Edward R. Tufte

The Visual Display of Quantitative Information

SECOND EDITION

Graphics Press · Cheshire, Connecticut

Contents

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For my parents

Edward E. Tufte and Virginia James Tufte

To the memory of

John W. Tukey (1915–2000)

Introduction to the Second Edition

This new edition provides high-resolution color reproductions of the many graphics of William Playfair, adds color to other images where appropriate, and includes all the changes and corrections accumulated during the 17 printings of the first edition.

This book began in 1975 when Dean Donald Stokes of Princeton's Woodrow Wilson School asked me to teach statistics to a dozen journalists who were visiting that year to learn some economics. I annotated a collection of readings, with a long section on statistical graphics. The literature here was thin, too often grimly devoted to explaining use of the ruling pen and to promulgating "graphic standards" indifferent to the nature of visual evidence and quantitative reasoning. Soon I wrote up some ideas. Then John Tukey, the phenomenal Princeton statistician, suggested that we give a series of joint seminars. Since the mid-1960s, Tukey had opened up the field, as his brilliant technical contributions made it clear that the study of statistical graphics was intellectually respectable and not just about pie charts and ruling pens.

After moving to Yale University, I finished the manuscript in 1982. A publisher was interested but planned to print only 2,000 copies and to charge a very high price, contrary to my hopes for a wide readership. I also sought to design the book so as to make it *self-exemplifying*—that is, the physical object itself would reflect the intellectual principles advanced in the book. Publishers seemed appalled at the prospect that an author might govern design.

Consequently I investigated self-publishing. This required a first-rate book designer, a lot of money (at least for a young professor), and a large garage. I found Howard Gralla who had designed many museum catalogs with great care and craft. He was willing to work closely with this difficult author who was filled with all sorts of opinions about design and typography. We spent the summer in his studio laying out the book, page by page. We were able to integrate graphics right into the text, sometimes into the middle of a sentence, eliminating the usual separation of text and image—one of the ideas *Visual Display* advocated. To finance the book I took out another mortgage on my home. The bank officer said this was the second most unusual loan that she had ever made; first place belonged to a loan to a circus to buy an elephant!

My view on self-publishing was to go all out, to make the best and most elegant and wonderful book possible, without compromise. Otherwise, why do it?

Most of all, the book, as a thing in itself, gave to me fresh new eyes for the intellectual and aesthetic joy of visual evidence, visual reasoning, and visual understanding.

January 2001
Cheshire, Connecticut

Introduction

Data graphics visually display measured quantities by means of the combined use of points, lines, a coordinate system, numbers, symbols, words, shading, and color.

The use of abstract, non-representational pictures to show numbers is a surprisingly recent invention, perhaps because of the diversity of skills required—the visual-artistic, empirical-statistical, and mathematical. It was not until 1750–1800 that statistical graphics—length and area to show quantity, time-series, scatterplots, and multivariate displays—were invented, long after such triumphs of mathematical ingenuity as logarithms, Cartesian coordinates, the calculus, and the basics of probability theory. The remarkable William Playfair (1759–1823) developed or improved upon nearly all the fundamental graphical designs, seeking to replace conventional tables of numbers with the systematic visual representations of his "linear arithmetic."

Modern data graphics can do much more than simply substitute for small statistical tables. 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. Furthermore, of all methods for analyzing and communicating statistical information, well-designed data graphics are usually the simplest and at the same time the most powerful.

The first part of this book reviews the graphical practice of the two centuries since Playfair. The reader will, I hope, rejoice in the graphical glories shown in Chapter 1 and then condemn the lapses and lost opportunities exhibited in Chapter 2. Chapter 3, on graphical integrity and sophistication, seeks to account for these differences in quality of graphical design.

The second part of the book provides a language for discussing graphics and a practical theory of data graphics. Applying to most visual displays of quantitative information, the theory leads to changes and improvements in design, suggests why some graphics might be better than others, and generates new types of graphics. The emphasis is on maximizing principles, empirical measures of graphical performance, and the sequential improvement of graphics through revision and editing. Insights into graphical design are to be gained, I believe, from theories of what makes for excellence in art, architecture, and prose.

This is a book about the design of statistical graphics and, as such, it is concerned both with design and with statistics. But it is also about how to communicate information through the simultaneous presentation of words, numbers, and pictures. The design of statistical graphics is a universal matter—like mathematics—and is not tied to the unique features of a particular language. The descriptive concepts (a vocabulary for graphics) and the principles advanced apply to most designs. I have at times provided evidence about the scope of these ideas, by showing how frequently a principle applies to (a random sample of) news and scientific graphics.

Each year, the world over, somewhere between 900 billion (9×10^{11}) and 2 trillion (2×10^{12}) images of statistical graphics are printed. The principles of this book apply to most of those graphics. Some of the suggested changes are small, but others are substantial, with consequences for hundreds of billions of printed pages.

But I hope also that the book has consequences for the viewers and makers of those images—that they will never view or create statistical graphics the same way again. That is in part because we are about to see, collected here, so many wonderful drawings, those of Playfair, of Minard, of Marey, and, nowadays, of the computer.

Most of all, then, this book is a celebration of data graphics.

PART I
Graphical Practice

1 *Graphical Excellence*

EXCELLENCE in statistical graphics consists of complex ideas communicated with clarity, precision, and efficiency. Graphical displays should

- show the data
- induce the viewer to think about the substance rather than about methodology, graphic design, the technology of graphic production, or something else
- avoid distorting what the data have to say
- present many numbers in a small space
- make large data sets coherent
- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure
- serve a reasonably clear purpose: description, exploration, tabulation, or decoration
- be closely integrated with the statistical and verbal descriptions of a data set.

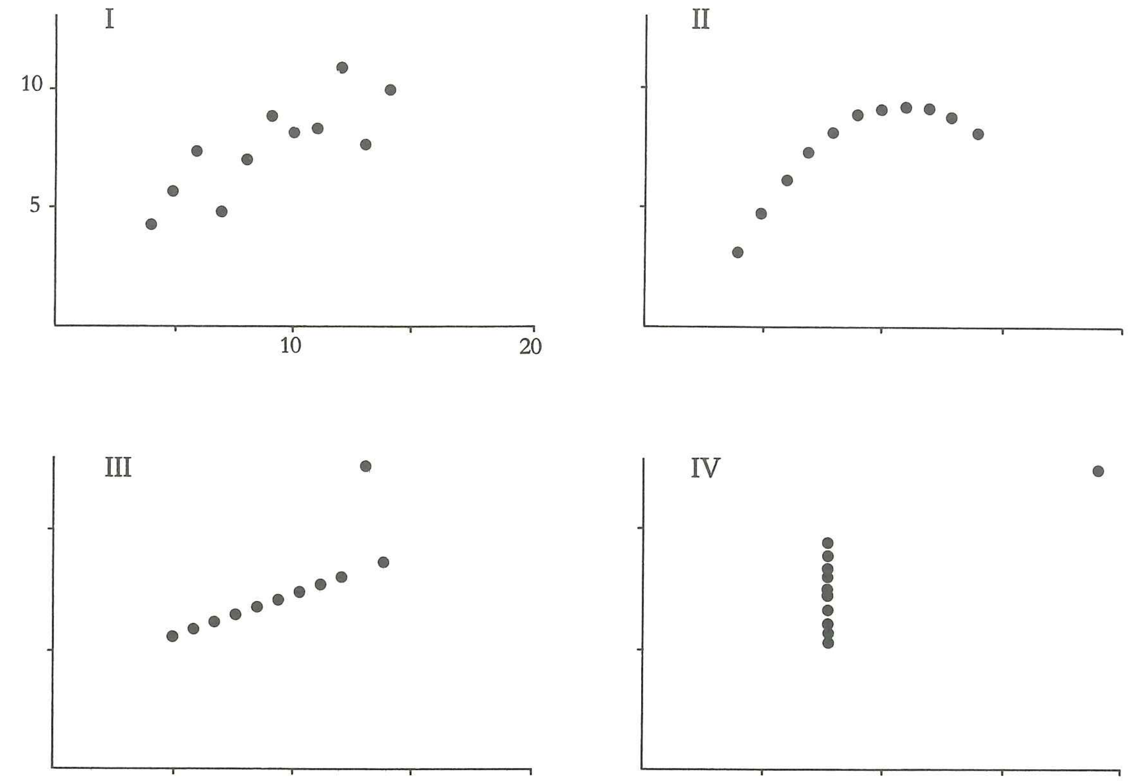
Graphics *reveal* data. Indeed graphics can be more precise and revealing than conventional statistical computations. Consider Anscombe's quartet: all four of these data sets are described by exactly the same linear model (at least until the residuals are examined).

I		II		III		IV	
X	Y	X	Y	X	Y	X	Y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

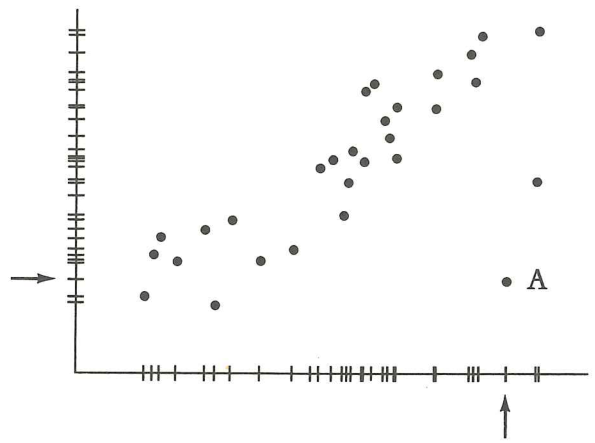
$N = 11$
mean of X's = 9.0
mean of Y's = 7.5
equation of regression line: $Y = 3 + 0.5X$
standard error of estimate of slope = 0.118
$t = 4.24$
sum of squares $X - \overline{X} = 110.0$
regression sum of squares = 27.50
residual sum of squares of Y = 13.75
correlation coefficient = .82
$r^2 = .67$

And yet how they differ, as the graphical display of the data makes vividly clear:

F. J. Anscombe, "Graphs in Statistical Analysis," *American Statistician*, 27 (February 1973), 17–21.



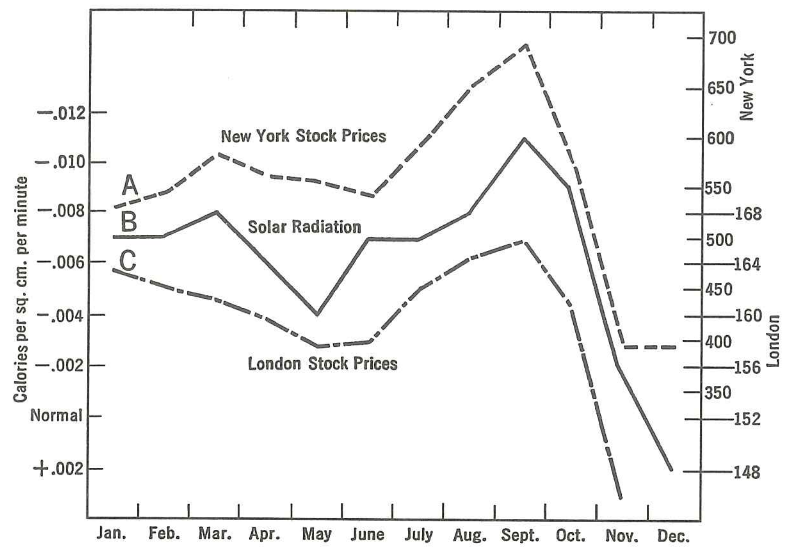
And likewise a graphic easily reveals point A, a wildshot observation that will dominate standard statistical calculations. Note that point A hides in the marginal distribution but shows up as clearly exceptional in the bivariate scatter.



Stephen S. Brier and Stephen E. Fienberg, "Recent Econometric Modelling of Crime and Punishment: Support for the Deterrence Hypothesis?" in Stephen E. Fienberg and Albert J. Reiss, Jr., eds., *Indicators of Crime and Criminal Justice: Quantitative Studies* (Washington, DC, 1980), 89.

Of course, statistical graphics, just like statistical calculations, are only as good as what goes into them. An ill-specified or preposterous model or a puny data set cannot be rescued by a graphic (or by calculation), no matter how clever or fancy. A silly theory means a silly graphic:

Edward R. Dewey and Edwin F. Dakin, *Cycles: The Science of Prediction* (New York, 1947), 144.



SOLAR RADIATION AND STOCK PRICES

A. New York stock prices (Barron's average). B. Solar Radiation, inverted, and C. London stock prices, all by months, 1929 (after Garcia-Mata and Shaffner).

Let us turn to the practice of graphical excellence, the efficient communication of complex quantitative ideas. Excellence, nearly always of a multivariate sort, is illustrated here for fundamental graphical designs: data maps, time-series, space-time narrative designs, and relational graphics. These examples serve several purposes, providing a set of high-quality graphics that can be discussed (and sometimes even redrawn) in constructing a theory of data graphics, helping to demonstrate a descriptive terminology, and telling in brief about the history of graphical development. Most of all, we will be able to see just how good statistical graphics can be.

Data Maps

These six maps report the age-adjusted death rate from various types of cancer for the 3,056 counties of the United States. Each map portrays some 21,000 numbers.[1] Only a picture can carry such a volume of data in such a small space. Furthermore, all that data, thanks to the graphic, can be thought about in many different ways at many different levels of analysis—ranging from the contemplation of general overall patterns to the detection of very fine county-by-county detail. To take just a few examples, look at the

- high death rates from cancer in the northeast part of the country and around the Great Lakes
- low rates in an east-west band across the middle of the country
- higher rates for men than for women in the south, particularly Louisiana (cancers probably caused by occupational exposure, from working with asbestos in shipyards)
- unusual hot spots, including northern Minnesota and a few counties in Iowa and Nebraska along the Missouri River
- differences in types of cancer by region (for example, the high rates of stomach cancer in the north-central part of the country —probably the result of the consumption of smoked fish by Scandinavians)
- rates in areas where you have lived.

The maps provide many leads into the causes—and avoidance—of cancer. For example, the authors report:

> In certain situations . . . the unusual experience of a county warrants further investigation. For example, Salem County, New Jersey, leads the nation in bladder cancer mortality among white men. We attribute this excess risk to occupational exposures, since about 25 percent of the employed persons in this county work in the chemical industry, particularly the manufacturing of organic chemicals, which may cause bladder tumors. After the finding was communicated to New Jersey health officials, a company in the area reported that at least 330 workers in a single plant had developed bladder cancer during the last 50 years. It is urgent that surveys of cancer risk and programs in cancer control be initiated among workers and former workers in this area.[2]

[1] Each county's rate is located in two dimensions and, further, at least four numbers would be necessary to reconstruct the size and shape of each county. This yields 7×3,056 entries in a data matrix sufficient to reproduce a map.

In highest decile, statistically significant

Significantly high, but not in highest decile

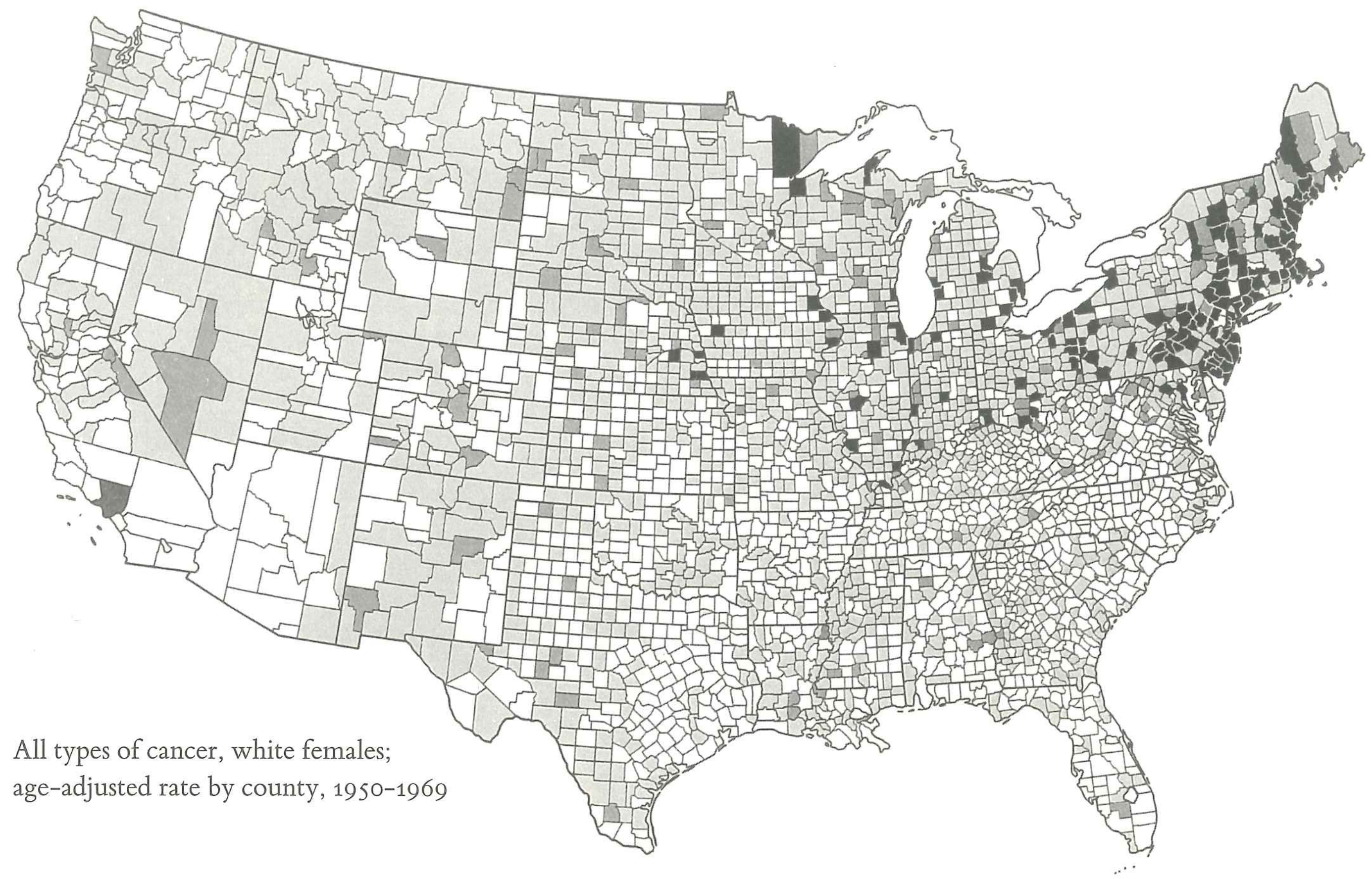
In highest decile, but not statistically significant

Not significantly different from U.S. as a whole

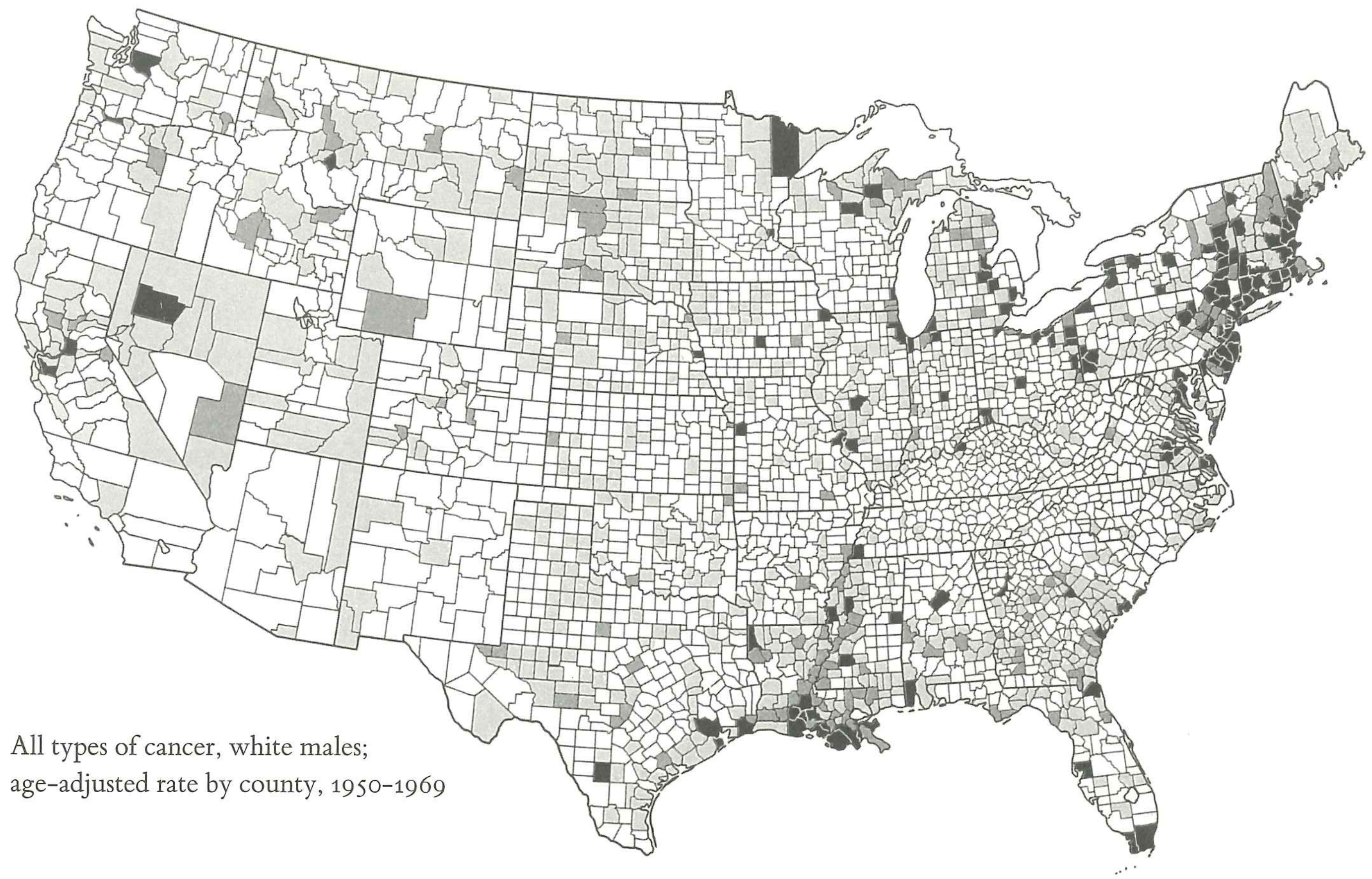
Significantly lower than U.S. as a whole

[2] Robert Hoover, Thomas J. Mason, Frank W. McKay, and Joseph F. Fraumeni, Jr., "Cancer by County: New Resource for Etiologic Clues," *Science*, 189 (September 19, 1975), 1006.

