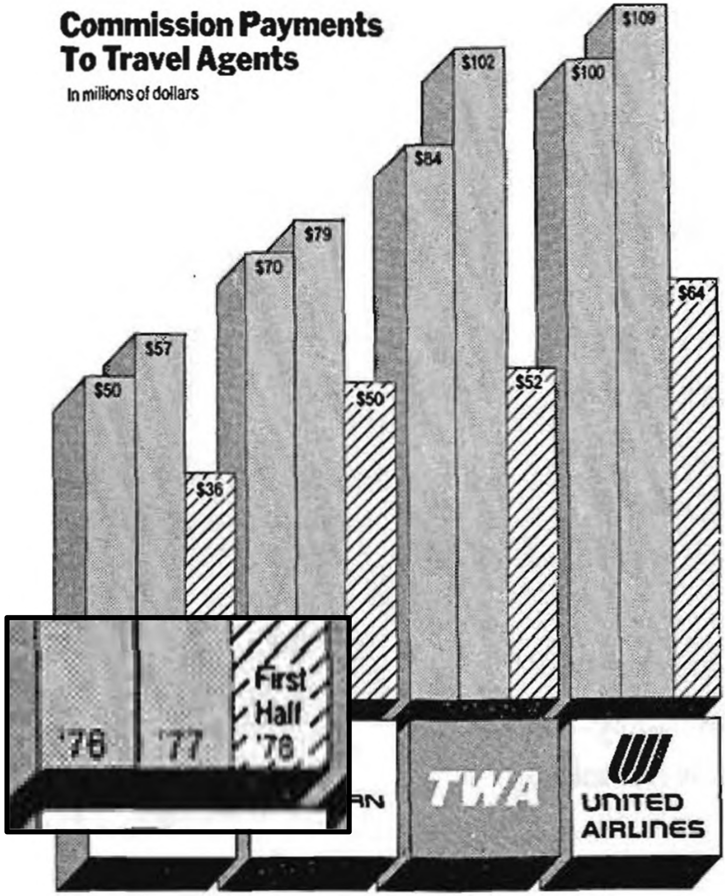
Tufte shows that PowerPoint, at least by default, departs drastically from these requirements.

Graphical integrity: How to avoid graphical lies



SECOND EDITION
The Visual Display
of Quantitative Information
EDWARD R. TUFTE

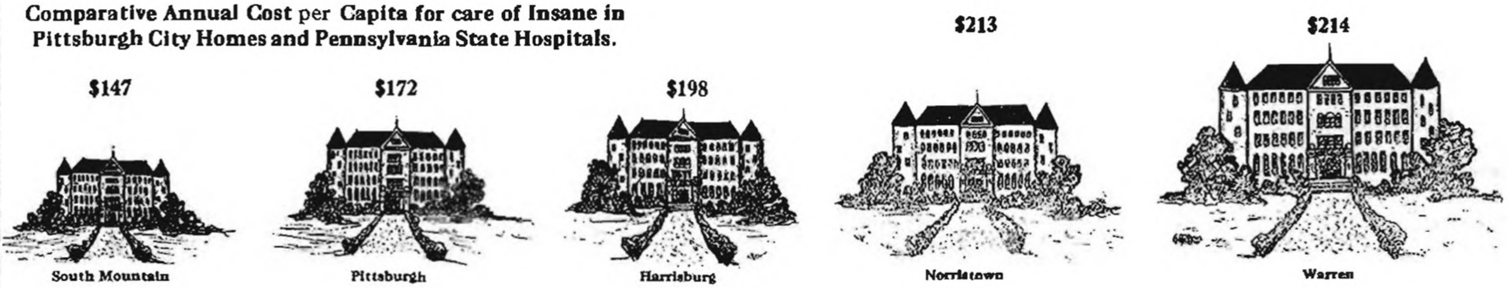
“For many people, the first word that comes to mind when they think about statistical charts is ‘lie’.“ (Edward Tufte)
“There are lies, damned lies and statistics.” (Mark Twain)



Telling the truth, and telling it straightforwardly, should be key goals of graphic displays.

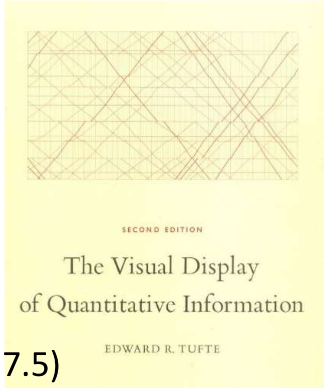
A few examples :

- The data itself may be wrong, for instance here half a year is reported.
- The format plot may create a distorted perception



Pittsburgh Civic Commission, *Report on Expenditures of the Department of Charities* (Pittsburgh, 1911), p. 7.

The lie factor



Several principles, according to Tufte should minimize the amount of misperception:
“The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.”

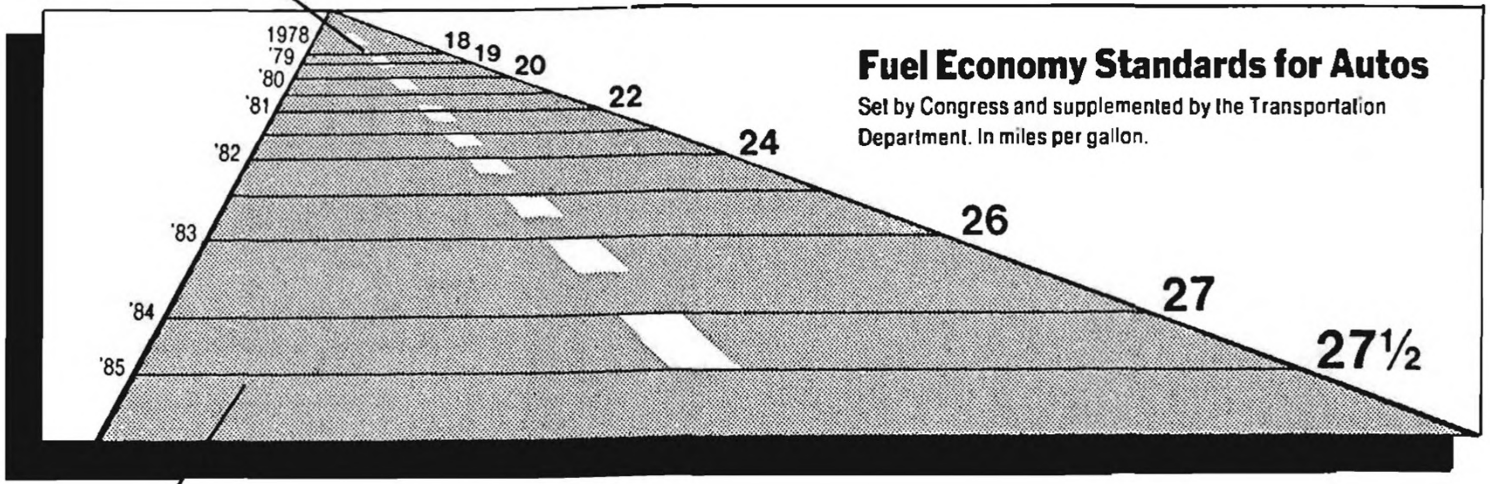
$$\text{Lie Factor} = \frac{\text{size of effect shown in graphic}}{\text{size of effect in data}}$$

In this graphic, the lie factor is huge:

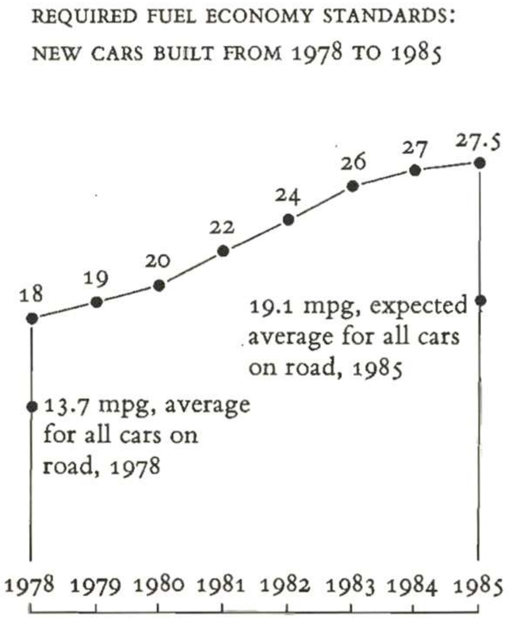
- The data (MPG) varies by 53% (from 18 to 27.5)
- The corresponding graphic length varies by 783% (from 0.6 to 5.3).

Therefore the lie factor is 14.8
Perspective causes more problems: the past is ahead of the road; non-linear scale; shrinking numbers (but not for dates?), etc…

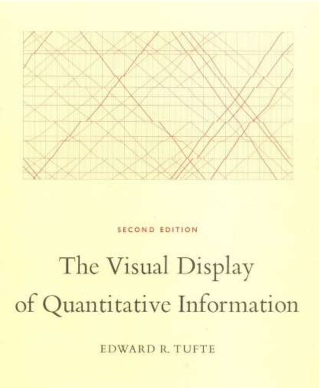
This line, representing 18 miles per gallon in 1978, is 0.6 inches long.



This line, representing 27.5 miles per gallon in 1985, is 5.3 inches long.



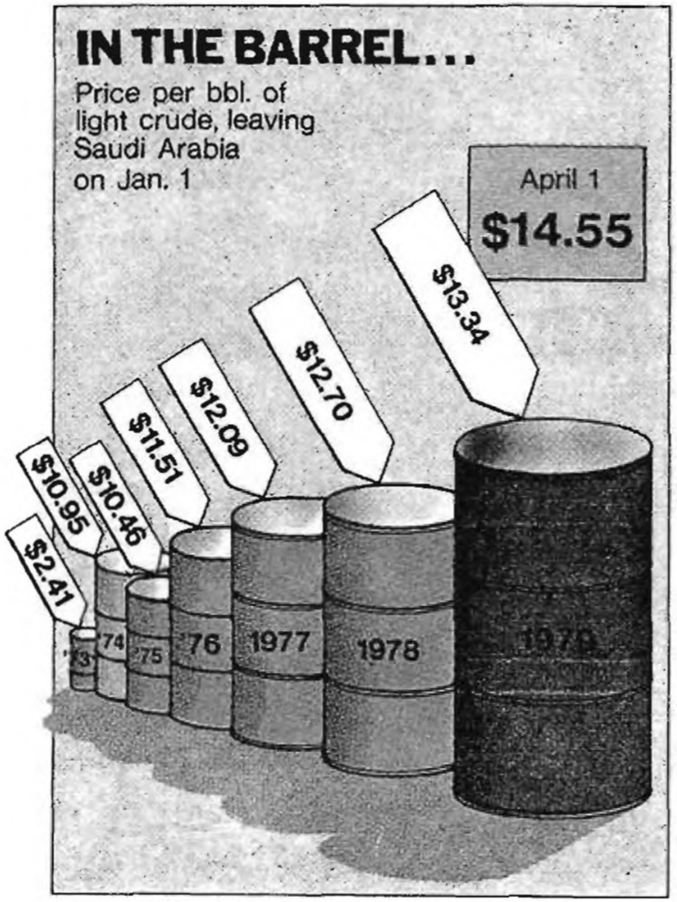
The lie factor



Here is another example where the use of a physical object (a barrel of oil) adds to the misperception.

It is completely unclear which scale the graphics' author used.