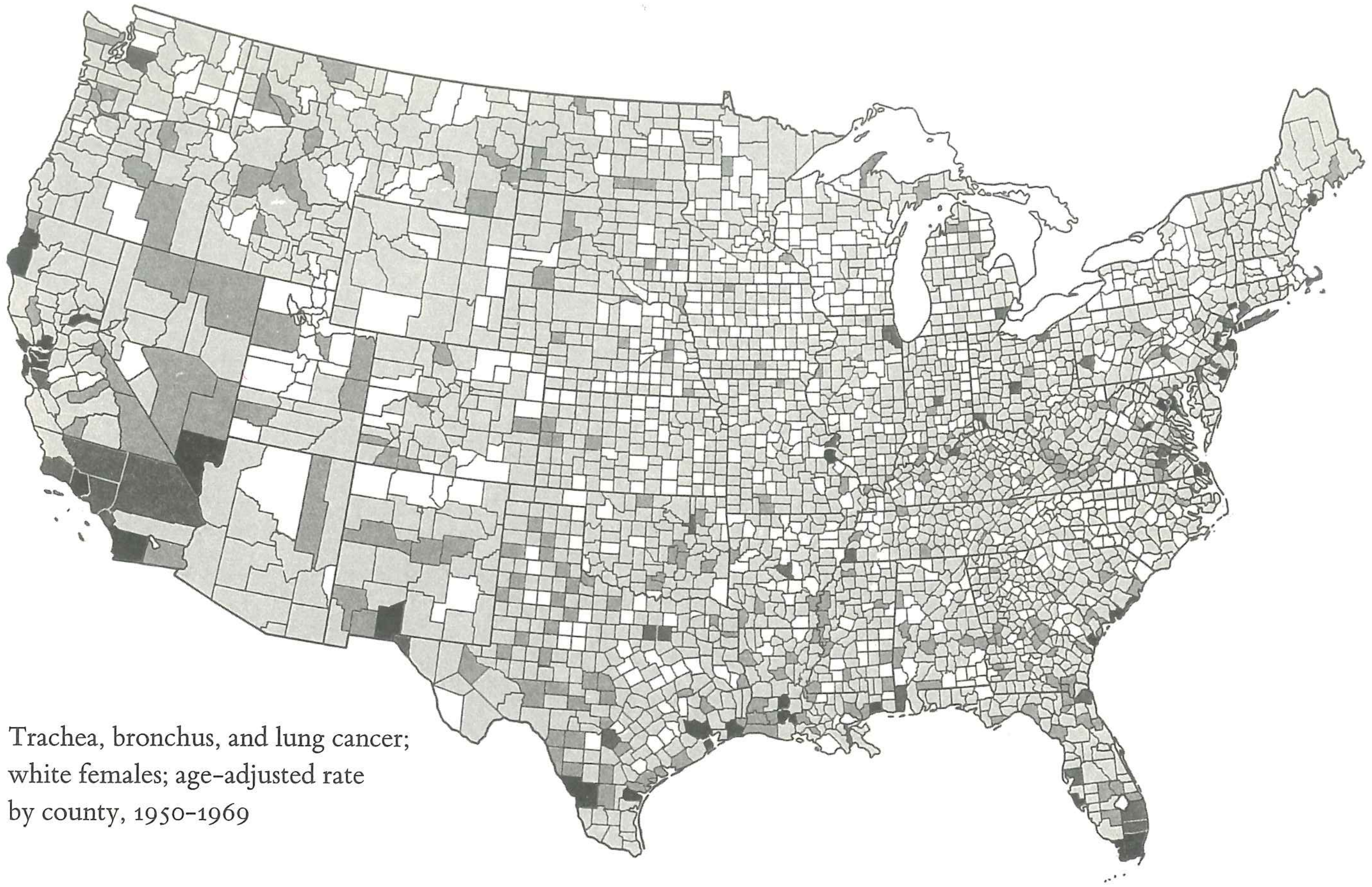
Maps from *Atlas of Cancer Mortality for U.S. Counties: 1950-1969*, by Thomas J. Mason, Frank W. McKay, Robert Hoover, William J. Blot, and Joseph F. Fraumeni, Jr. (Washington, DC: Public Health Service, National Institutes of Health, 1975). The six maps shown here were redesigned and redrawn by Lawrence Fahey and Edward Tufte.



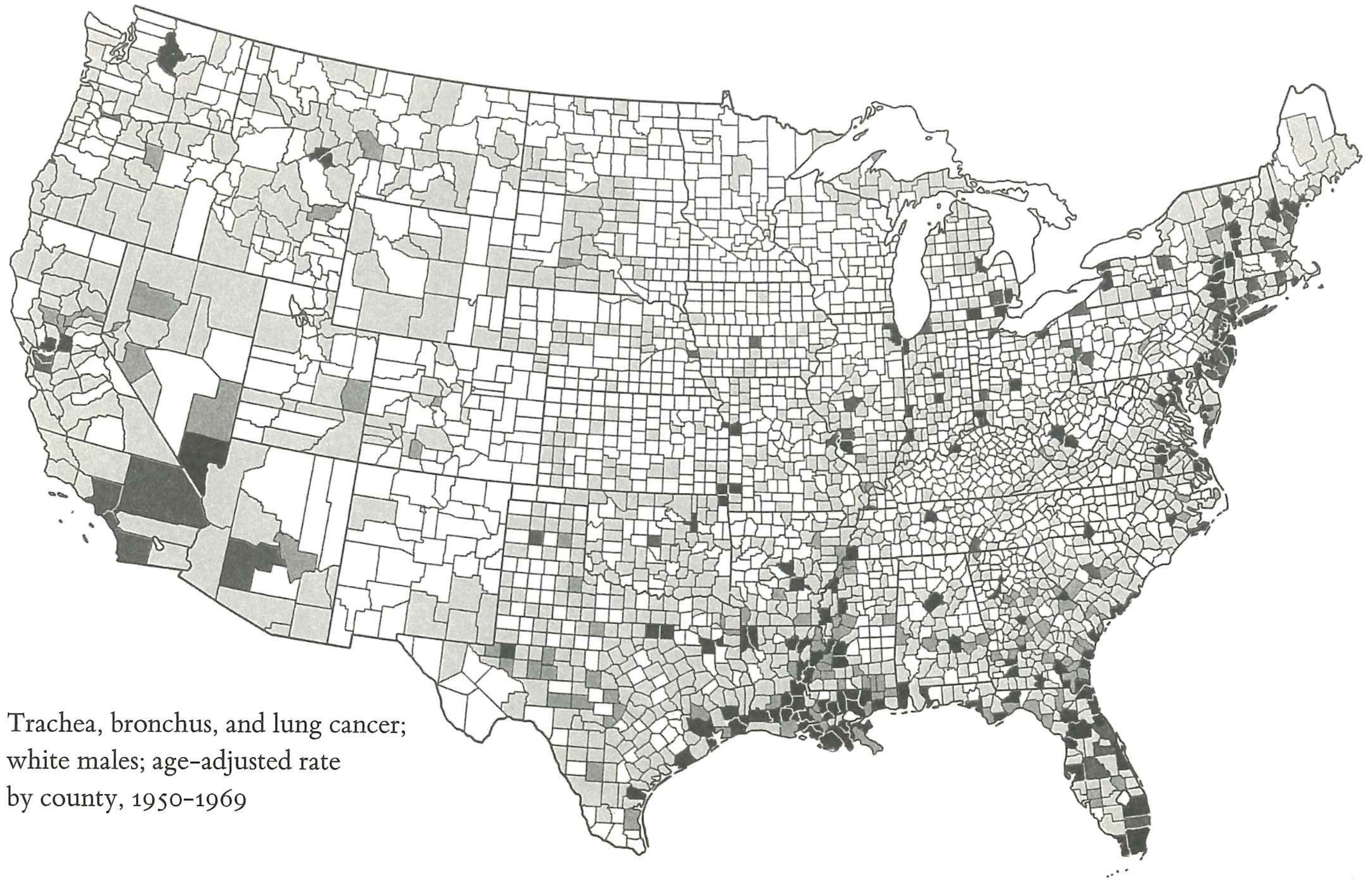
All types of cancer, white females; age-adjusted rate by county, 1950-1969



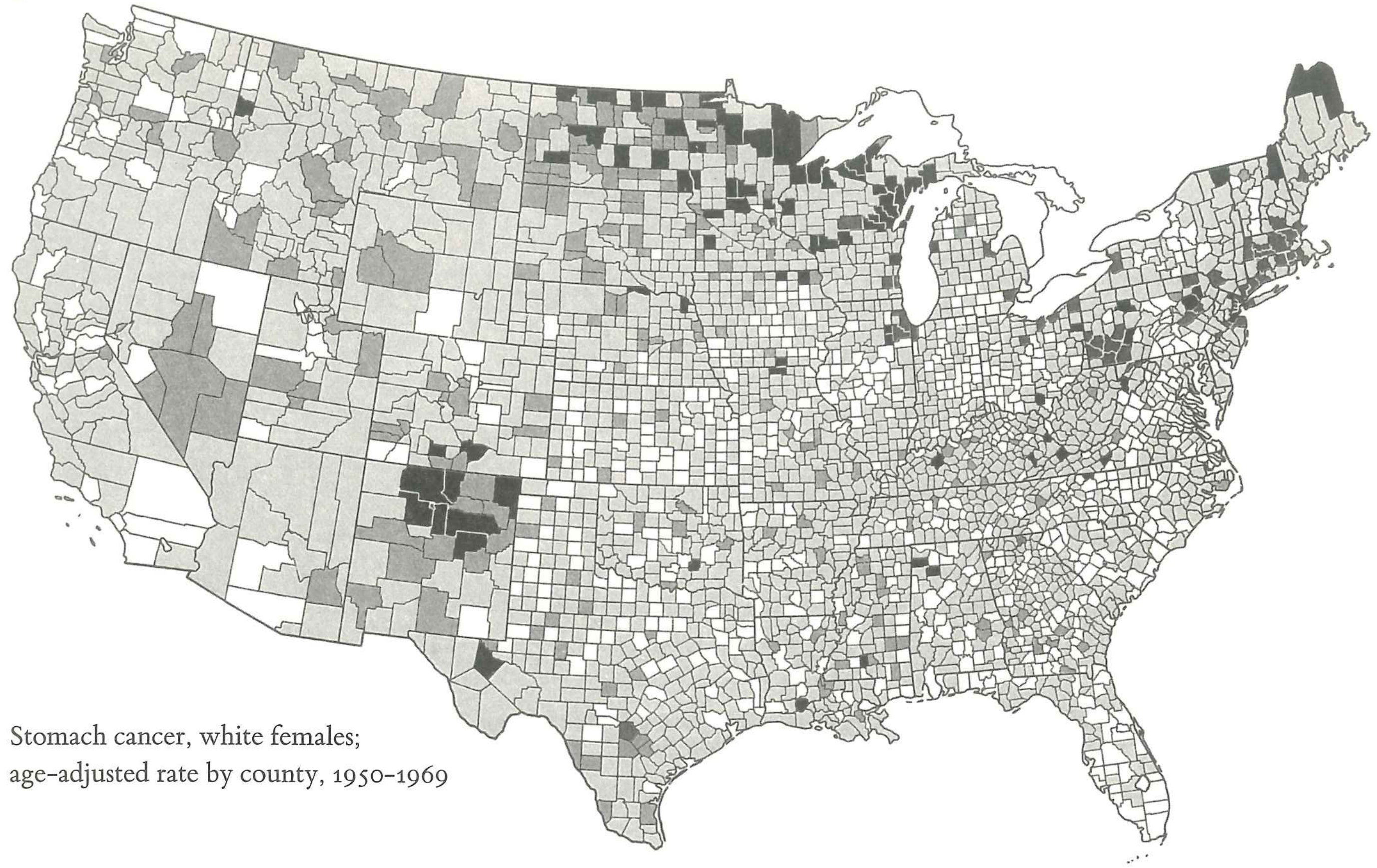
All types of cancer, white males; age-adjusted rate by county, 1950-1969



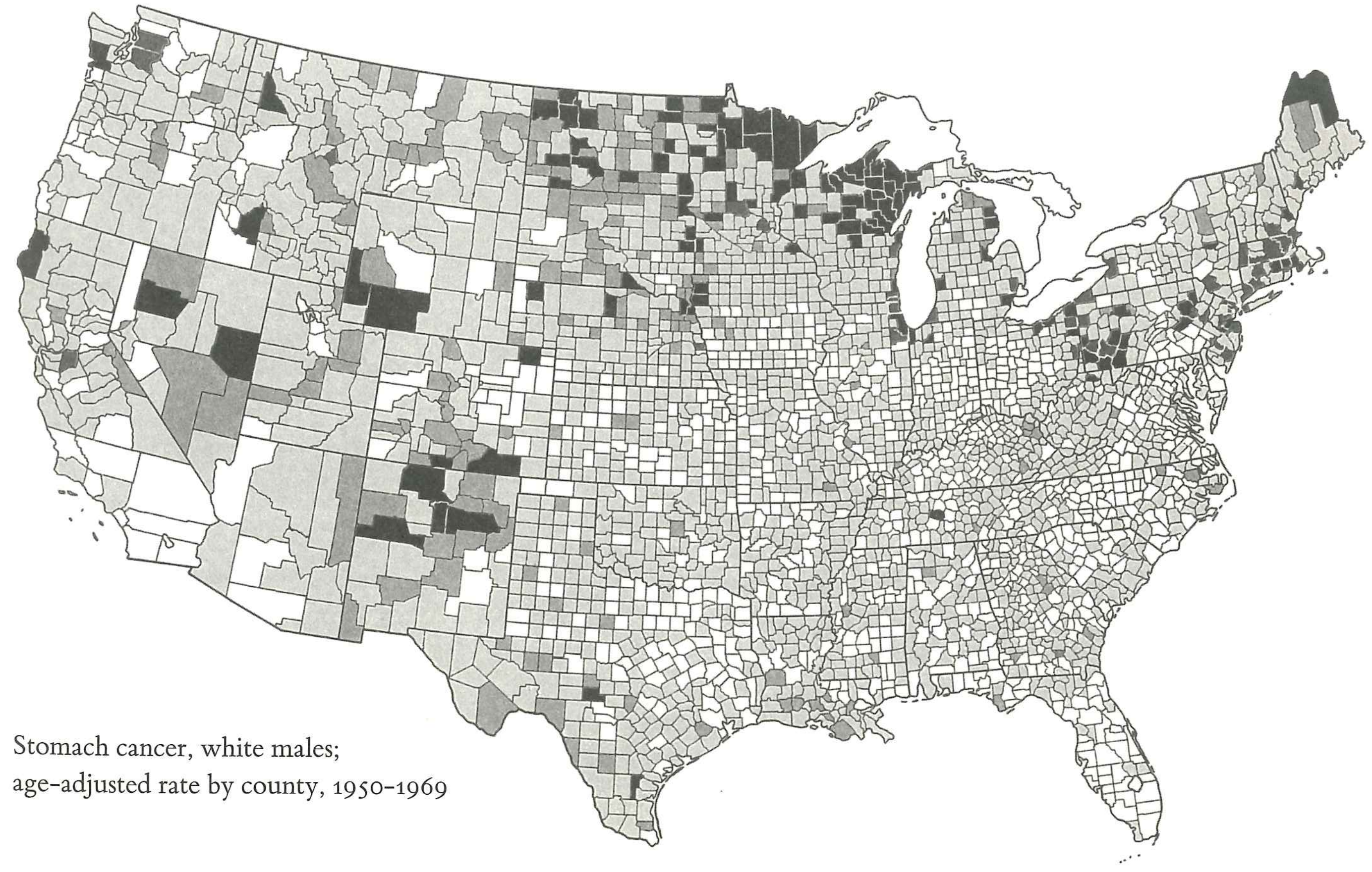
Trachea, bronchus, and lung cancer;
white females; age-adjusted rate
by county, 1950–1969



Trachea, bronchus, and lung cancer;
white males; age-adjusted rate
by county, 1950–1969



Stomach cancer, white females;
age-adjusted rate by county, 1950–1969



Stomach cancer, white males;
age-adjusted rate by county, 1950–1969

The maps repay careful study. Notice how quickly and naturally our attention has been directed toward exploring the substantive content of the data rather than toward questions of methodology and technique. Nonetheless the maps do have their flaws. They wrongly equate the visual importance of each county with its geographic area rather than with the number of people living in the county (or the number of cancer deaths). Our visual impression of the data is entangled with the circumstance of geographic boundaries, shapes, and areas—the chronic problem afflicting shaded-in-area designs of such "blot maps" or "patch maps."