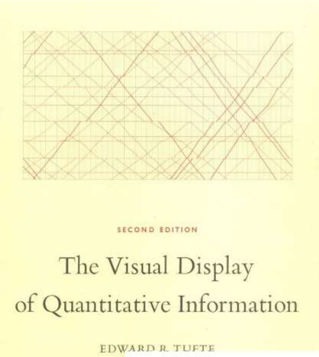
By area, the lie factor is 9.4, but the graphic suggests that volume should be used, in which case the lie factor is 59.4 !!



Note that this graphic, just like the preceding one, has no scale bar, and the numerical labels are hard to read.

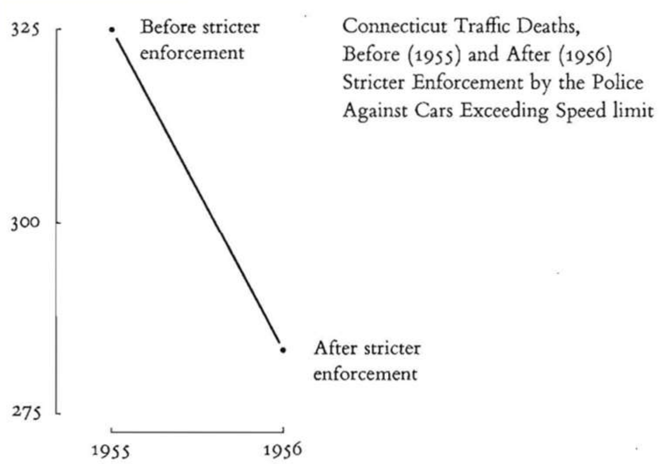
“Clear, detailed and thorough labeling should be used to defeat graphical distortion and ambiguity.”

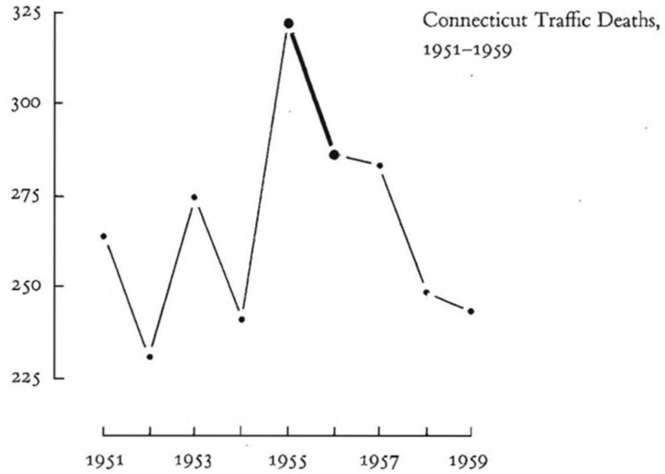
“Write out explanations of the data on the graphic itself. Label important events in the data.”

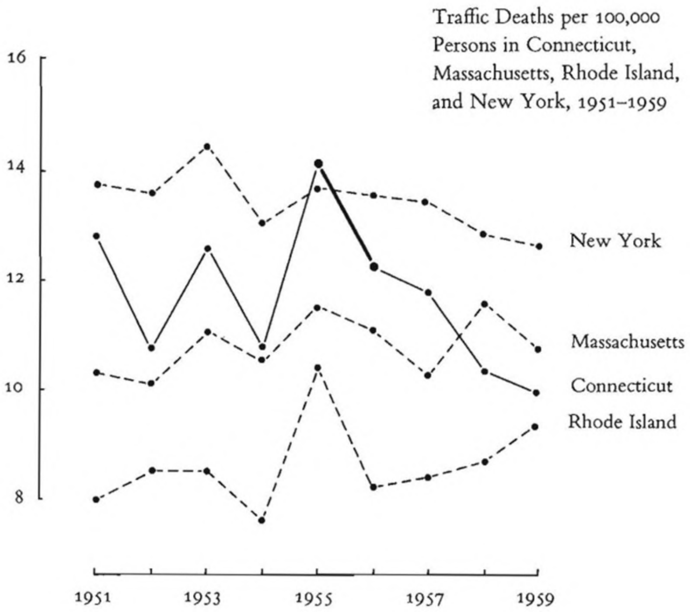


Another way to lie: omitting the context

“Graphics must not quote data out of context” (Edward Tufte)

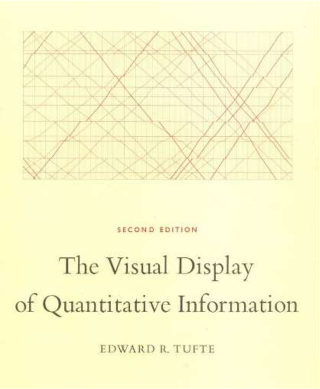

Connecticut Traffic Deaths, Before (1955) and After (1956) Stricter Enforcement by the Police Against Cars Exceeding Speed limit


Connecticut Traffic Deaths, 1951–1959


Traffic Deaths per 100,000 Persons in Connecticut, Massachusetts, Rhode Island, and New York, 1951–1959

Conclusion: Six principles for graphical integrity:

1. Representation of **numbers directly proportional** to the numerical quantities involved.
2. Clear **labeling**, explanations directly on the data itself.
3. “Show **data variations, not design variations**” (do not vary the design in addition to the data, e.g. due to perspective)
4. (for money) use values corrected for inflation; use standardized units
5. Do not use more dimensions of the graphic that there are dimensions in the data
6. Do not quote data out of context.