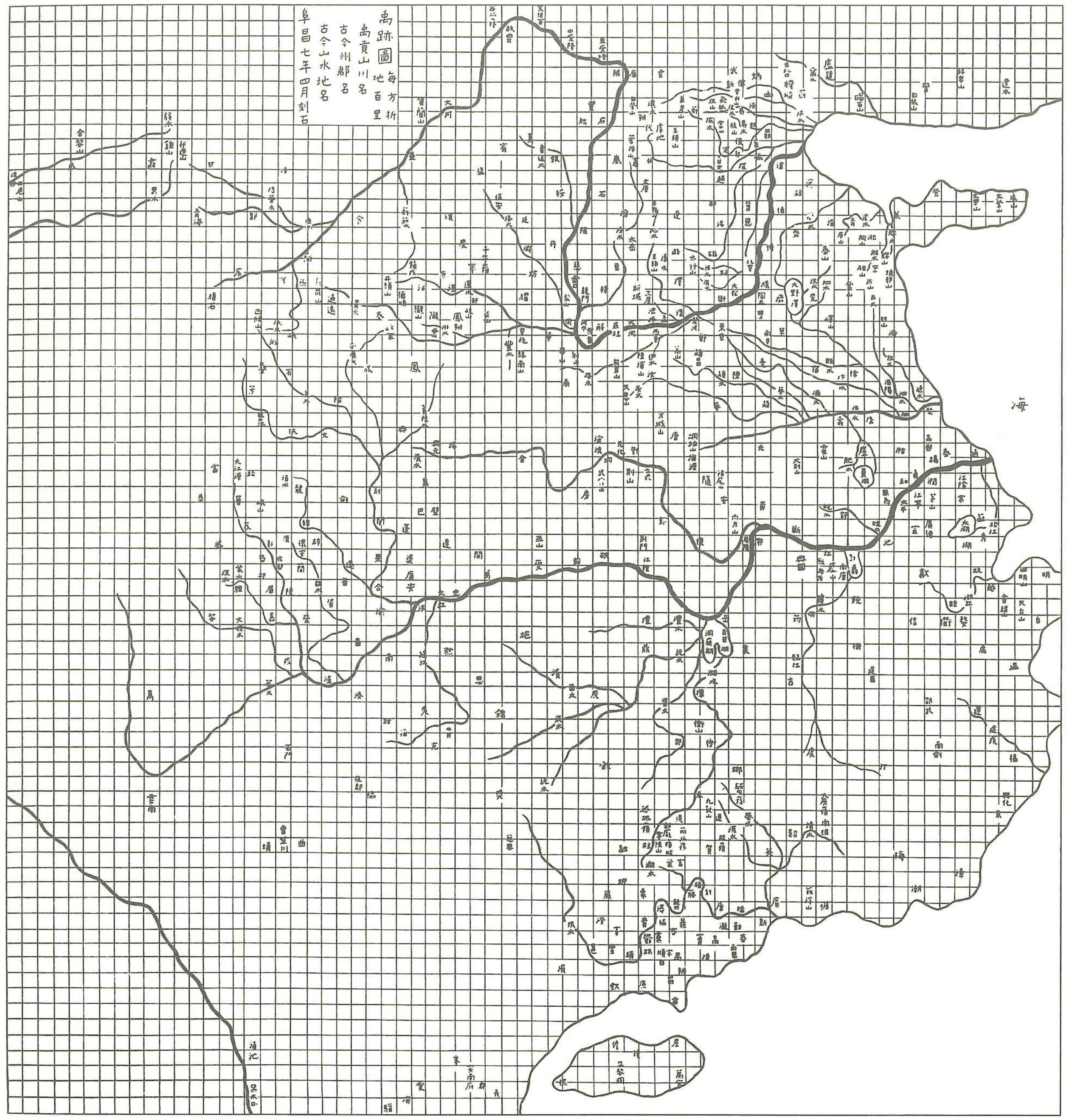
A further shortcoming, a defect of data rather than graphical composition, is that the maps are founded on a suspect data source, death certificate reports on the cause of death. These reports fall under the influence of diagnostic fashions prevailing among doctors and coroners in particular places and times, a troublesome adulterant of the evidence purporting to describe the already sometimes ambiguous matter of the exact bodily site of the primary cancer. Thus part of the regional clustering seen on the maps, as well as some of the hot spots, may reflect varying diagnostic customs and fads along with the actual differences in cancer rates between areas.

Data maps have a curious history. It was not until the seventeenth century that the combination of cartographic and statistical skills required to construct the data map came together, fully 5,000 years after the first geographic maps were drawn on clay tablets. And many highly sophisticated geographic maps were produced centuries before the first map containing any statistical material was drawn.[3] For example, a detailed map with a full grid was engraved during the eleventh century A.D. in China. The Yü Chi Thu (Map of the Tracks of Yü the Great) shown here is described by Joseph Needham as the

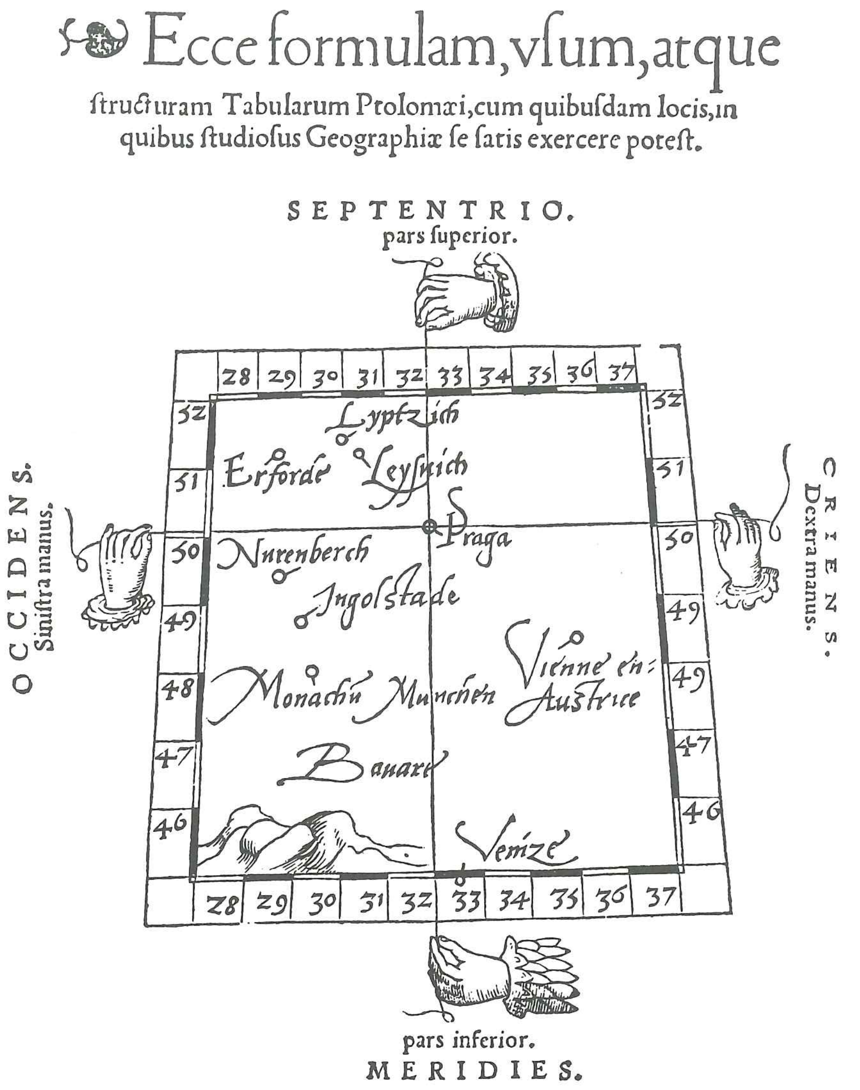
> . . . most remarkable cartographic work of its age in any culture, carved in stone in +1137 but probably dating from before +1100. The scale of the grid in 100 *li* to the division. The coastal outline is relatively firm and the precision of the network of river systems extraordinary. The size of the original, which is now in the Pei Lin Museum at Sian, is about 3 feet square. The name of the geographer is not known. . . . Anyone who compares this map with the contemporary productions of European religious cosmography cannot but be amazed at the extent to which Chinese geography was at that time ahead of the West. . . . There was nothing like it in Europe till the Escorial MS. map of about +1550. . . .[4]

[3] Data maps are usually described as "thematic maps" in cartography. For a thorough account, see Arthur H. Robinson, *Early Thematic Mapping in the History of Cartography* (Chicago, 1982). On the history of statistical graphics, see H. Gray Funkhouser, "Historical Development of the Graphical Representation of Statistical Data," *Osiris*, 3 (November 1937), 269–404; and James R. Beniger and Dorothy L. Robyn, "Quantitative Graphics in Statistics: A Brief History," *American Statistician*, 32 (February 1978), 1–11.

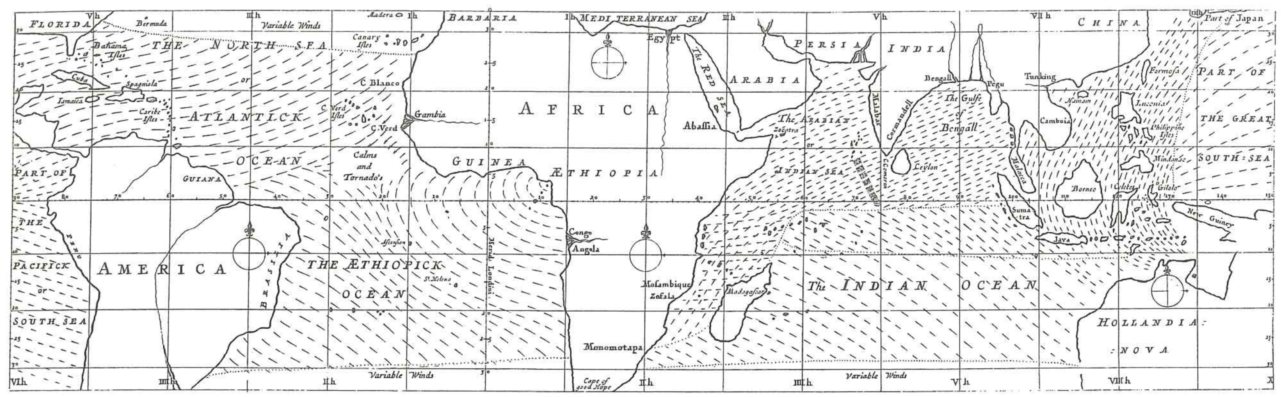
[4] Joseph Needham, *Science and Civilisation in China* (Cambridge, 1959), vol. 3, 546–547.



E. Chavannes, "Les Deux Plus Anciens Spécimens de la Cartographie Chinoise," *Bulletin de l'École Française de l'Extrême Orient*, 3 (1903), 1–35, Carte B.

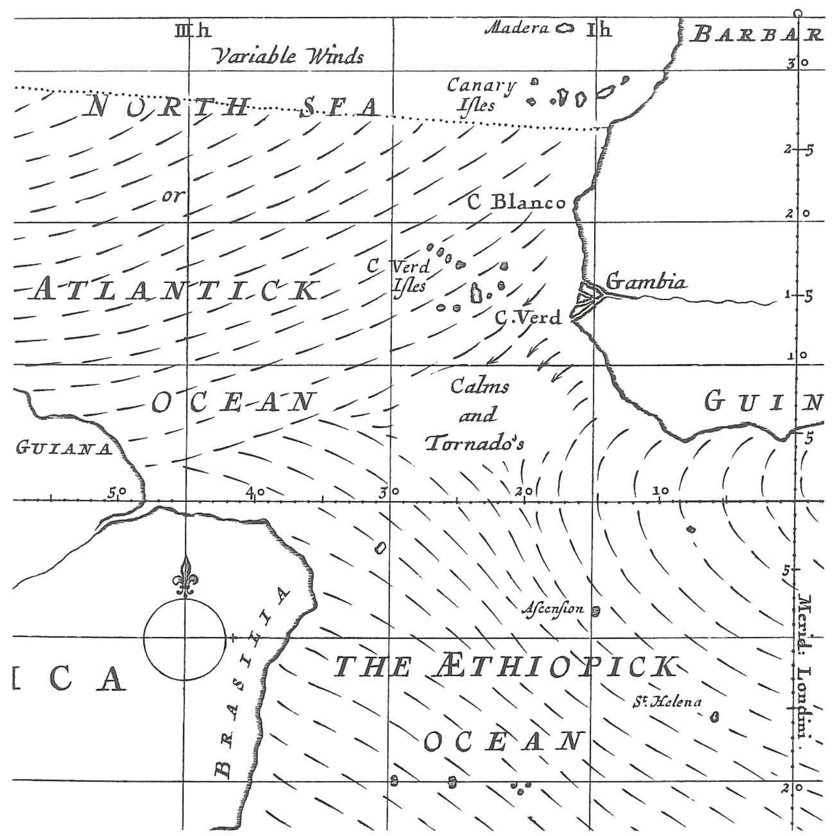


The 1546 edition of *Cosmographia* by Petrus Apianus contained examples of map design that show how very close European cartography by that time had come to achieving statistical graphicacy, even approaching the bivariate scatterplot. But, according to the historical record, no one had yet made the quantitative abstraction of placing a measured quantity on the map's surface at the intersection of the two threads instead of the name of a city, let alone the more difficult abstraction of replacing latitude and longitude with some other dimensions, such as time and money. Indeed, it was not until 1786 that the first economic time-series was plotted.



One of the first data maps was Edmond Halley's 1686 chart showing trade winds and monsoons on a world map.[5] The detailed section below shows the cartographic symbolization; with, as Halley wrote, "... the sharp end of each little stroak pointing out that part of the Horizon, from whence the wind continually comes; and where there are Monsoons the rows of stroaks run alternately backwards and forwards, by which means they are thicker [denser] than elsewhere."

[5] Norman J. W. Thrower, "Edmond Halley as a Thematic Geo-Cartographer," *Annals of the Association of American Geographers*, 59 (December 1969), 652–676.

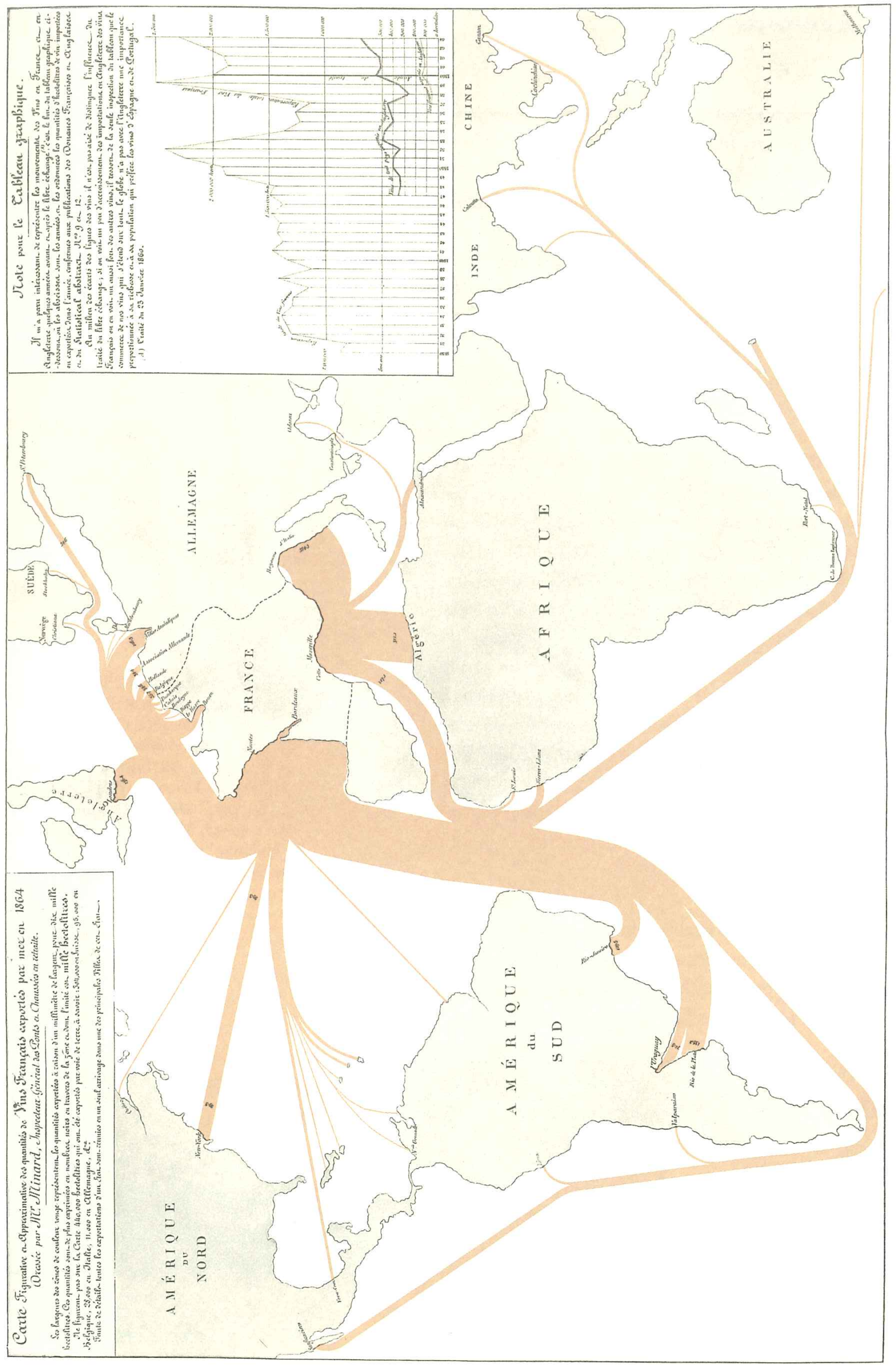


Edmond Halley, "An Historical Account of the Trade Winds, and Monsoons, Observable in the Seas Between and Near the Tropicks; With an Attempt to Assign the Phisical Cause of Said Winds," *Philosophical Transactions*, 183 (1686), 153–168.

An early and most worthy use of a map to chart patterns of disease was the famous dot map of Dr. John Snow, who plotted the location of deaths from cholera in central London for September 1854. Deaths were marked by dots and, in addition, the area's eleven water pumps were located by crosses. Examining the scatter over the surface of the map, Snow observed that cholera occurred almost entirely among those who lived near (and drank from) the Broad Street water pump. He had the handle of the contaminated pump removed, ending the neighborhood epidemic which had taken more than 500 lives.[6] The pump is located at the center of the map, just to the right of the D in BROAD STREET. Of course the link between the pump and the disease might have been revealed by computation and analysis without graphics, with some good luck and hard work. But, here at least, graphical analysis testifies about the data far more efficiently than calculation.

[6] E.W. Gilbert, "Pioneer Maps of Health and Disease in England," *Geographical Journal*, 124 (1958), 172–183. Shown here is a redrawing of John Snow's map. For a reproduction and detailed analysis of the original map, see Edward Tufte, *Visual Explanations: Images and Quantities, Evidence and Narrative* (Cheshire, Connecticut, 1997), Chapter 2. Ideally, see John Snow, *On the Mode of Communication of Cholera* (London, 1855).

Charles Joseph Minard gave quantity as well as direction to the data measures located on the world map in his portrayal of the 1864 exports of French wine:

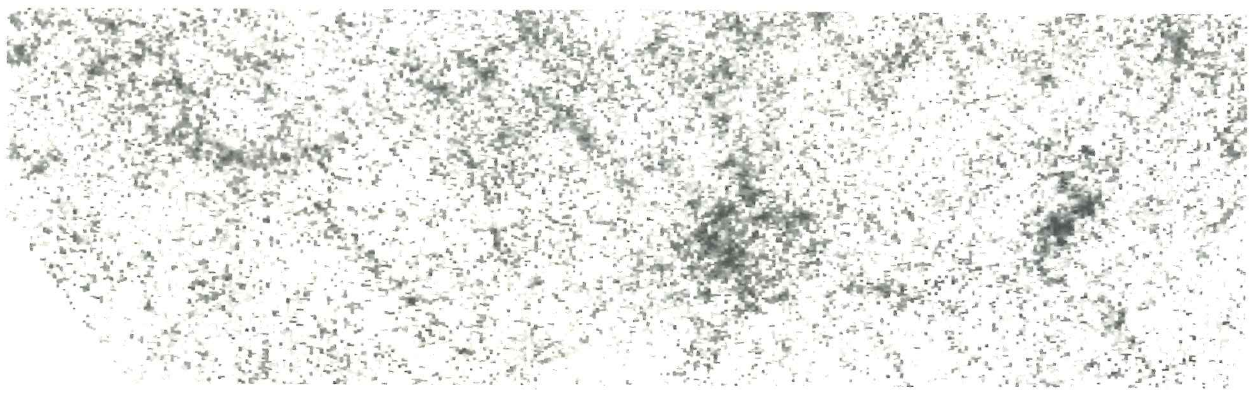


Charles Joseph Minard, *Tableaux Graphiques et Cartes Figuratives de M. Minard*, 1845–1869, a portfolio of his work held by the Bibliothèque de l'École Nationale des Ponts et Chaussées, Paris.

Computerized cartography and modern photographic techniques have increased the density of information some 5,000-fold in the best of current data maps compared to Halley's pioneering effort. This map shows the distribution of 1.3 million galaxies (including some overlaps) in the northern galactic hemisphere. The map divides the sky into 1,024 × 2,222 rectangles. The number of galaxies counted in each of the 2,275,328 rectangles is represented by ten gray tones; the darker the tone, the greater the number of galaxies counted. The north galactic pole is at the center. The sharp edge on the left results from the earth blocking the view from the observatory. In the area near the perimeter of the map, the view is obscured by the interstellar dust of the galaxy in which we live (the Milky Way) as the line of sight passes through the flattened disk of our galaxy. The curious texture of local clusters of galaxies seen in this truly new view of the universe was not anticipated by students of galaxies, who had, of course, microscopically examined millions of photographs of galaxies before seeing this macroscopic view. Although the clusters are clearly evident (and accounted for by a theory of galactic origins), the seemingly random filaments may be happenstance. The producers of the map note the "strong temptation to conclude that the galaxies are arranged in a remarkable filamentary pattern on scales of approximately 5° to 15°, but we caution that this visual impression may be misleading because the eye tends to pick out linear patterns even in random noise. Indeed, roughly similar patterns are seen on maps constructed from simulated catalogs where no linear structure has been built in. . . ."[7]

[7] Michael Seldner, B. H. Siebers, Edward J. Groth and P. James E. Peebles, "New Reduction of the Lick Catalog of Galaxies," *Astronomical Journal*, 82 (April 1977), 249–314. See Gillian R. Knapp, "Mining the Heavens: The Sloan Digital Sky Survey," *Sky & Telescope* (August 1997), 40–48; Margaret J. Geller and John P. Huchra, "Mapping the Universe," *Sky & Telescope* (August 1991), 134–139.

The most extensive data maps, such as the cancer atlas and the count of the galaxies, place millions of bits of information on a single page before our eyes. No other method for the display of statistical information is so powerful.



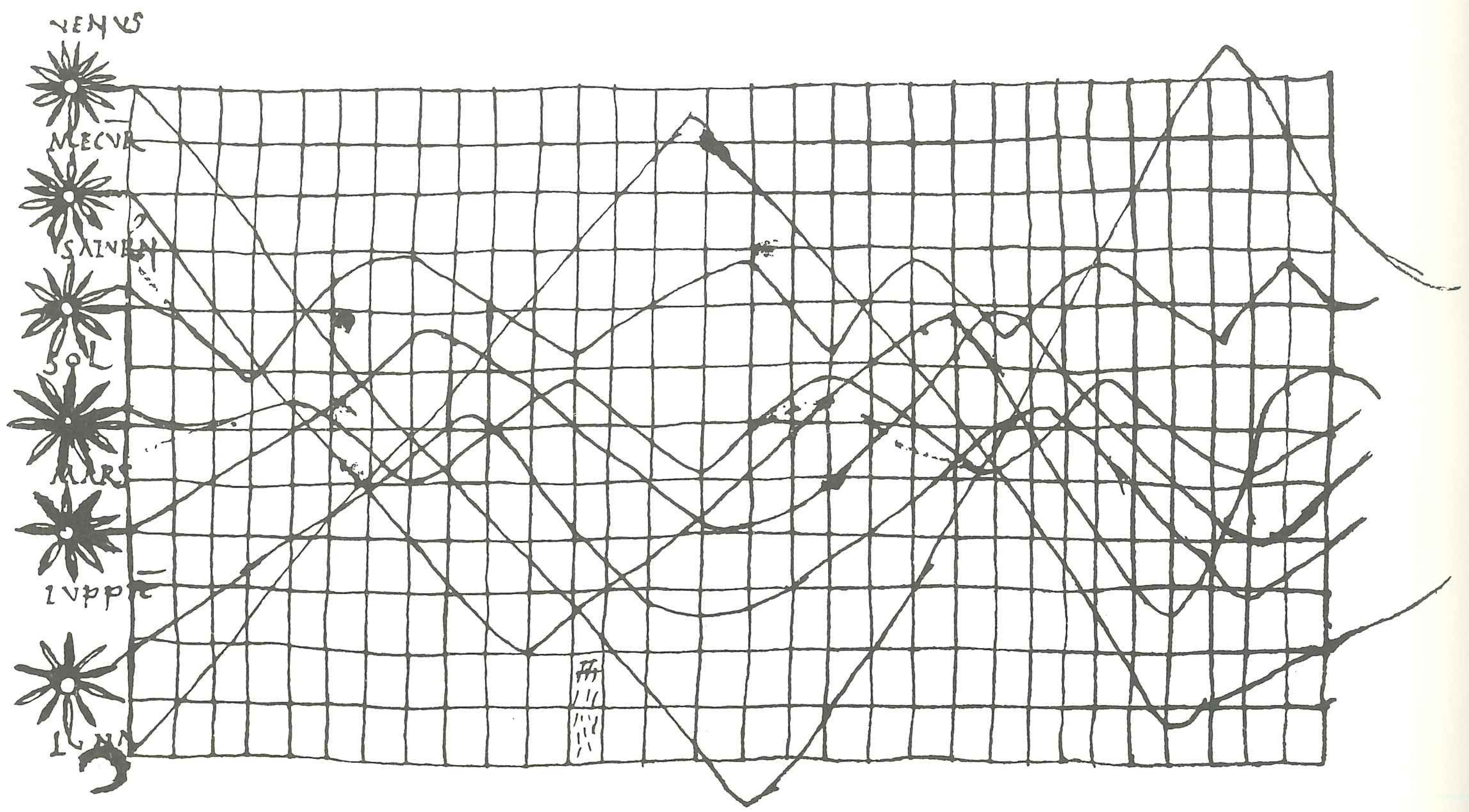
Time-Series

The time-series plot is the most frequently used form of graphic design.[8] With one dimension marching along to the regular rhythm of seconds, minutes, hours, days, weeks, months, years, centuries, or millennia, the natural ordering of the time scale gives this design a strength and efficiency of interpretation found in no other graphic arrangement.

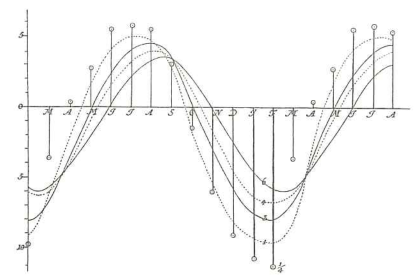
This reputed tenth- (or possibly eleventh-) century illustration of the inclinations of the planetary orbits as a function of time, apparently part of a text for monastery schools, is the oldest known example of an attempt to show changing values graphically. It appears as a mysterious and isolated wonder in the history of data graphics, since the next extant graphic of a plotted time-series shows up some 800 years later. According to Funkhouser, the astronomical content is confused and there are difficulties in reconciling the graph and its accompanying text with the actual movements of the planets. Particularly disconcerting is the wavy path ascribed to the sun.[9] An erasure and correction of a curve occur near the middle of the graph.

[8] A random sample of 4,000 graphics drawn from 15 of the world's newspapers and magazines published from 1974 to 1980 found that more than 75 percent of all the graphics published were time-series. Chapter 3 reports more on this.

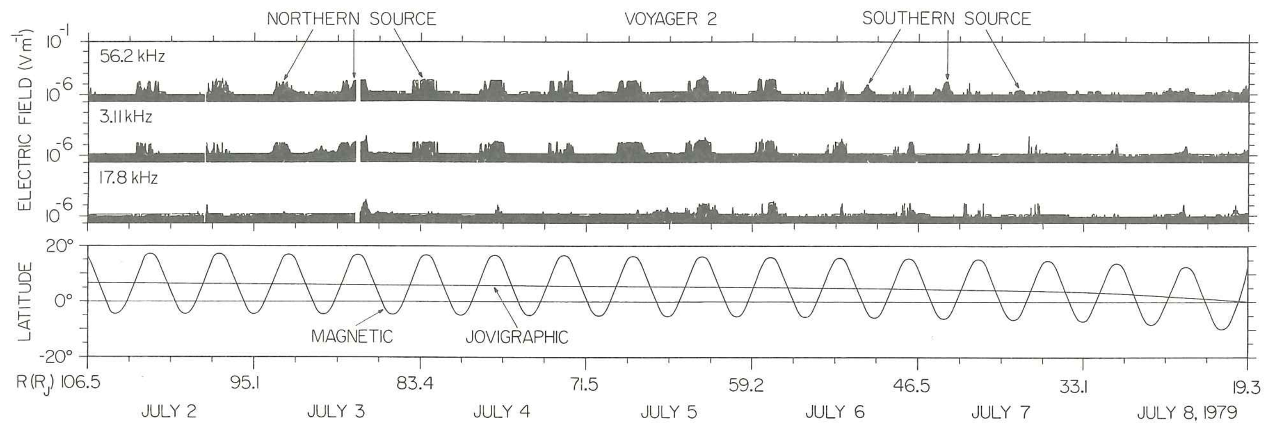
[9] H. Gray Funkhouser, "A Note on a Tenth Century Graph," *Osiris*, 1 (January 1936), 260–262.



It was not until the late 1700s that time-series charts began to appear in scientific writings. This drawing of Johann Heinrich Lambert, one of a long series, shows the periodic variation in soil temperature in relation to the depth under the surface. The greater the depth, the greater the time-lag in temperature responsiveness. Modern graphic designs showing time-series periodicities differ little from those of Lambert, although the data bases are far larger.



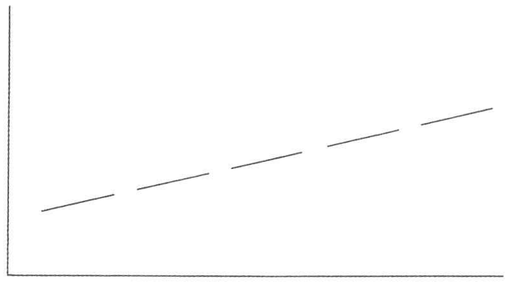
J. H. Lambert, *Pyrometrie* (Berlin, 1779).



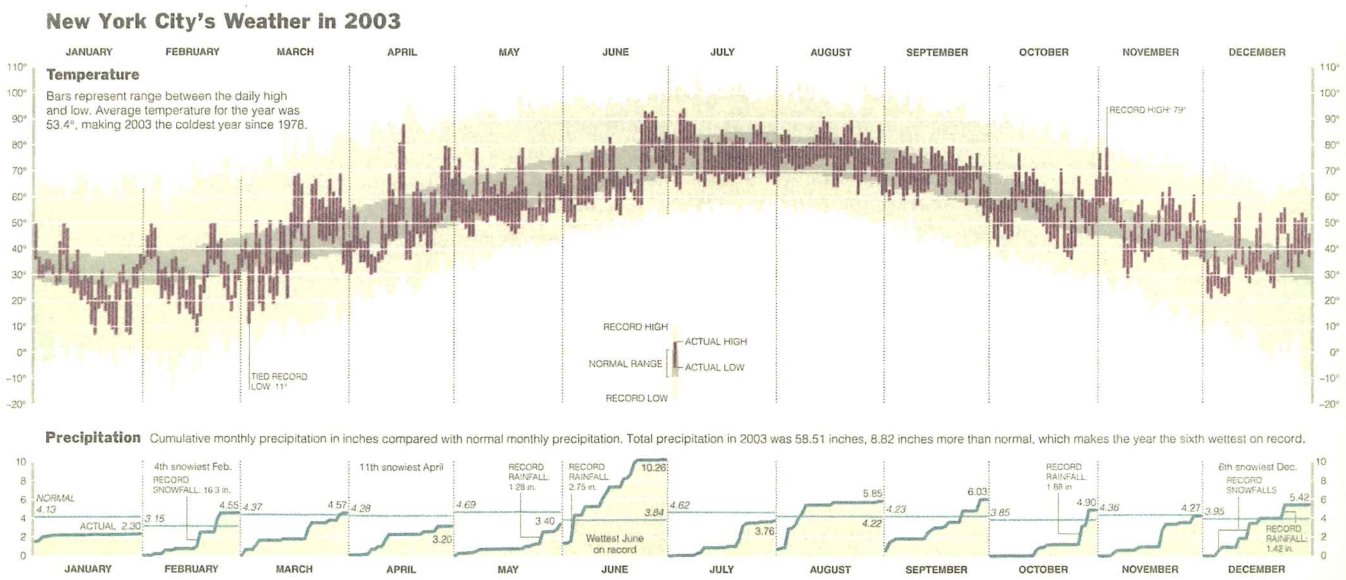
This plot of radio emissions from Jupiter is based on data collected by Voyager 2 in its pass close by the planet in July 1979. The radio intensity increases and decreases in a ten-hour cycle as Jupiter rotates. Maximum intensity occurs when the Jovian north magnetic pole is tipped toward the spacecraft, indicating a northern hemisphere source. A southern source was detected on July 7, as the spacecraft neared the equatorial plane. The horizontal scale shows the distance of the spacecraft from the planet measured in terms of Jupiter radii (R). Note the use of dual labels on the horizontal to indicate both the date and distance from Jupiter. The entire bottom panel also serves to label the horizontal scale, describing the changing orientation of the spacecraft relative to Jupiter as the planet is approached. The multiple time-series enforce not only comparisons within each series over time (as do all time-series plots) but also comparisons between the three different sampled radio bands shown. This richly multivariate display is based on 453,600 instrument samples of eight bits each. The resulting 3.6 million bits were reduced by peak and average processing to the 18,900 points actually plotted on the graphic.

D. A. Gurnett, W. S. Kurth, and F. L. Scarf, "Plasma Wave Observations Near Jupiter: Initial Results from Voyager 2," *Science* 206 (November 23, 1979), 987–991; and letter from Donald A. Gurnett to Edward R. Tufte, June 27, 1980.

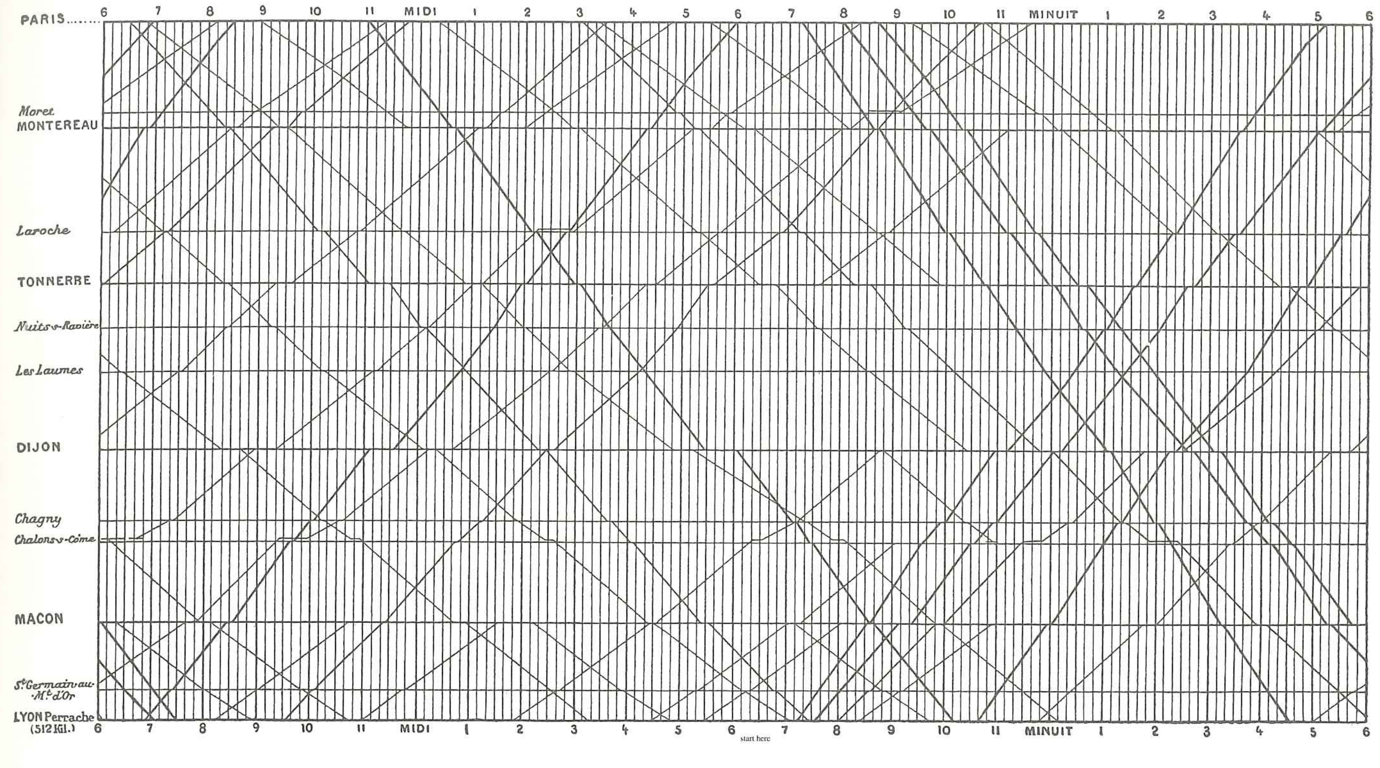
Time-series displays are at their best for big data sets with real variability. Why waste the power of data graphics on simple linear changes,



which can usually be better summarized in one or two numbers? Instead, graphics should be reserved for the richer, more complex, more difficult statistical material. This New York City weather summary for 2003 depicts 3,322 numbers. The daily high and low temperatures are shown in relation to the long-run average. The path of the normal temperatures also provides a forecast of expected change over the year; in the middle of February, for instance, New York City residents can look forward to warming at the rate of about 1.5 degrees per week all the way to July, the yearly peak. This distinguished graphic successfully organizes a large collection of numbers, makes comparisons between different parts of the data, and tells a story.



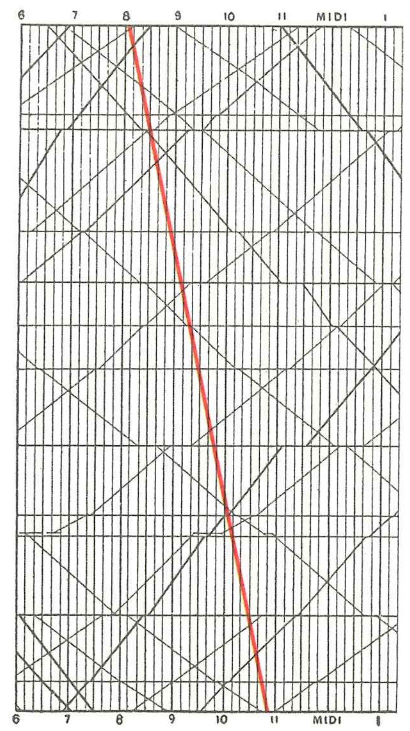
New York Times, January 4, 2004, A15.



E. J. Marey, *La méthode graphique* (Paris, 1885), 20. The method is attributed to the French engineer, Ibry.

A design with similar strengths is Marey's graphical train schedule for Paris to Lyon in the 1880s. Arrivals and departures from a station are located along the horizontal; length of stop at a station is indicated by the length of the horizontal line. The stations are separated in proportion to their actual distance apart. The slope of the line reflects the speed of the train: the more nearly vertical the line, the faster the train. The intersection of two lines locates the time and place that trains going in opposite directions pass each other.