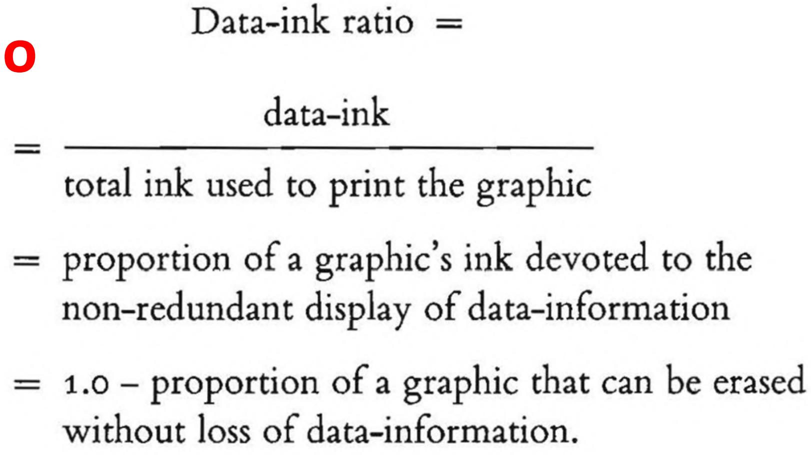
SECOND EDITION

The Visual Display
of Quantitative Information

EDWARD R. TUFTE

Good design maximizes the data-ink ratio

Graphical excellence means that most of the ink on the page is dedicated to the data, or to useful information about the data (labels, events, etc).
Consequences:
"Erase non-data ink" and "redundant data-ink" (within reason!).
"Revise and edit".
Example: can you spot all of the differences before/after?



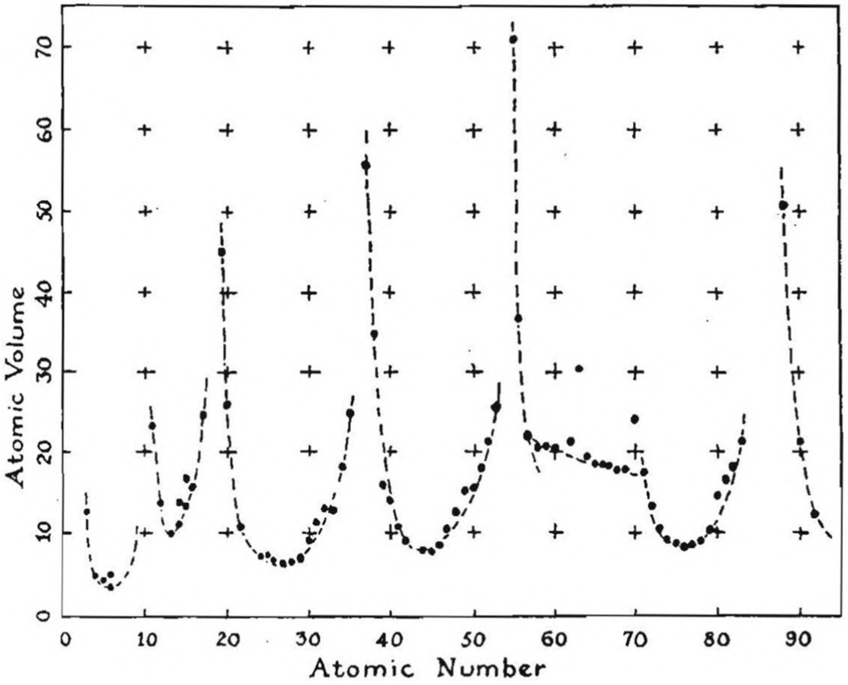
Data-ink ratio =

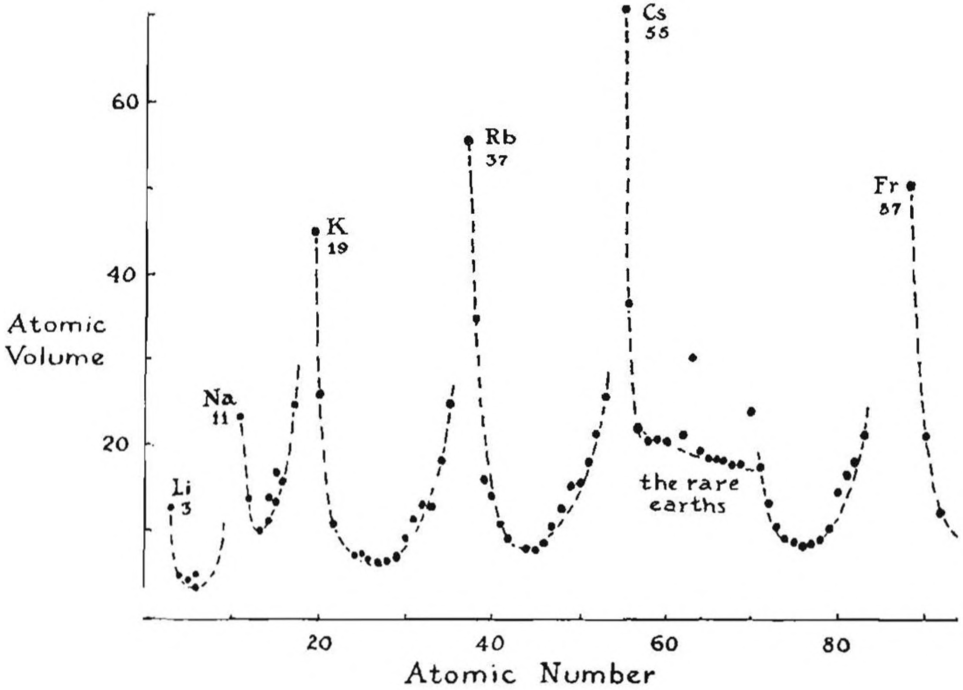
$$= \frac{\text{data-ink}}{\text{total ink used to print the graphic}}$$

= proportion of a graphic's ink devoted to the non-redundant display of data-information