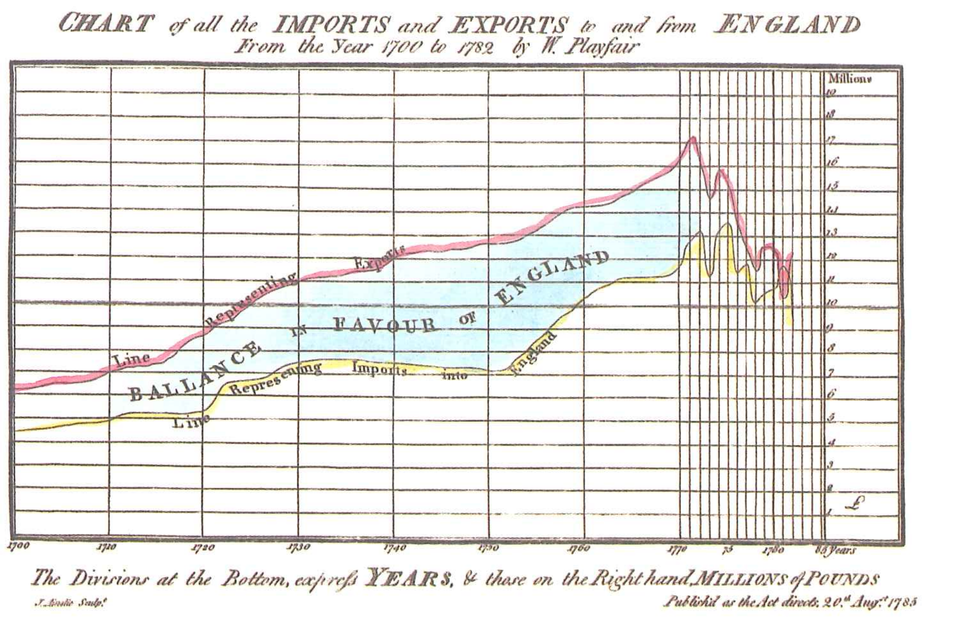
In 1981 a new express train from Paris to Lyon cut the trip to under three hours, compared to more than nine hours when Marey published the graphical train schedule. The path of the modern TGV (*train à grande vitesse*) is shown, overlaid on the schedule of 100 years before:



The two great inventors of modern graphical designs were J. H. Lambert (1728–1777), a Swiss-German scientist and mathematician, and William Playfair (1759–1823), a Scottish political economist.[10] The first known time-series using economic data was published in Playfair's remarkable book, *The Commercial and Political Atlas* (London, 1786). Note the graphical arithmetic, which shows the shifting balance of trade by the difference between the import and export time-series. Playfair contrasted his new graphical method with the tabular presentation of data:

> Information, that is imperfectly acquired, is generally as imperfectly retained; and a man who has carefully investigated a printed table, finds, when done, that he has only a very faint and partial idea of what he has read; and that like a figure imprinted on sand, is soon totally erased and defaced. The amount of mercantile transactions in money, and of profit or loss, are capable of being as easily represented in drawing, as any part of space, or as the face of a country; though, till now, it has not been attempted. Upon that principle these Charts were made; and, while they give a simple and distinct idea, they are as near perfect accuracy as is any way useful. On inspecting any one of these Charts attentively, a sufficiently distinct impression will be made, to remain unimpaired for a considerable time, and the idea which does remain will be simple and complete, at once including the duration and the amount. [pages 3–4]

For Playfair, graphics were preferable to tables because graphics showed the shape of the data in a comparative perspective. Time-

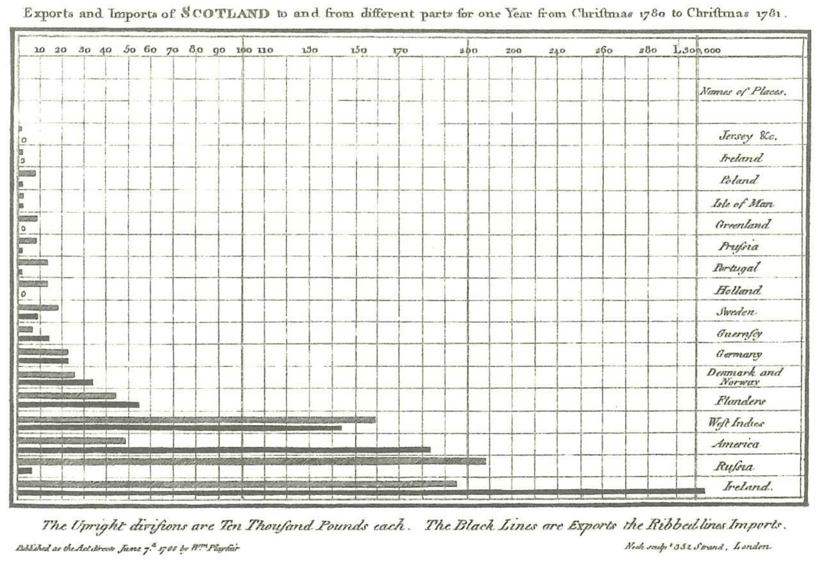


[10] Laura Tilling, "Early Experimental Graphs," *British Journal for the History of Science*, 8 (1975), 193–213.

series plots did this, and all but one of the 44 charts in the first edition of *The Commercial and Political Atlas* were time-series. That one exception is the first known bar chart, which Playfair invented because year-to-year data were missing and he needed a design to portray the one-year data that were available. Nonetheless he was skeptical about his innovation:

> This Chart is different from the others in principle, as it does not comprehend any portion of time, and it is much inferior in utility to those that do; for though it gives the extent of the different branches of trade, it does not compare the same branch of commerce with itself at different periods; nor does it imprint upon the mind that distinct idea, in doing which, the chief advantage of Charts consists: for as it wants the dimension that is formed by duration, there is no shape given to the quantities. [page 101]

He was right: small, noncomparative, highly labeled data sets usually belong in tables.

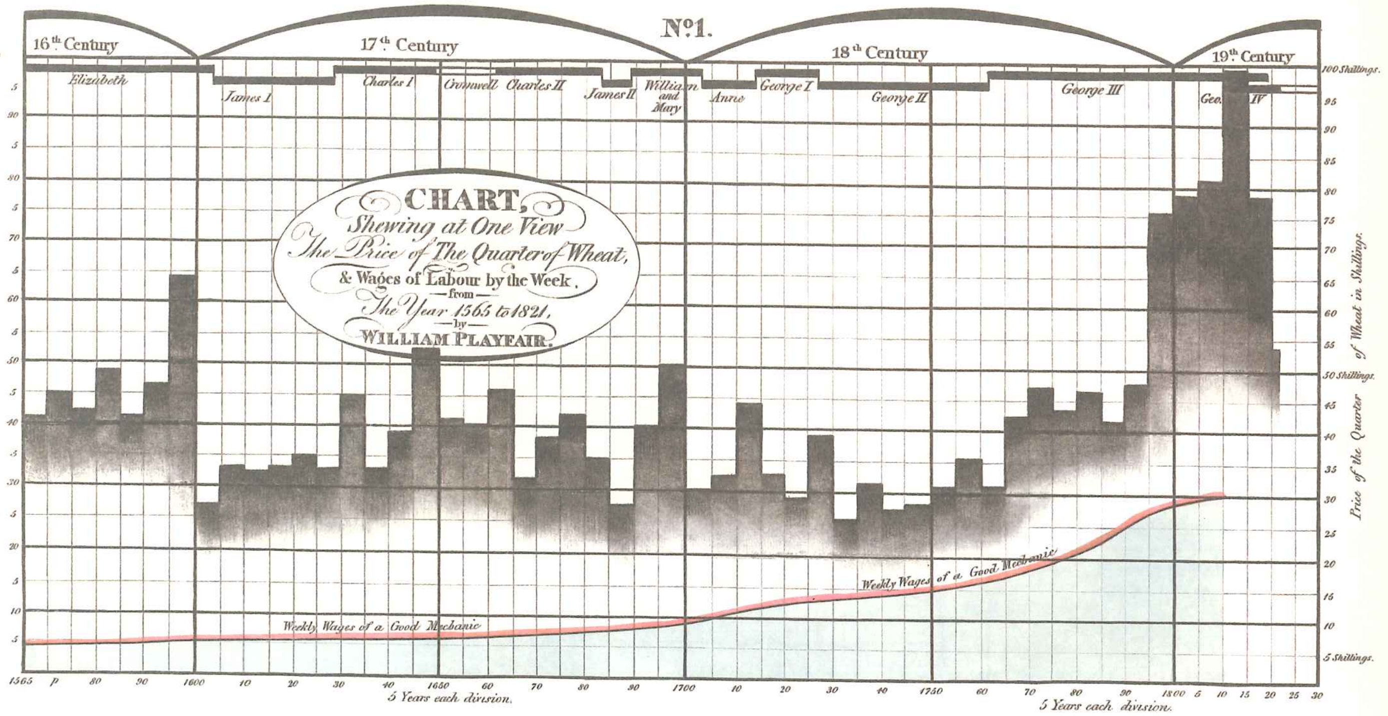


The chart does show, at any rate, the imports (cross-hatched lines) and exports (solid lines) to and from Scotland in 1781 for 17 countries, which are ordered by volume of trade. The horizontal scale is at the top, possibly to make it more convenient to see in plotting the points by hand. Zero values are nicely indicated both by the absence of a bar and by a "o." The horizontal scale mistakenly repeats "200." In nearly all his charts, Playfair placed the labels for the vertical scale on the right side of the page (suggesting that he plotted the data points using his left hand).

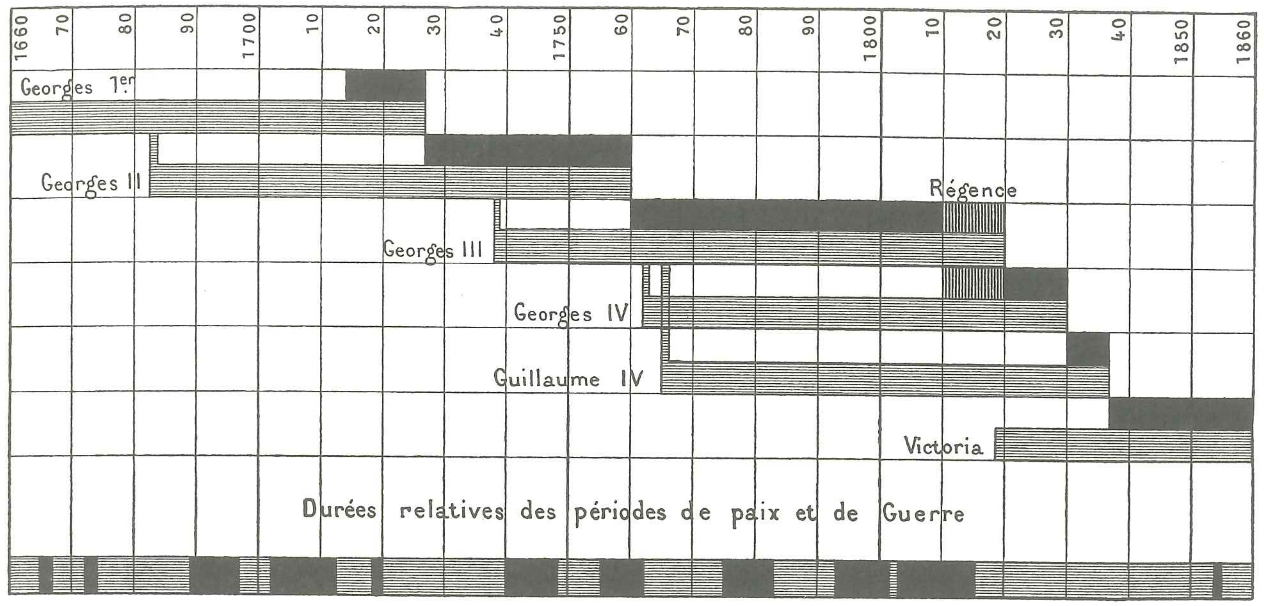
Playfair's last book addressed the question whether the price of wheat had increased relative to wages. In his *Letter on our agricultural distresses, their causes and remedies; accompanied with tables and copper-plate charts shewing and comparing the prices of wheat, bread and labour, from 1565 to 1821*, Playfair wrote:

> You have before you, my Lords and Gentlemen, a chart of the prices of wheat for 250 years, made from official returns; on the same plate I have traced a line representing, as nearly as I can, the wages of good mechanics, such as smiths, masons, and carpenters, in order to compare the proportion between them and the price of wheat at every different period. . . . the main fact deserving of consideration is, that never at any former period was wheat so cheap, in proportion to mechanical labour, as it is at the present time. . . . [pages 29–31]

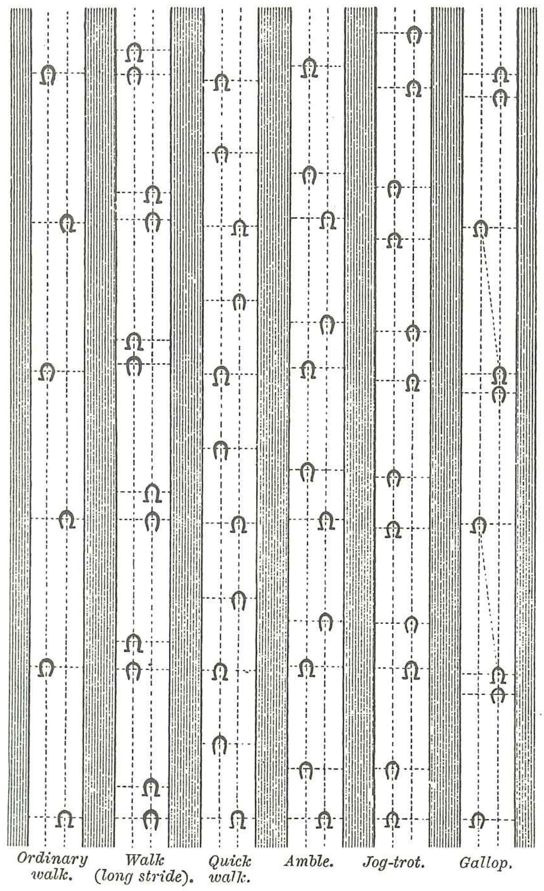
Here Playfair plotted three parallel time-series: prices, wages, and the reigns of British kings and queens.



The history and genealogy of royalty was long a graphical favorite. This superb construction of E. J. Marey brings together several sets of facts about English rulers into a time-series that conveys a sense of the march of history. Marey (1830–1904) also pioneered the development of graphical methods in human and animal physiology, including studies of horses moving at different paces,

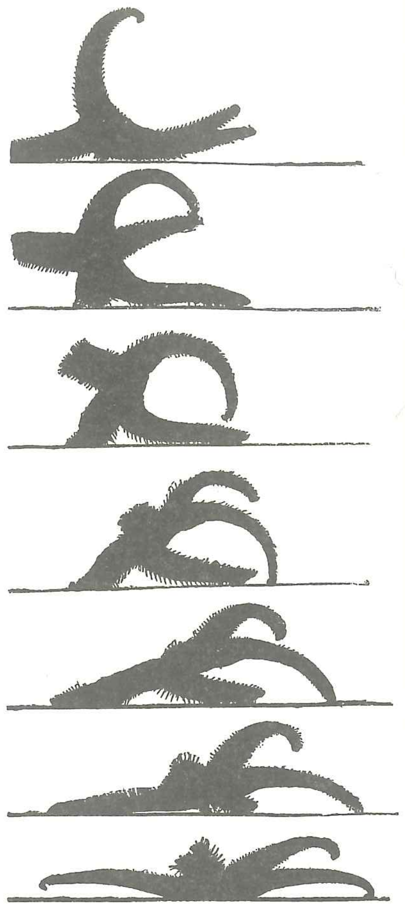


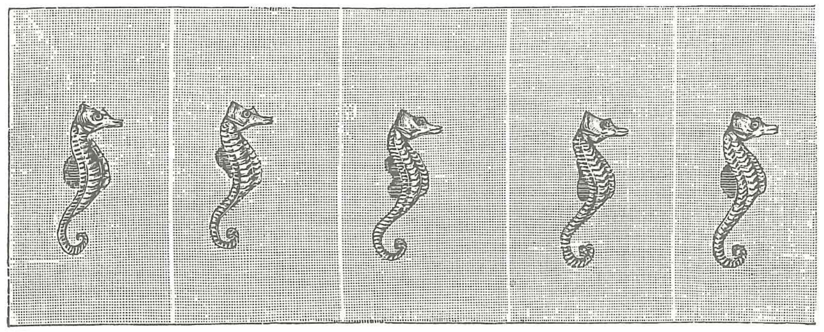
E. J. Marey, *La Méthode Graphique* (Paris, 1885), 6.



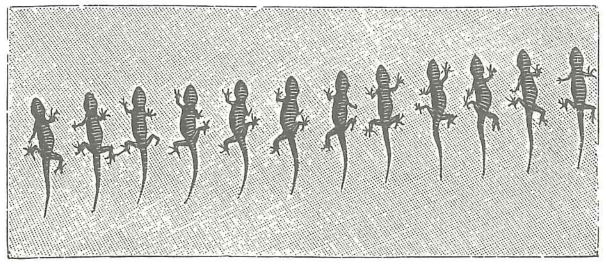
E. J. Marey, *Movement* (London, 1895). Beginning with the tracks of the horse, the time-series are from pages 191, 224, 222, 265, 60, and 61.

the movement of a starfish turning itself over (read images from the bottom upwards),



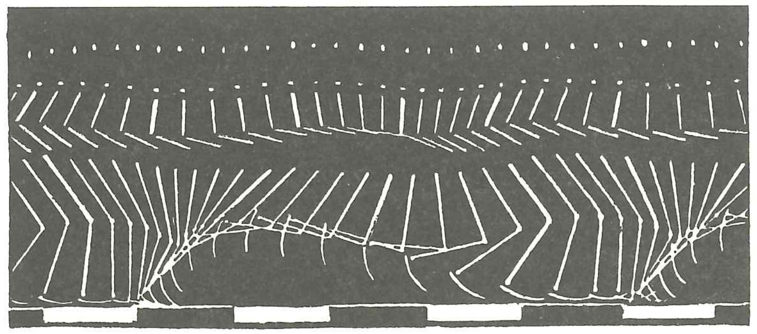


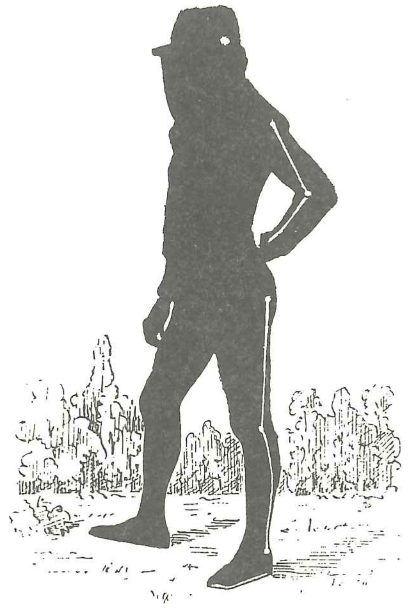
the undulations of the dorsal fin of a descending sea horse,



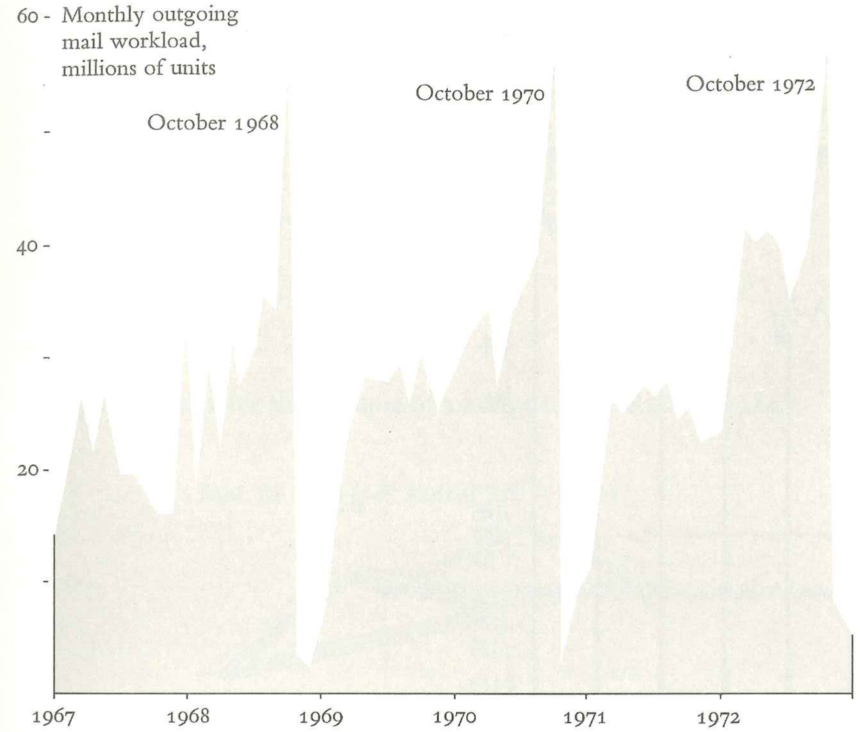
as well as the advance of the gecko.

Marey's man in black velvet, photographed in stick-figure images, became the time-series forerunner of Marcel Duchamp's *Nude Descending a Staircase*.

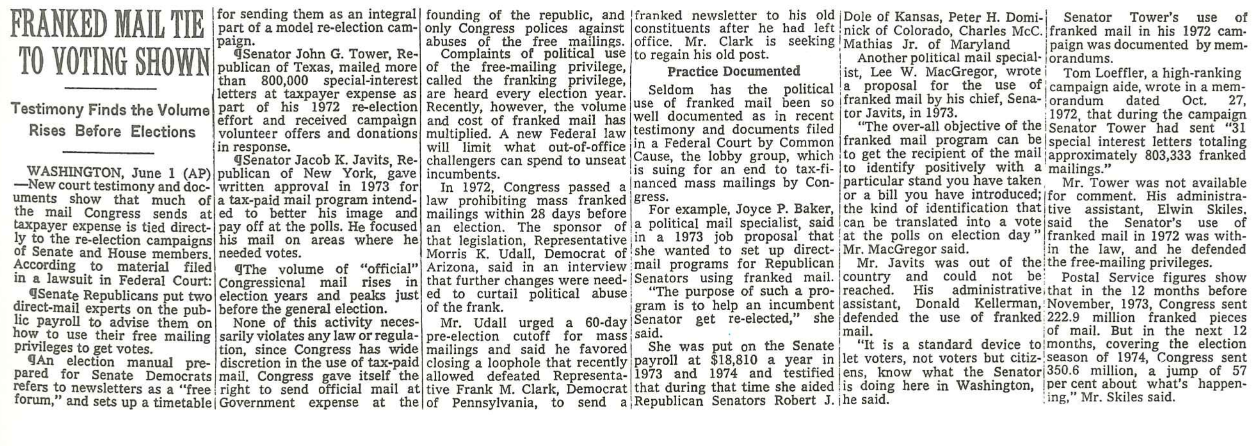




The problem with time-series is that the simple passage of time is not a good explanatory variable: descriptive chronology is not causal explanation. There are occasional exceptions, especially when there is a clear mechanism that drives the Y-variable. This time-series does testify about causality: the outgoing mail of the U.S. House of Representatives peaks every two years, just before the election day:



The graphic is worth at least 700 words, the number used in a news report describing how incumbent representatives exploit their free mailing privileges to advance their re-election campaigns:



FRANKED MAIL TIE TO VOTING SHOWN

Testimony Finds the Volume Rises Before Elections

WASHINGTON, June 1 (AP)—New court testimony and documents show that much of the mail Congress sends at taxpayer expense is tied directly to the re-election campaigns of Senate and House members. According to material filed in a lawsuit in Federal Court:

¶Senate Republicans put two direct-mail experts on the public payroll to advise them on how to use their free mailing privileges to get votes.

¶An election manual prepared for Senate Democrats refers to newsletters as a "free forum," and sets up a timetable for sending them as an integral part of a model re-election campaign.

¶Senator John G. Tower, Republican of Texas, mailed more than 800,000 special-interest letters at taxpayer expense as part of his 1972 re-election effort and received campaign volunteer offers and donations in response.

¶Senator Jacob K. Javits, Republican of New York, gave written approval in 1973 for a tax-paid mail program intended to better his image and pay off at the polls. He focused his mail on areas where he needed votes.

¶The volume of "official" Congressional mail rises in election years and peaks just before the general election.

None of this activity necessarily violates any law or regulation, since Congress has wide discretion in the use of tax-paid mail. Congress gave itself the right to send official mail at Government expense at the founding of the republic, and only Congress polices against abuses of the free mailings.

Complaints of political use of the free-mailing privilege, called the franking privilege, are heard every election year. Recently, however, the volume and cost of franked mail has multiplied. A new Federal law will limit what out-of-office challengers can spend to unseat incumbents.

In 1972, Congress passed a law prohibiting mass franked mailings within 28 days before an election. The sponsor of that legislation, Representative Morris K. Udall, Democrat of Arizona, said in an interview that further changes were needed to curtail political abuse of the frank.

Mr. Udall urged a 60-day pre-election cutoff for mass mailings and said he favored closing a loophole that recently allowed defeated Representative Frank M. Clark, Democrat of Pennsylvania, to send a franked newsletter to his old constituents after he had left office. Mr. Clark is seeking to regain his old post.

Practice Documented

Seldom has the political use of franked mail been so well documented as in recent testimony and documents filed in a Federal Court by Common Cause, the lobby group, which is suing for an end to tax-financed mass mailings by Congress.

For example, Joyce P. Baker, a political mail specialist, said in a 1973 job proposal that she wanted to set up direct-mail programs for Republican Senators using franked mail.

"The purpose of such a program is to help an incumbent Senator get re-elected," she said.

She was put on the Senate payroll at $18,810 a year in 1973 and 1974 and testified that during that time she aided Republican Senators Robert J. Dole of Kansas, Peter H. Dominick of Colorado, Charles McC. Mathias Jr. of Maryland

Another political mail specialist, Lee W. MacGregor, wrote a proposal for the use of franked mail by his chief, Senator Javits, in 1973.

"The over-all objective of the franked mail program can be to get the recipient of the mail to identify positively with a particular stand you have taken or a bill you have introduced; the kind of identification that can be translated into a vote at the polls on election day" Mr. MacGregor said.

Mr. Javits was out of the country and could not be reached. His administrative assistant, Donald Kellerman, defended the use of franked mail.

"It is a standard device to let voters, not voters but citizens, know what the Senator is doing here in Washington, he said.

Senator Tower's use of franked mail in his 1972 campaign was documented by memorandums.

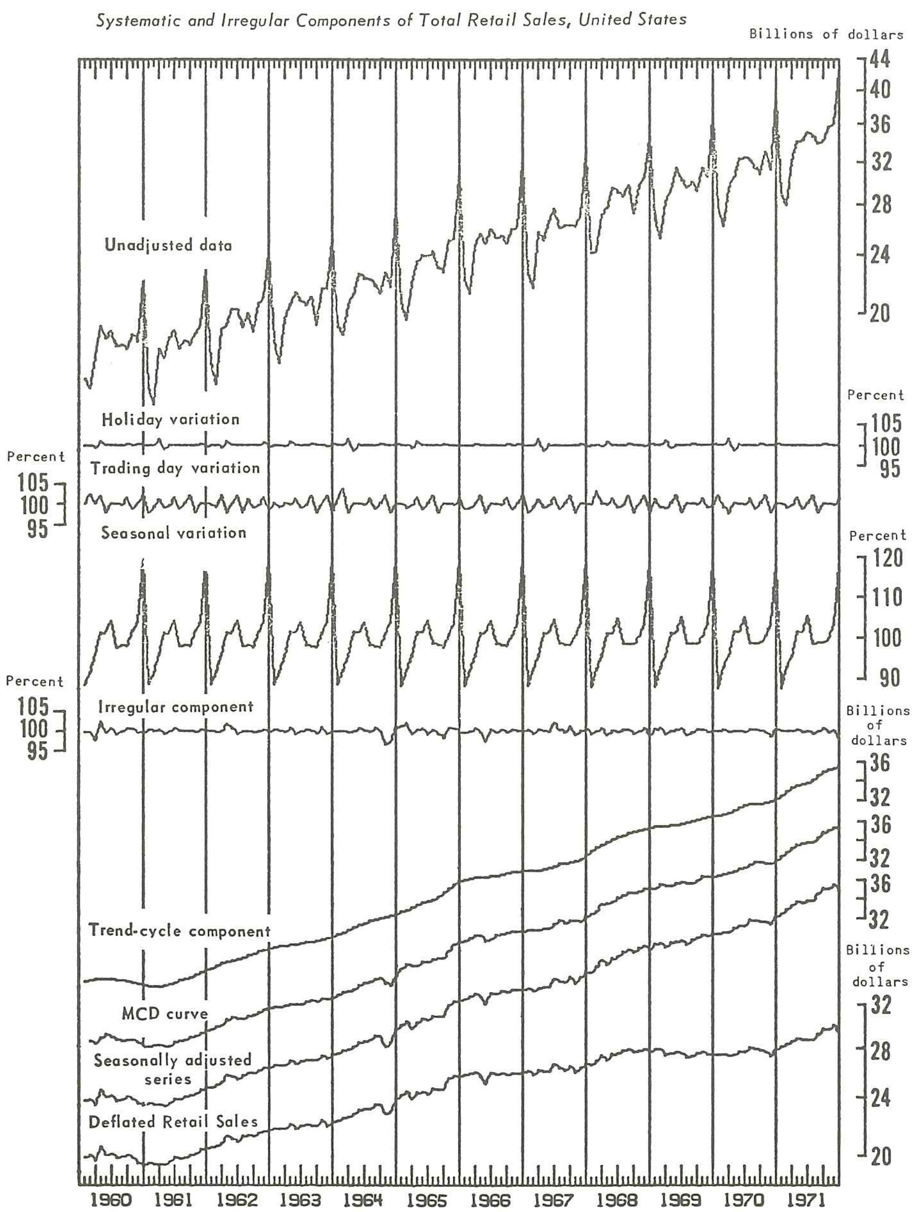
Tom Loeffler, a high-ranking campaign aide, wrote in a memorandum dated Oct. 27, 1972, that during the campaign Senator Tower had sent "31 special interest letters totaling approximately 803,333 franked mailings."

Mr. Tower was not available for comment. His administrative assistant, Elwin Skiles, said the Senator's use of franked mail in 1972 was within the law, and he defended the free-mailing privileges.

Postal Service figures show that in the 12 months before November, 1973, Congress sent 222.9 million franked pieces of mail. But in the next 12 months, covering the election season of 1974, Congress sent 350.6 million, a jump of 57 per cent about what's happening," Mr. Skiles said.

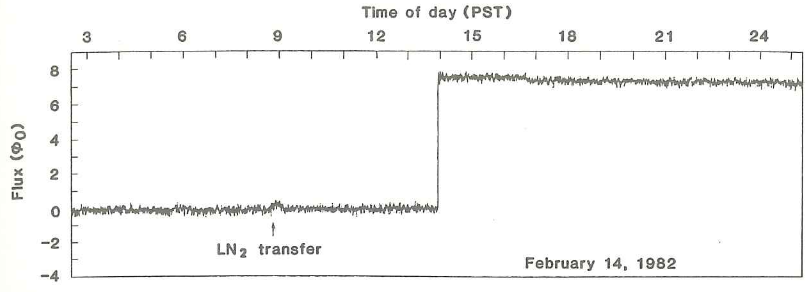
Time-series plots can be moved toward causal explanation by smuggling additional variables into the graphic design. For example, this decomposition of economic data, arraying 1,296 numbers, breaks out the top series into seasonal and trading-day fluctuations (which dominate short-term changes) to reveal the long-run trend adjusted for inflation. (Note a significant defect in the design, however: the vertical grid conceals the height of the December peaks.) The next step would be to bring in additional variables to explain the transformed and improved series at the bottom.[11]

[11] See William S. Cleveland and Irma J. Terpenning, "Graphical Methods for Seasonal Adjustment," *Journal of the American Statistical Association* 77 (March 1982), 52–62.



Julius Shiskin, "Measuring Current Economic Fluctuations," *Statistical Reporter* (July 1973), 3.

Finally, a vivid design (with appropriate data) is the before-after time-series:

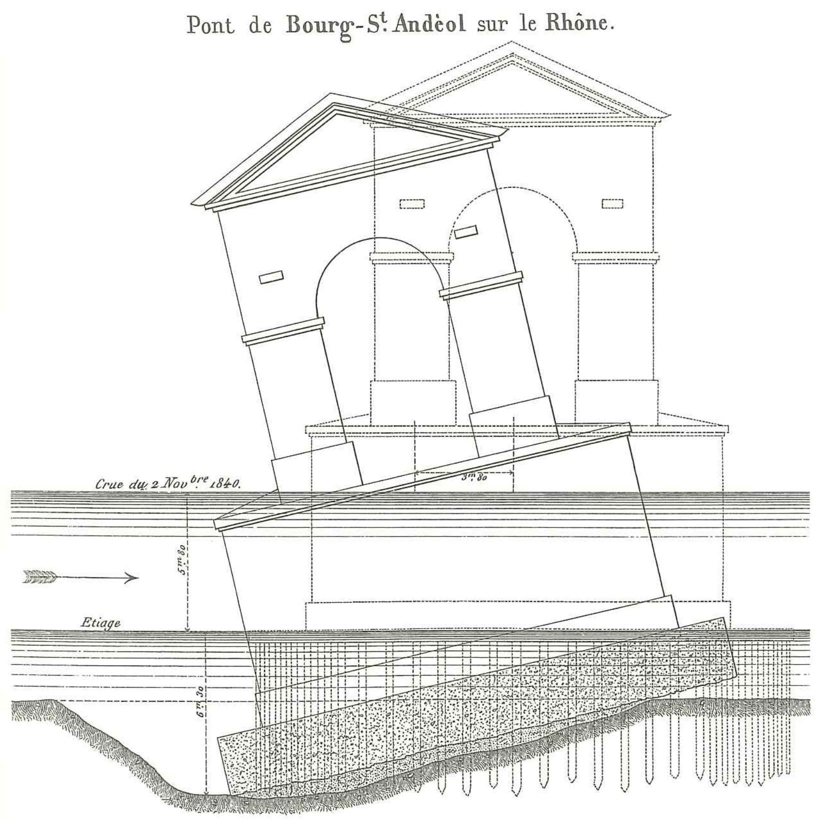


A monopole?

Cabrera's candidate monopole signal looms over a disturbance caused by a liquid nitrogen transfer earlier in the day. The jump in magnetic flux through the superconducting detector loop (or equivalently, the jump in the loop's supercurrent) is just the right magnitude to be a monopole. Moreover, the current remained stable for many hours afterward.

M. Mitchell Waldrop, "In Search of the Magnetic Monopole," *Science* (June 4, 1982), 1087.

And before and after the collapse of a bridge on the Rhône in 1840:



Charles Joseph Minard, "De la Chute des Ponts dans les grandes Crues," (October 24, 1856), Figure 3, in Minard, *Collection de ses brochures* (Paris, 1821–1869), held by the Bibliothèque de l'École Nationale des Ponts et Chaussées, Paris.

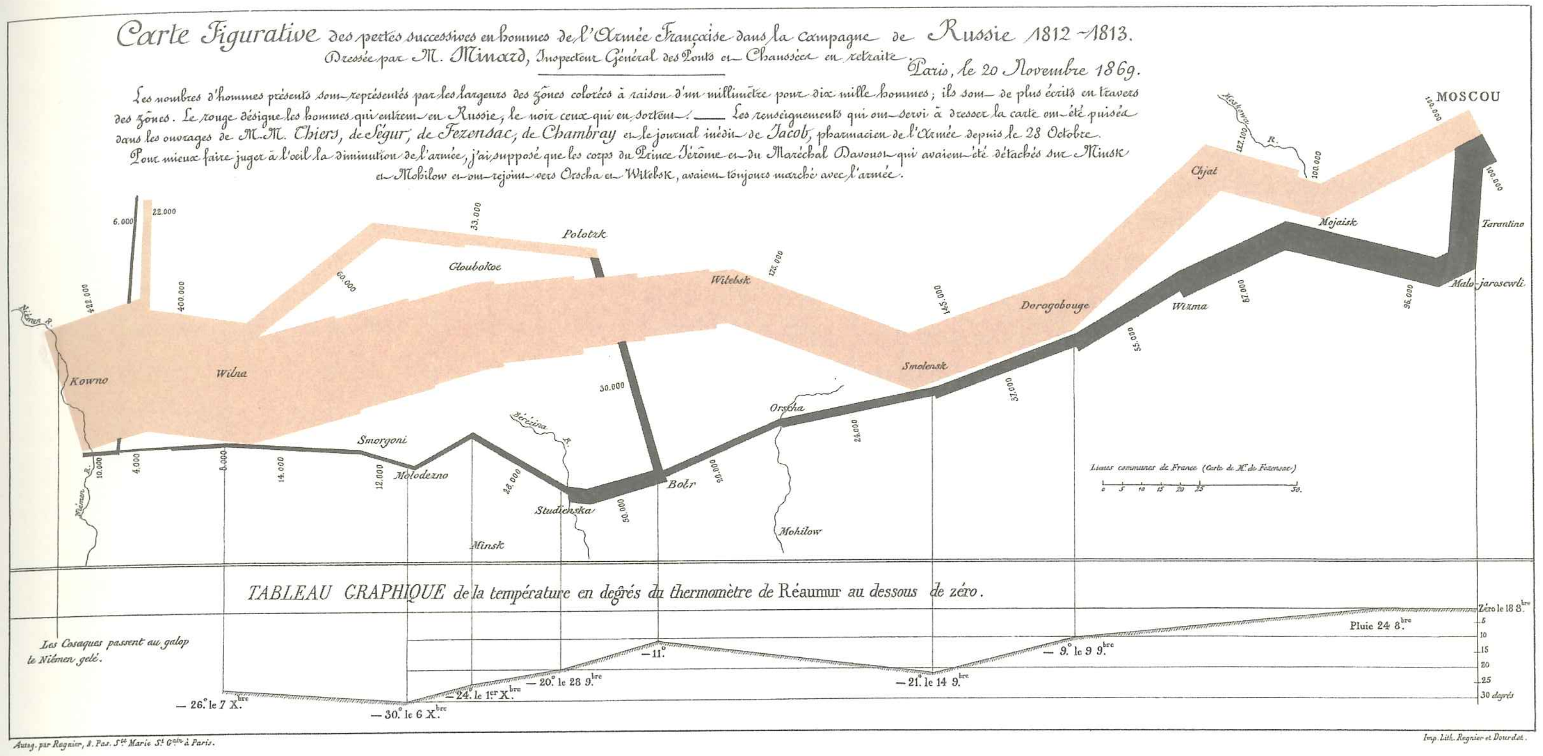
Narrative Graphics of Space and Time

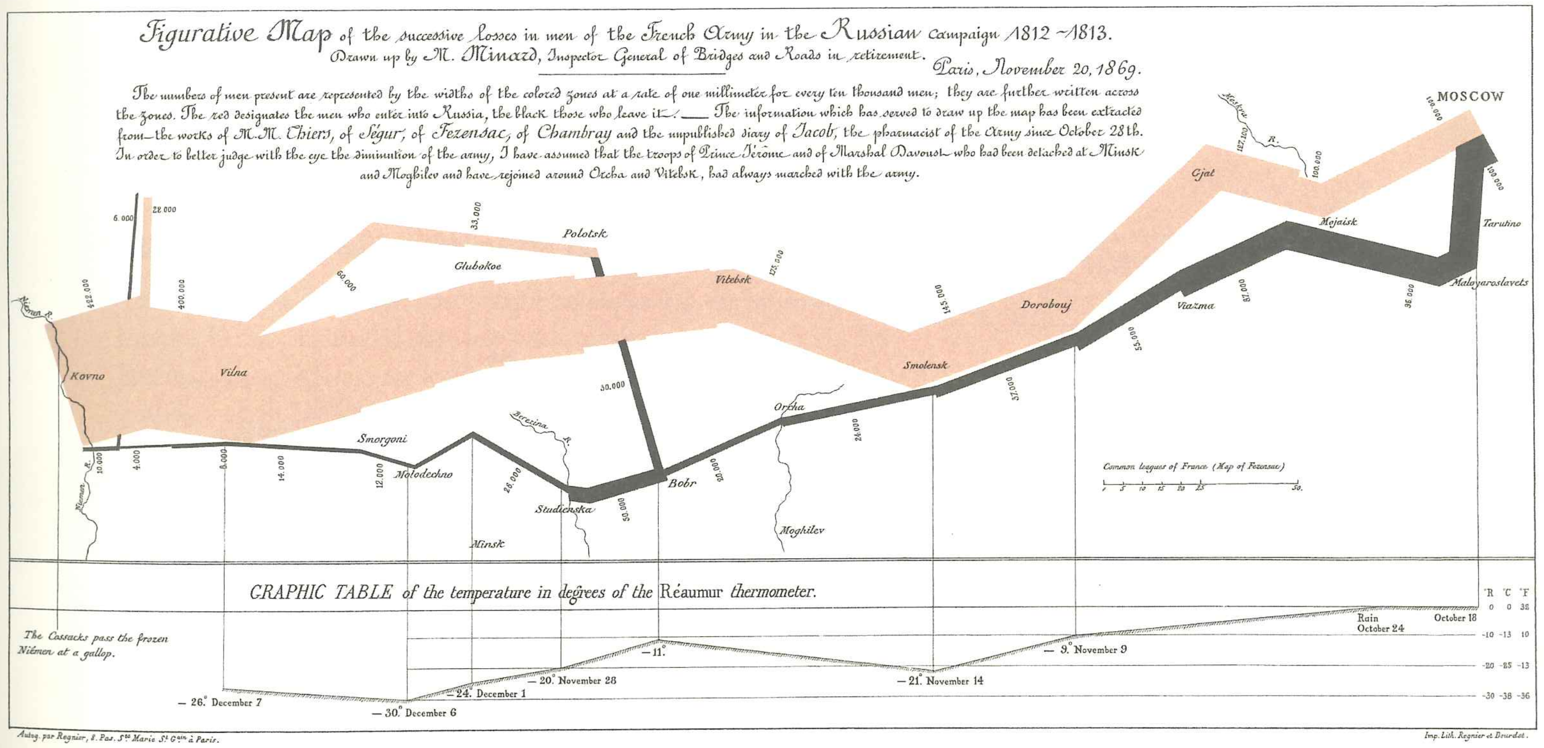
An especially effective device for enhancing the explanatory power of time-series displays is to add spatial dimensions to the design of the graphic, so that the data are moving over space (in two or three dimensions) as well as over time. Three excellent space-time-story graphics illustrate here how multivariate complexity can be subtly integrated into graphical architecture, integrated so gently and unobtrusively that viewers are hardly aware that they are looking into a world of four or five dimensions. Occasionally graphics are belligerently multivariate, advertising the technique rather than the data. But not these three.