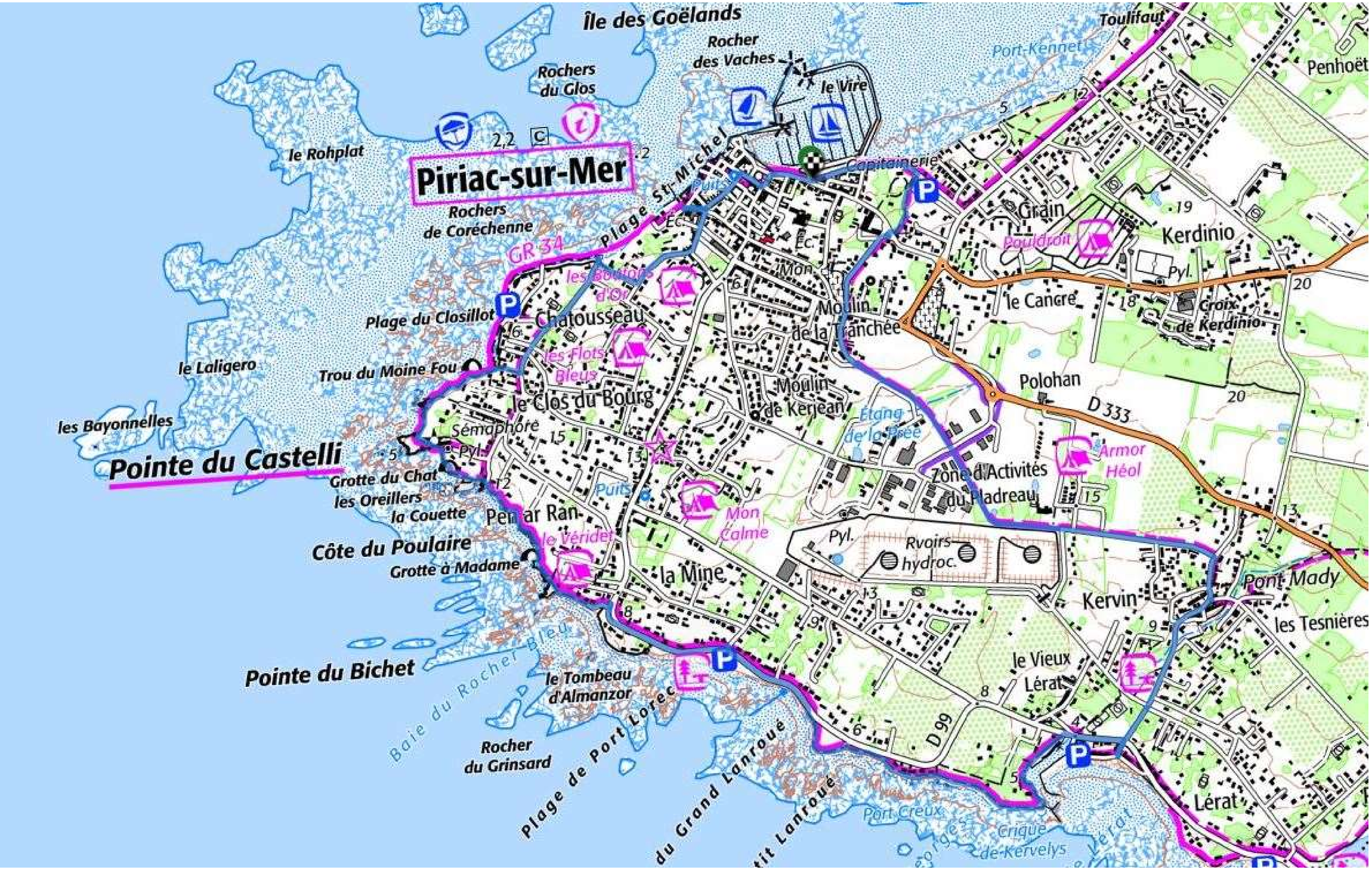
= 1.0 − proportion of a graphic that can be erased without loss of data-information.

Linus Pauling, *General Chemistry* (San Francisco, 1947), p.