The first is the classic of Charles Joseph Minard (1781–1870), the French engineer, which shows the terrible fate of Napoleon's army in Russia. Described by E. J. Marey as seeming to defy the pen of the historian by its brutal eloquence,[12] this combination of data map and time-series, drawn in 1869, portrays a sequence of devastating losses suffered in Napoleon's Russian campaign of 1812. Beginning at left on the Polish-Russian border near the Niemen River, the thick tan flow-line shows the size of the Grand Army (422,000) as it invaded Russia in June 1812. The width of this band indicates the size of the army at each place on the map. In September, the army reached Moscow, which was by then sacked and deserted, with 100,000 men. The path of Napoleon's retreat from Moscow is depicted by the darker, lower band, which is linked to a temperature scale and dates at the bottom of the chart. It was a bitterly cold winter, and many froze on the march out of Russia. As the graphic shows, the crossing of the Berezina River was a disaster, and the army finally struggled back into Poland with only 10,000 men remaining. Also shown are the movements of auxiliary troops, as they sought to protect the rear and the flank of the advancing army. Minard's graphic tells a rich, coherent story with its multivariate data, far more enlightening than just a single number bouncing along over time. *Six* variables are plotted: the size of the army, its location on a two-dimensional surface, direction of the army's movement, and temperature on various dates during the retreat from Moscow. At upper right we see Minard's French original, which was printed as a two-color lithograph in the form of a small poster. And at lower right, our English translation.

It may well be the best statistical graphic ever drawn.

[12] E. J. Marey, *La méthode graphique* (Paris, 1885), 73. For more on Minard, see Arthur H. Robinson, "The Thematic Maps of Charles Joseph Minard," *Imago Mundi*, 21 (1967), 95–108.



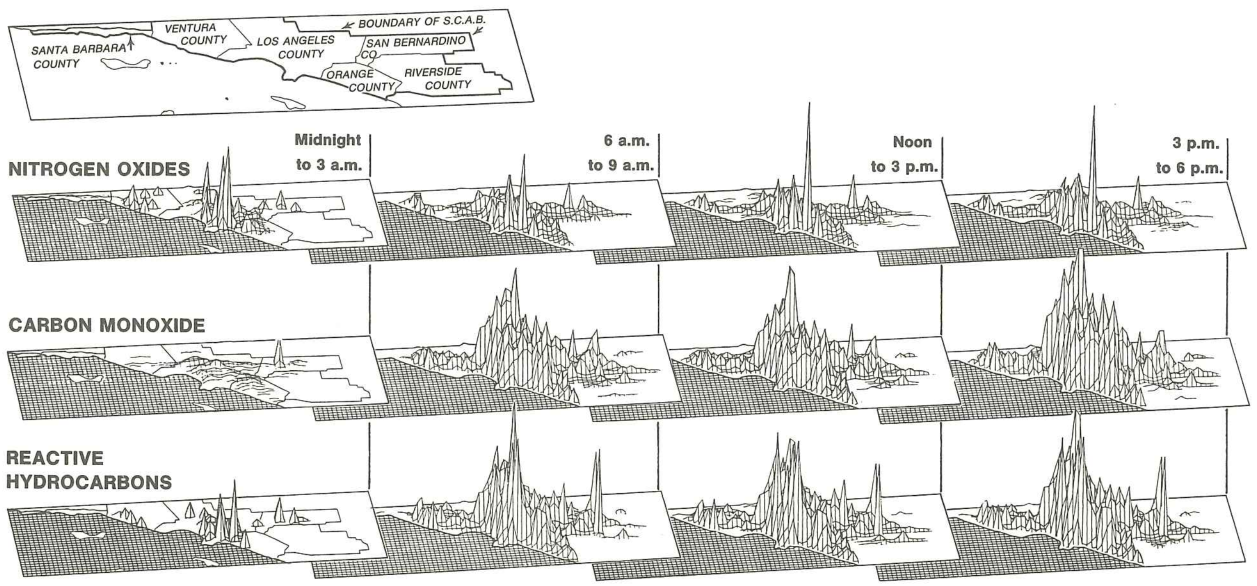


Upper image from Charles Joseph Minard, *Tableaux Graphiques et Cartes Figuratives de M. Minard, 1845–1869*, Bibliothèque de l'École Nationale des Ponts et Chaussées, Paris, item 28 (62 by 25 cm, or 25 by 10 in). English translation by Dawn Finley and redrawing by Elaine Morse, completed August 2002.

The next time-space graphic, drawn by a computer, displays the levels of three air pollutants located over a two-dimensional surface (six counties in southern California) at four times during the day. Nitrogen oxides (top row) are emitted by power plants, refineries, and vehicles. Refineries along the coast and Kaiser Steel's Fontana plant produce the post-midnight peaks shown in the first panel; traffic and power plants (with their heavy daytime demand) send levels up during the day. Carbon monoxide (second row) is low after midnight except out at the steel plant; morning traffic then begins to generate each day's ocean of carbon monoxide, with the greatest concentration at the convergence of five freeways in downtown Los Angeles. Reactive hydrocarbons (third row), like nitrogen oxides, come from refineries after midnight and then increase with traffic during the day. Each of the 12 time-space-pollutant slices summarizes pollutants for 2,400 spatial locations (2,400 squares five kilometers on a side). Thus 28,800 pollutant readings are shown, except for those masked by peaks.

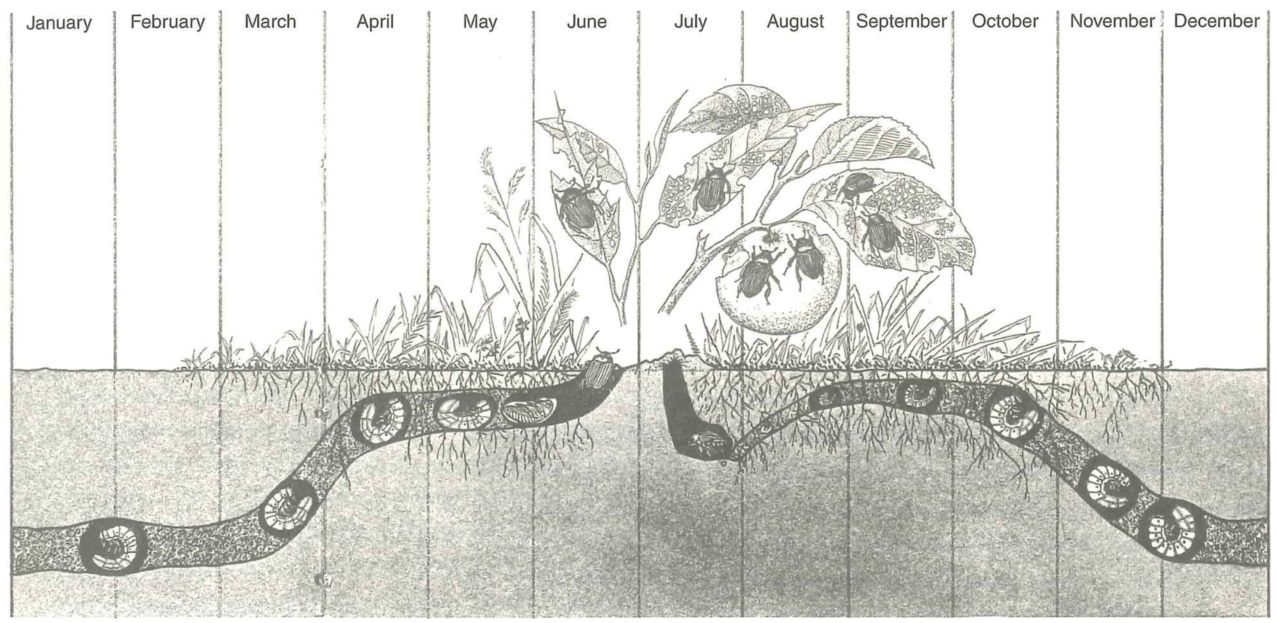
The air pollution display is a *small multiple*. The same graphical design structure is repeated for each of the twelve slices or multiples. Small multiples are economical: once viewers understand the design of one slice, they have immediate access to the data in all the other slices. Thus, as the eye moves from one slice to the next, the constancy of the design allows the viewer to focus on changes in the data rather than on changes in graphical design.

Los Angeles Times, July 22, 1979; based on work of Gregory J. McRae, California Institute of Technology.



Our third example of a space-time-story graphic ingeniously mixes space and time on the horizontal axis. This design moves well beyond the conventional time-series because of its clever plotting field, with location relative to the ground surface on the vertical axis and time/space on the horizontal. The life cycle of the Japanese beetle is shown.

L. Hugh Newman, *Man and Insects* (London, 1965), 104–105.

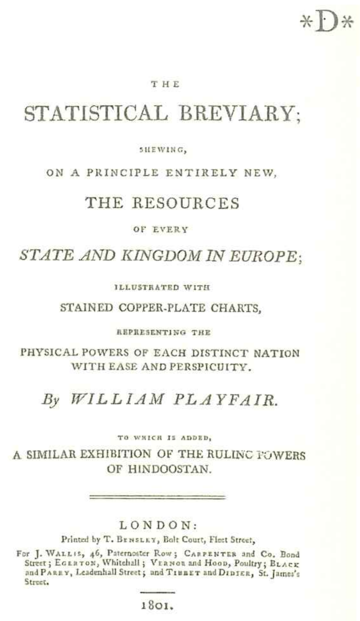


More Abstract Designs: Relational Graphics

The invention of data graphics required replacing the latitude-longitude coordinates of the map with more abstract measures not based on geographical analogy. Moving from maps to statistical graphics was a big step, and thousands of years passed before this step was taken by Lambert, Playfair, and others in the eighteenth century. Even so, analogies to the physical world served as the conceptual basis for early time-series. Playfair repeatedly compared his charts to maps and, in the preface to the first edition of *The Commercial and Political Atlas*, argued that his charts corresponded to a physical realization of the data:

> Suppose the money we pay in any one year for the expence of the Navy were in guineas, and that these guineas were laid down upon a large table in a straight line, and touching each other, and those paid next year were laid down in another

straight line, and the same continued for a number of years: these lines would be different lengths, as there were fewer or more guineas; and they would make a shape, the dimensions of which would agree exactly with the amount of the sums; and the value of a guinea would be represented by the part of space which it covered. The Charts are exactly this upon a small scale, and one division represents the breadth or value of ten thousand or a hundred thousand guineas as marked, with the same exactness that a square inch upon a map may represent a square mile of country. And they, therefore, are a representation of the real money laid down in different lines, as it was originally paid away. [pages iii–iv]


D

THE

STATISTICAL BREVIARY;

SHEWING,

ON A PRINCIPLE ENTIRELY NEW,

THE RESOURCES

OF EVERY

STATE AND KINGDOM IN EUROPE;

ILLUSTRATED WITH

STAINED COPPER-PLATE CHARTS,

REPRESENTING THE

PHYSICAL POWERS OF EACH DISTINCT NATION WITH EASE AND PERSPICUITY.

By WILLIAM PLAYFAIR.

TO WHICH IS ADDED,

A SIMILAR EXHIBITION OF THE RULING POWERS OF HINDOOSTAN.

LONDON:

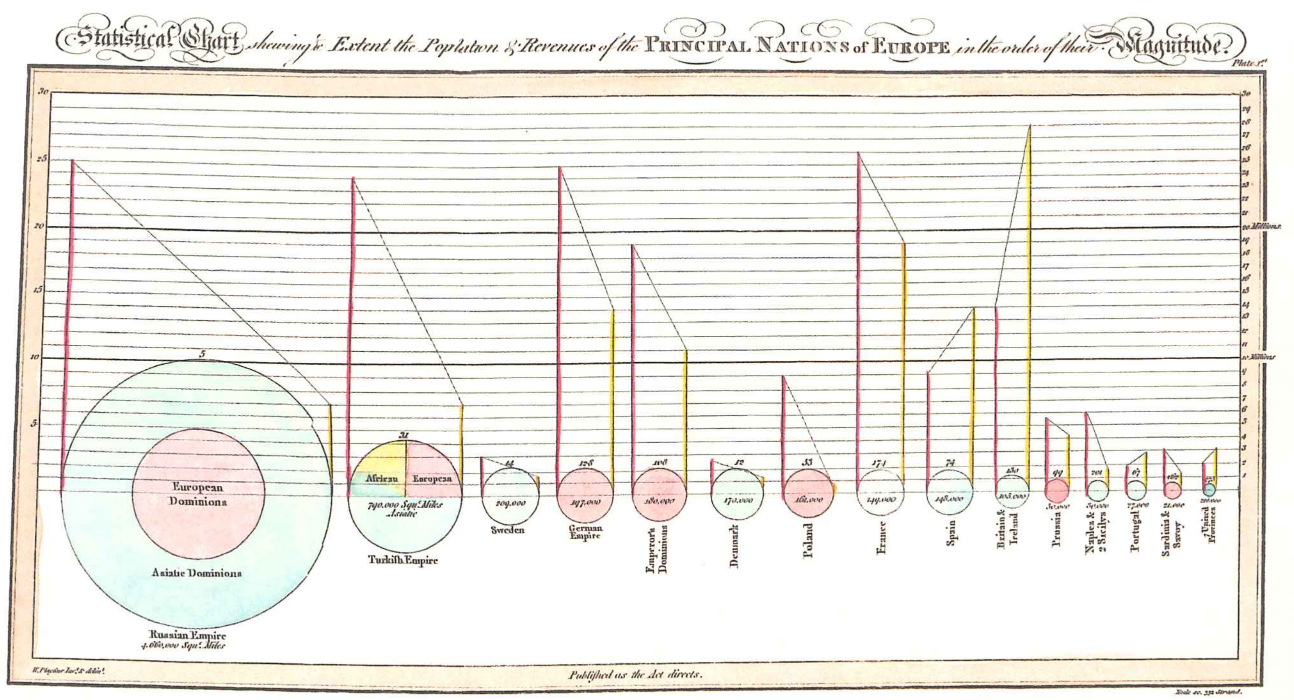
Printed by T. Bensley, Bolt Court, Fleet Street,

For J. Wallis, 46, Paternoster Row; Carpenter and Co. Bond Street; Egerton, Whitehall; Vernor and Hood, Poultry; Black and Parry, Leadenhall Street; and Tibbet and Didier, St. James's Street.

1801.

Fifteen years later in *The Statistical Breviary*, his most theoretical book about graphics, Playfair broke free of analogies to the physical world and drew graphics as designs-in-themselves.

One of four plates in *The Statistical Breviary*, this graphic is distinguished by its multivariate data, the use of area to depict quantity, and the pie chart—in apparently the first application of these devices. The circle represents the area of each country; the line on the left, the population in millions read on the vertical scales; the line on the right, the revenue (taxes) collected in millions of pounds sterling read also on the vertical scale; and the "dotted lines drawn between the population and revenue, are merely intended to connect together the lines belonging to the same country. The ascent



of those lines being from right to left, or from left to right, shews whether in proportion to its population the country is burdened with heavy taxes or otherwise" (pages 13–14). The slope of the dotted line is uninformative, since it is dependent on the diameter of the circle as well as the height of the two verticals. However, the sign of the slope does make sense, taking Playfair to his familiar point about what he regarded as excessive taxation in Britain (sixth circle from the right, with the slope running opposite to most countries). Playfair was enthusiastic about the multivariate arrangement because it fostered comparisons:

> The author of this work applied the use of lines to matters of commerce and finance about fifteen years ago, with great success. His mode was generally approved of as not only facilitating, but rendering those studies more clear, and retained more easily by the memory. The present charts are in like manner intended to aid statistical studies, by shewing to the eye the sizes of different countries represented by similar forms, for where forms are not similar, the eye cannot compare them easily nor accurately. From this circumstance it happens, that we have a more accurate idea of the sizes of the planets, which are spheres, than of the nations of Europe which we see on the maps, all of which are irregular forms in themselves as well as unlike to each other. Size, Population, and Revenue, are the three principal objects of attention upon the general scale of statistical studies, whether we are actuated by curiosity or interest; I have therefore represented these three objects in one view. . . . [page 15]

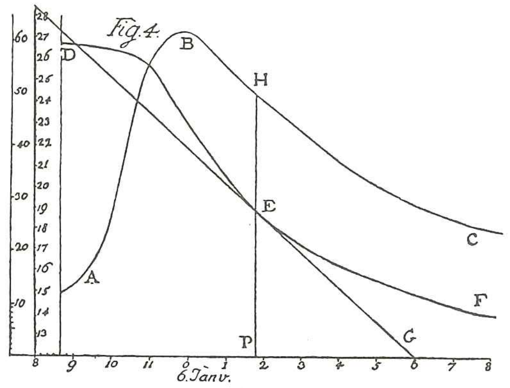
But here Playfair had a forerunner—and one who thought more clearly about the abstract problems of graphical design than did Playfair, who lacked mathematical skills. A most remarkable and explicit early theoretical statement advancing the general (non-analogical) relational graphic was made by J. H. Lambert in 1765, 35 years before *The Statistical Breviary*:

> We have in general two variable quantities, x, y, which will be collated with one another by observation, so that we can determine for each value of x, which may be considered as an abscissa, the corresponding ordinate y. Were the experiments or observations completely accurate, these ordinates would give a number of points through which a straight or curved line should be drawn. But as this is not so, the line deviates to a greater or lesser extent from the observational points. It must therefore be drawn in such a way that it comes as near as possible to its true position and goes, as it were, through the middle of the given points.[13]

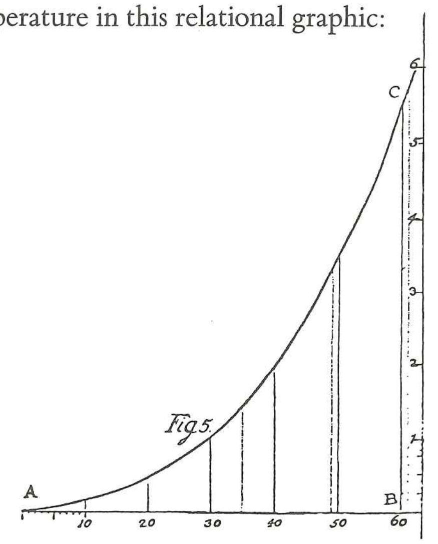
[13] Johann Heinrich Lambert, *Beyträge zum Gebrauche der Mathematik und deren Anwendung* (Berlin, 1765), as quoted in Laura Tilling, "Early Experimental Graphs," *British Journal for the History of Science*, 8 (1975), 204–205.

Lambert drew a graphical derivation of the evaporation rate of water as a function of temperature, according to Tilling. The analysis begins with two time-series: DEF, showing the decreasing height of water in a capillary tube as a function of time, and ABC, the temperature. The slope of the curve DEF is then taken (note the tangent DEG) at a number of places, yielding the rate of evaporation:

J. H. Lambert, "Essai d'hygrométrie ou sur la mesure de l'humidité," *Mémoires de l'Académie Royale des Sciences et Belles-Lettres . . . 1769* (Berlin, 1771), plate 1, facing p. 126; from Tilling's article.