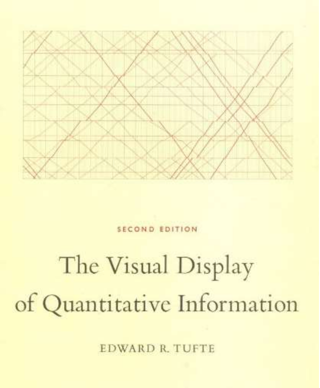




A model of very high data density and multiscale reading: geographic maps



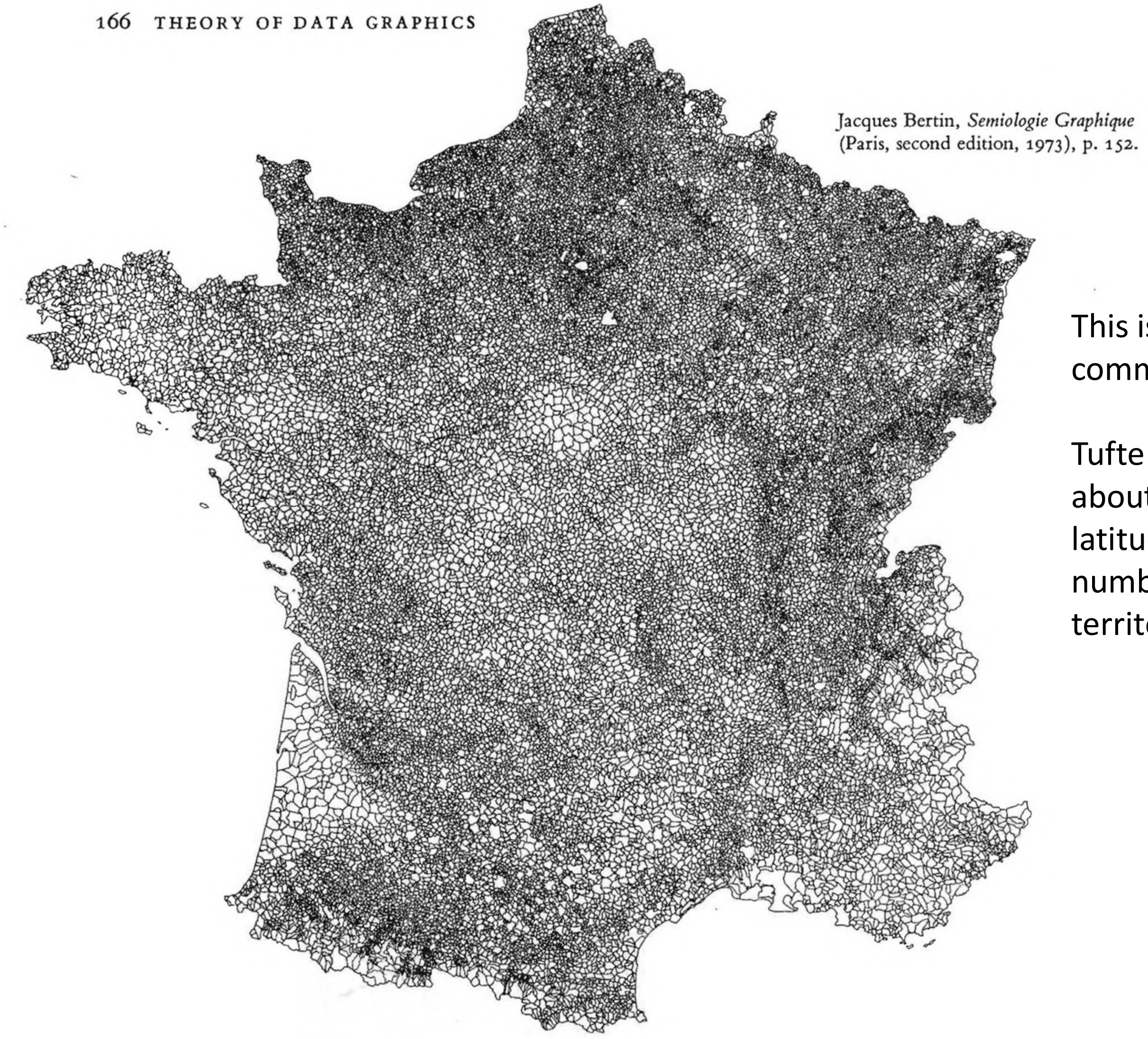
A model of very high data density and multiscale reading: geographic maps



SECOND EDITION

The Visual Display
of Quantitative Information

EDWARD R. TUFTE

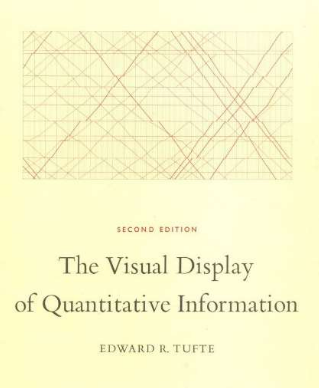


166 THEORY OF DATA GRAPHICS

Jacques Bertin, *Semiologie Graphique*
(Paris, second edition, 1973), p. 152.

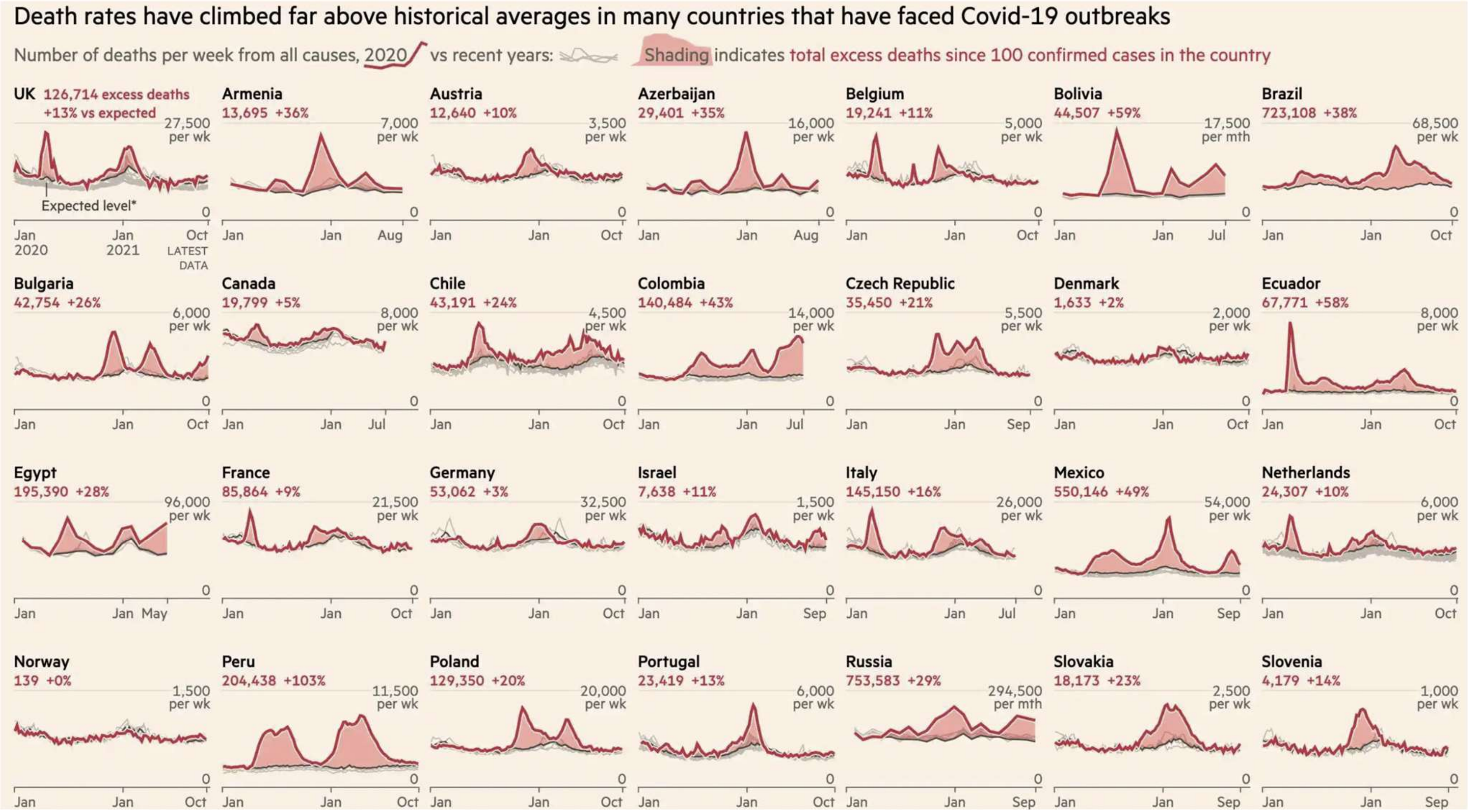
This is a map of the boundaries of 30,000 communes of France.

Tufte estimates that the map involves about 240,000 numbers (30,000 latitudes and longitudes, and ~6 numbers to capture the shape of the territory of each commune).

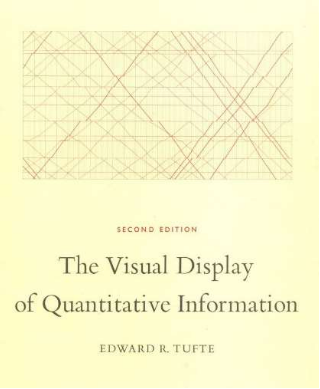


Consequences of these ideas: (1) small multiples

Small multiples are graphics that share the same format, but not the same content.
Once the readers get familiar with the format, they can easily spot the parallels and differences between conditions.
Example: John Burn-Murdoch's Covid 19 graphics for the Financial Times:

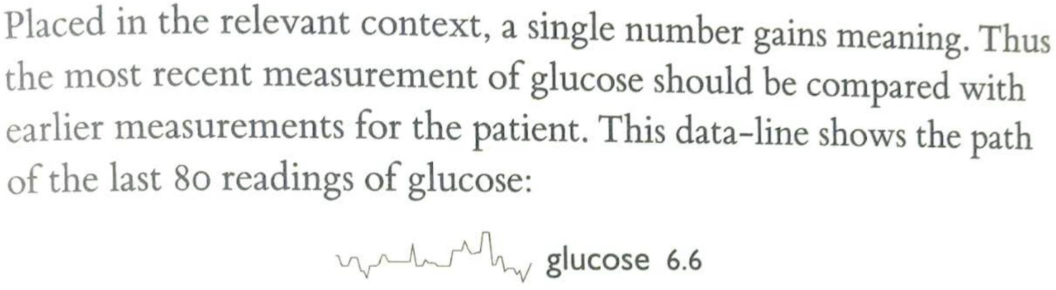

Death rates have climbed far above historical averages in many countries that have faced Covid-19 outbreaks

Number of deaths per week from all causes, 2020 vs recent years: Shading indicates total excess deaths since 100 confirmed cases in the country



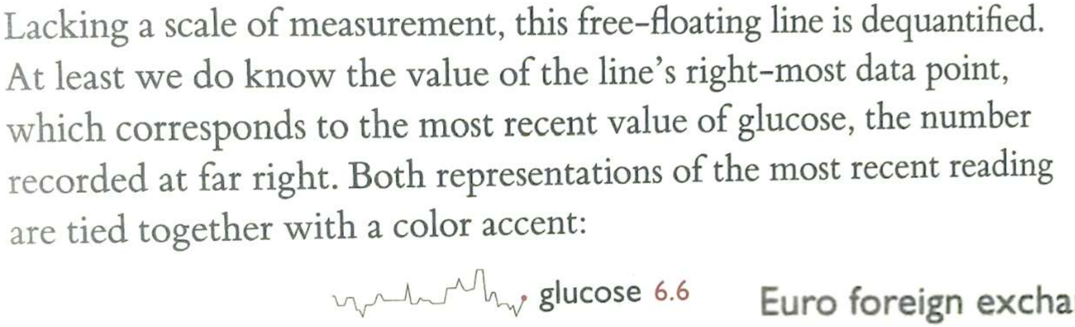
Consequences of these ideas: (2) sparklines

Reading proves that we can achieve extremely high information density on a page.
The fovea can discern shapes at a very high resolution – a feat that we already use for reading letters and numbers.
Can we also recycle this capacity for graphics? Yes!
A lot of data can be embedded within text – as a small, high-resolution, graphic.
"Sparklines are *datawords:* data-intense, design-simple, word-sized graphics."



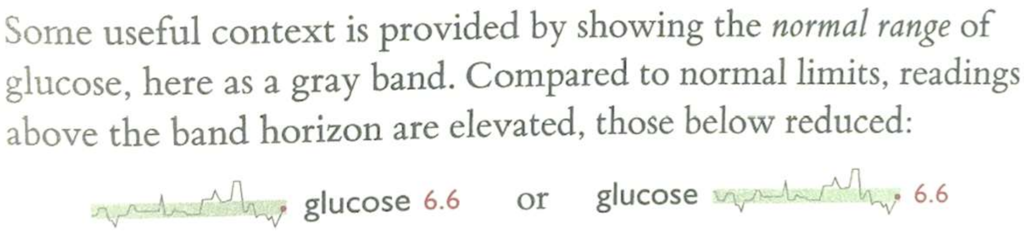
Placed in the relevant context, a single number gains meaning. Thus the most recent measurement of glucose should be compared with earlier measurements for the patient. This data-line shows the path of the last 80 readings of glucose:

glucose 6.6



Lacking a scale of measurement, this free-floating line is dequantified. At least we do know the value of the line's right-most data point, which corresponds to the most recent value of glucose, the number recorded at far right. Both representations of the most recent reading are tied together with a color accent:

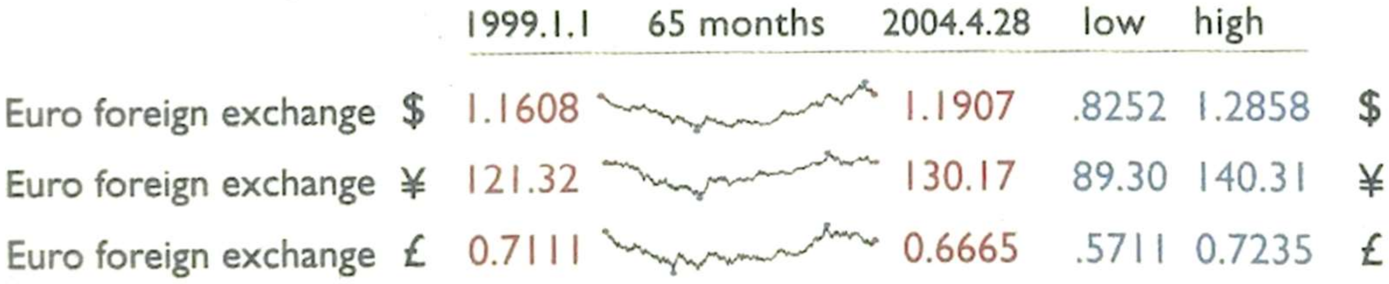
glucose 6.6



Some useful context is provided by showing the *normal range* of glucose, here as a gray band. Compared to normal limits, readings above the band horizon are elevated, those below reduced:

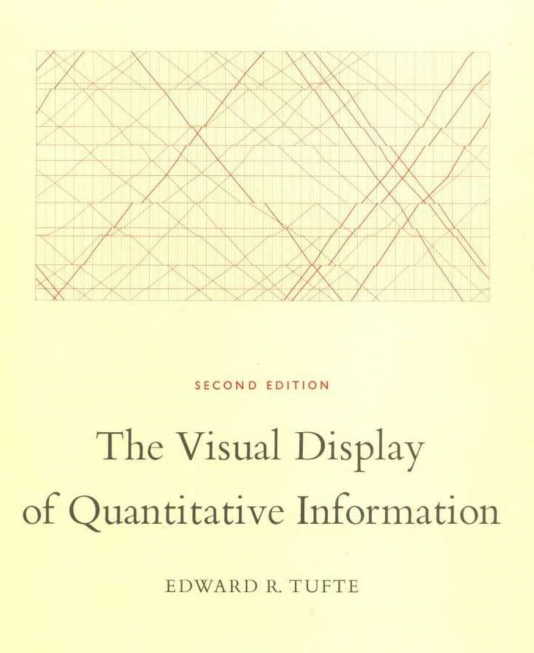
glucose 6.6 or glucose 6.6

Because they are small, sparklines easily fit into arrays of "small multiples" (as available in most spreadsheet software):



		1999.1.1	65 months	2004.4.28	low	high	
Euro foreign exchange	$	1.1608		1.1907	.8252	1.2858	$
Euro foreign exchange	¥	121.32		130.17	89.30	140.31	¥
Euro foreign exchange	£	0.7111		0.6665	.5711	0.7235	£

Conclusions



SECOND EDITION

The Visual Display of Quantitative Information

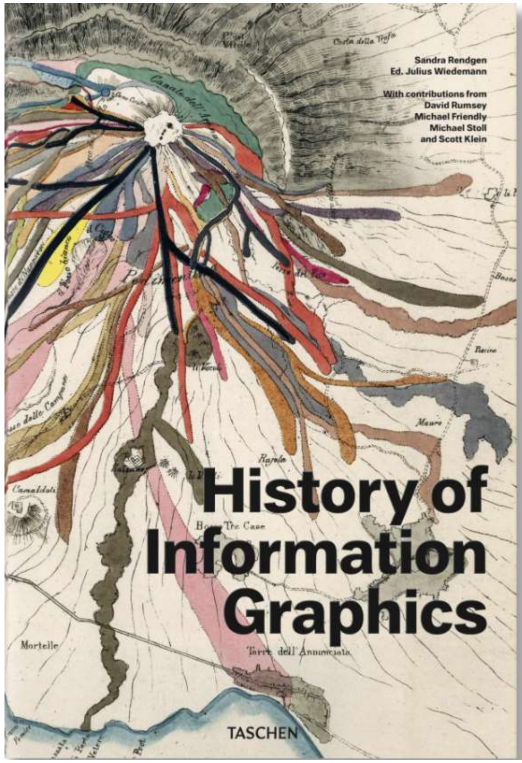
EDWARD R. TUFTE

Graphics appeared in recent history as the outcome of a long evolution with many successive inventions :

- a language of graphic **signs** (painted caves, engravings…)
- **maps** of space
- **measurement** of spatial dimensions (e.g. the nilometer)
- measurement of **any quantity** (from the clepsydra to Marey)
- x and y **coordinates**
- visualizing the **relations** between variables (linear, non-linear; from Descartes to Bertin)
- rich plots using up to 8 **perceptual dimensions** (Minard, Bertin)

Recent concepts involve

- **optimization** of the perception of quantitative information
- **data density**: maximizing the data-ink ratio (Tufte), small multiples, sparklines
- graphic **integrity**



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History of Information Graphics

TASCHEN