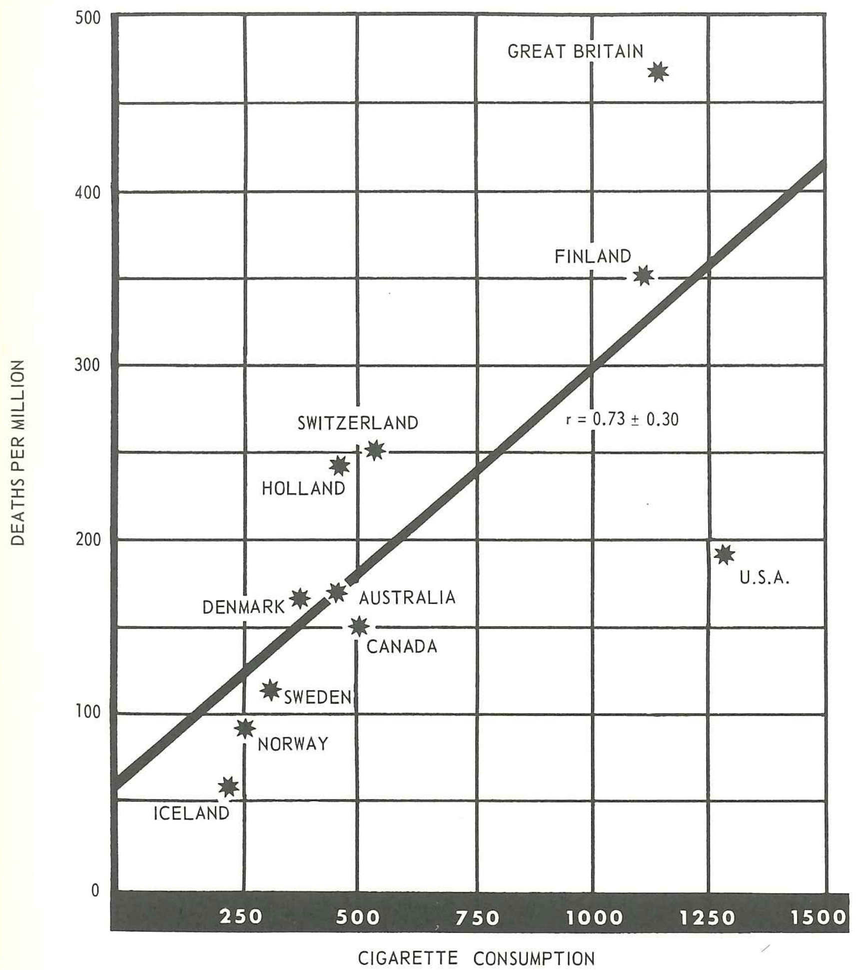
To complete the graphical calculus, the measured rate is plotted against the corresponding temperature in this relational graphic:



Thus, by the early 1800s, graphical design was at last no longer dependent on direct analogy to the physical world—thanks to the work of Lambert and Playfair. This meant, quite simply but quite profoundly, that any variable quantity could be placed in relationship to any other variable quantity, measured for the same units of observation. Data graphics, because they were relational and not tied to geographic or time coordinates, became relevant

to all quantitative inquiry. Indeed, in modern scientific literature, about 40 percent of published graphics have a relational form, with two or more variables (none of which are latitude, longitude, or time). This is no accident, since the relational graphic—in its barest form, the scatterplot and its variants—is the greatest of all graphical designs. It links at least two variables, encouraging and even imploring the viewer to assess the possible causal relationship between the plotted variables. It confronts causal theories that X causes Y with empirical evidence as to the actual relationship between X and Y, as in the case of the relationship between lung cancer and smoking:

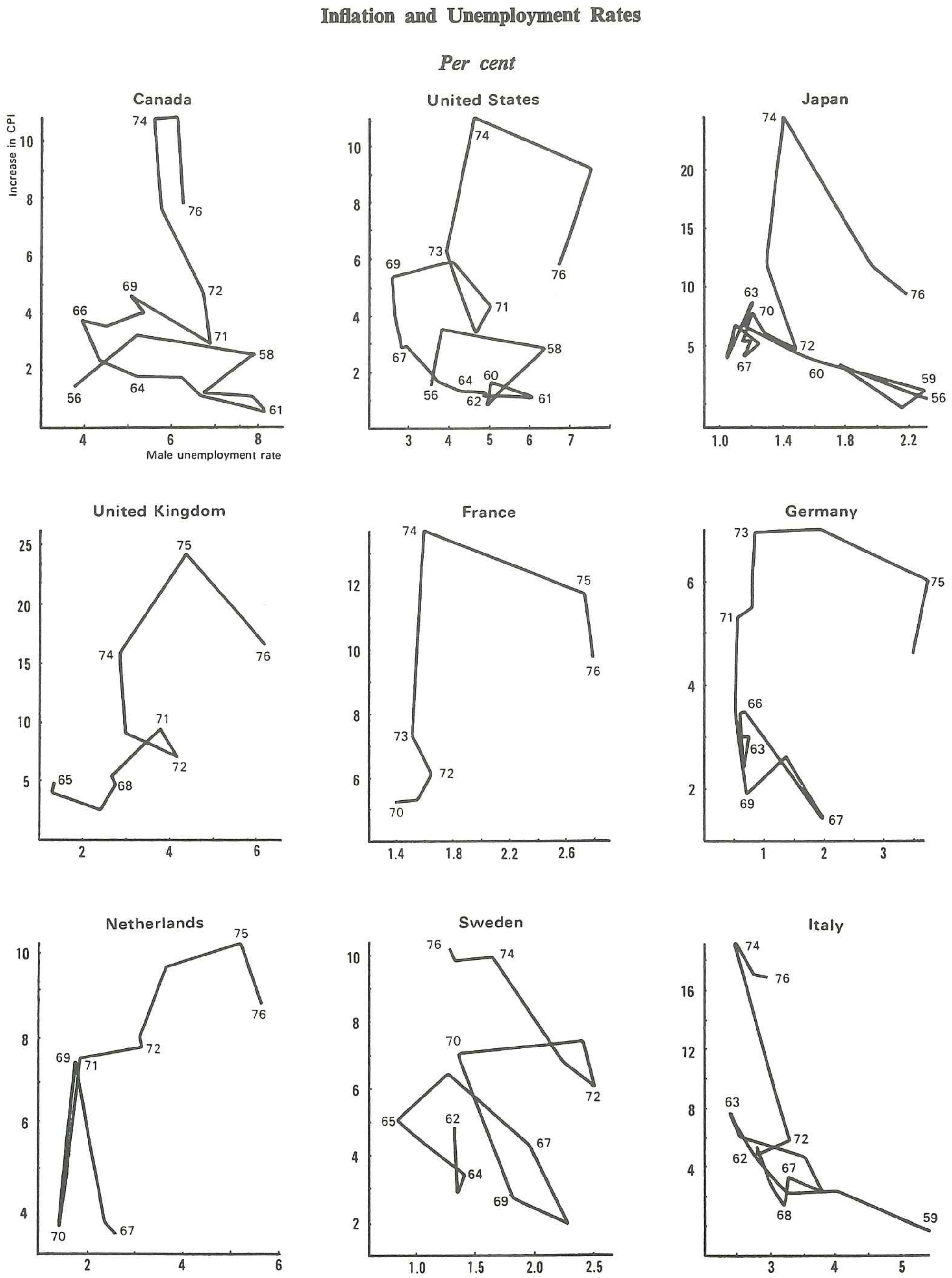
CRUDE MALE DEATH RATE FOR LUNG CANCER IN 1950 AND PER CAPITA CONSUMPTION OF CIGARETTES IN 1930 IN VARIOUS COUNTRIES.



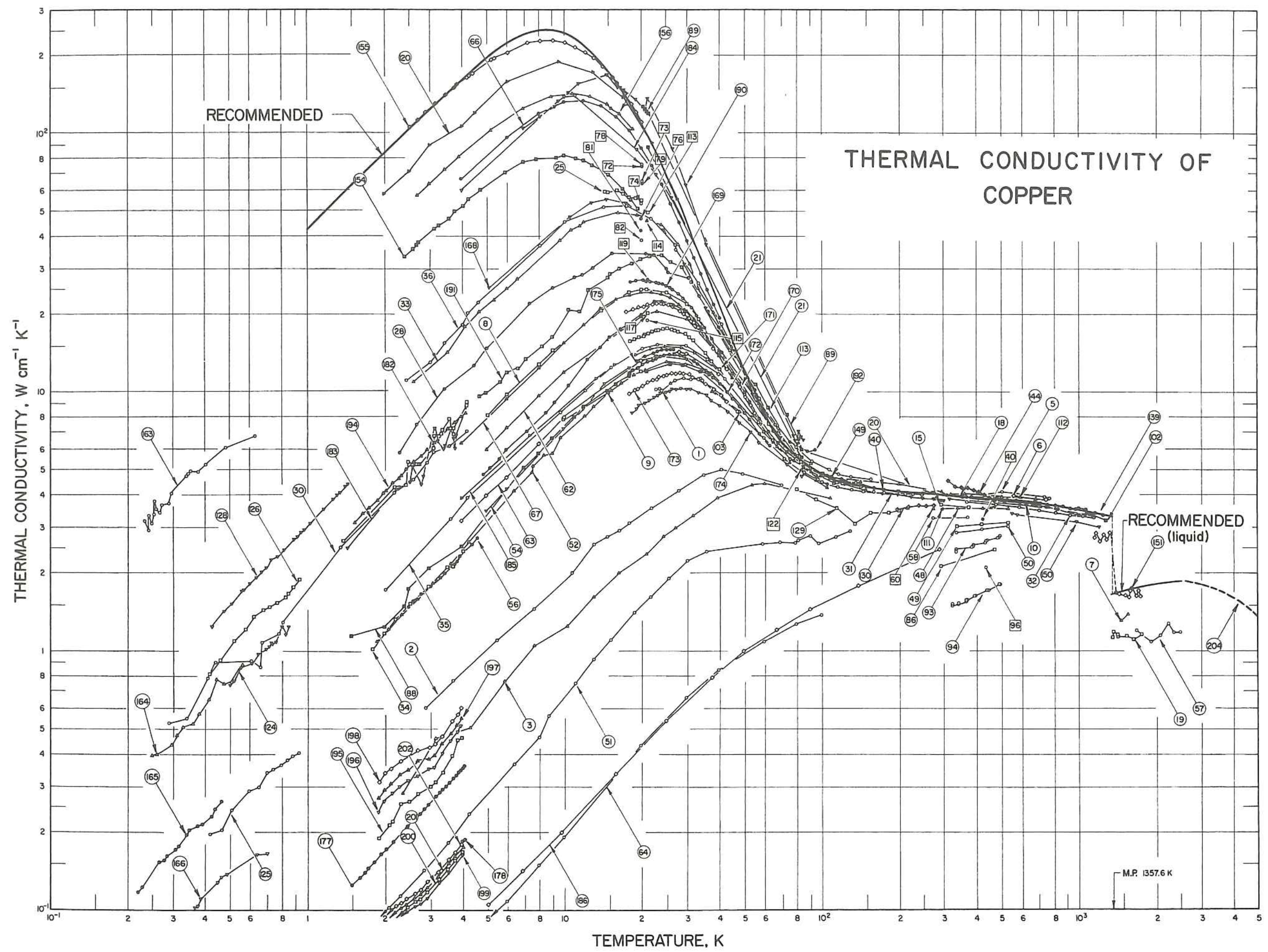
Report of the Advisory Committee to the Surgeon General, *Smoking and Health* (Washington, DC, 1964), 176; based on R. Doll, "Etiology of Lung Cancer," *Advances in Cancer Research*, 3 (1955), 1–50.

These small-multiple relational graphs show unemployment and inflation over time in "Phillips curve" plots for nine countries, demonstrating the collapse of what was once thought to be an inverse relationship between the variables.

Paul McCracken, et al., *Towards Full Employment and Price Stability* (Paris, 1977), 106.



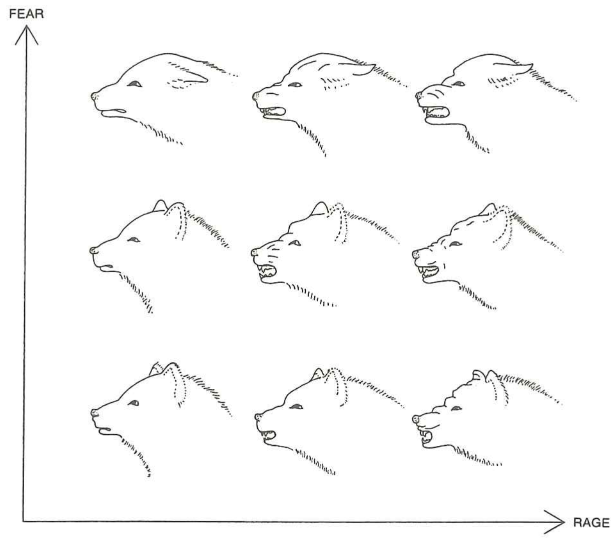
Theory and measured observations diverge in the physical sciences, also. Here the relationship between temperature and the thermal conductivity of copper is assessed in a series of measurements from different laboratories. The connected points are from a single publication, cited by an identification number. The very different answers reported in the published literature result mainly from impurities in the samples of copper. Note how effectively the graphic organizes a vast amount of data, recording findings of hundreds of studies on a single page and, at the same time, enforcing comparisons of the varying results.



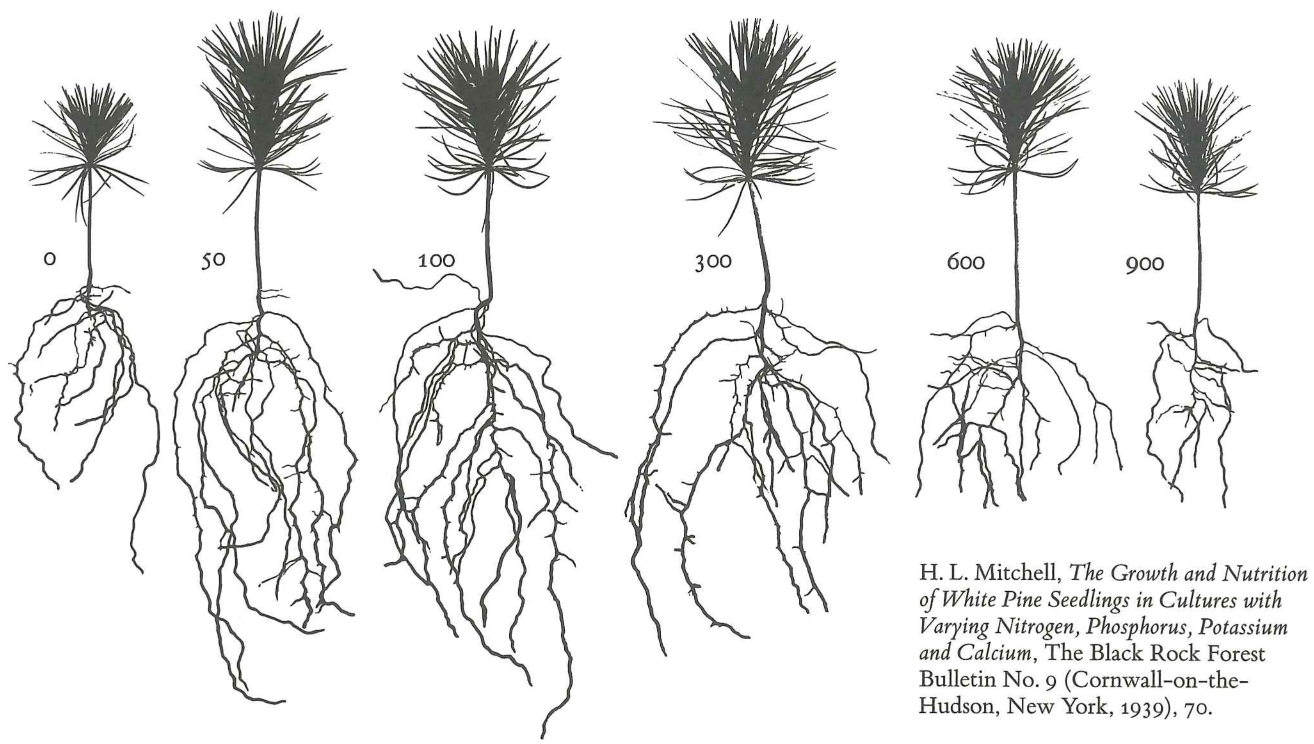
C. Y. Ho, R. W. Powell, and P. E. Liley, *Thermal Conductivity of the Elements: A Comprehensive Review*, supplement no. 1, *Journal of Physical and Chemical Reference Data*, 3 (1974), 1–244.

Finally, two relational designs of a different sort—wherein the data points are themselves data. Here the effect of two variables interacting is portrayed by the faces on the plotting field:

E. C. Zeeman, "Catastrophe Theory," *Scientific American*, 234 (April 1976), 67; based on Konrad Z. Lorenz, *King Solomon's Ring* (New York, 1952).



And similarly, the varying sizes of white pine seedlings after growing for one season in sand containing different amounts of calcium, in parts per million in nutrient-sand cultures:



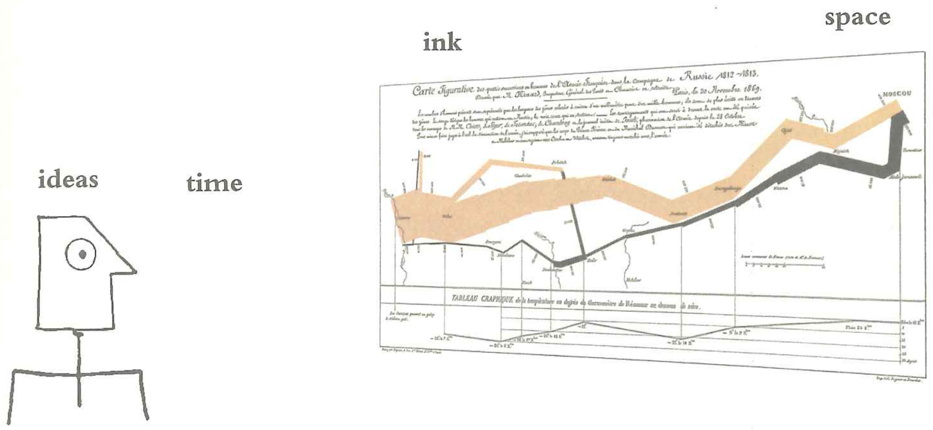
H. L. Mitchell, *The Growth and Nutrition of White Pine Seedlings in Cultures with Varying Nitrogen, Phosphorus, Potassium and Calcium*, The Black Rock Forest Bulletin No. 9 (Cornwall-on-the-Hudson, New York, 1939), 70.

Principles of Graphical Excellence

Graphical excellence is the well-designed presentation of interesting data—a matter of *substance*, of *statistics*, and of *design*.

Graphical excellence consists of complex ideas communicated with clarity, precision, and efficiency.

Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space.



Graphical excellence is nearly always multivariate.

And graphical excellence requires telling the truth about the data.

As to the propriety and justness of representing sums of money, and time, by parts of space, tho' very readily agreed to by most men, yet a few seem to apprehend that there may possibly be some deception in it, of which they are not aware. . . .

William Playfair, *The Commercial and Political Atlas* (London, 1786)

People said: "With the chart on the wall, with the figures published, let's emulate and rouse our enthusiasm in production."

State Statistical Bureau of the People's Republic of China, *Statistical Work in the New China* (Beijing, 1979)

Get it right or let it alone.
The conclusion you jump to may be your own.

James Thurber, *Further Fables for Our Time* (New York, 1956)

2 *Graphical Integrity*

For many people the first word that comes to mind when they think about statistical charts is "lie." No doubt some graphics do distort the underlying data, making it hard for the viewer to learn the truth. But data graphics are no different from words in this regard, for any means of communication can be used to deceive. There is no reason to believe that graphics are especially vulnerable to exploitation by liars; in fact, most of us have pretty good graphical lie detectors that help us see right through frauds.

Much of twentieth-century thinking about statistical graphics has been preoccupied with the question of how some amateurish chart might fool a naive viewer. Other important issues, such as the use of graphics for serious data analysis, were largely ignored. At the core of the preoccupation with deceptive graphics was the assumption that data graphics were mainly devices for showing the obvious to the ignorant. It is hard to imagine any doctrine more likely to stifle intellectual progress in a field. The assumption led down two fruitless paths in the graphically barren years from 1930 to 1970: First, that graphics had to be "alive," "communicatively dynamic," overdecorated and exaggerated (otherwise all the dullards in the audience would fall asleep in the face of those boring statistics). Second, that the main task of graphical analysis was to detect and denounce deception (the dullards could not protect themselves).

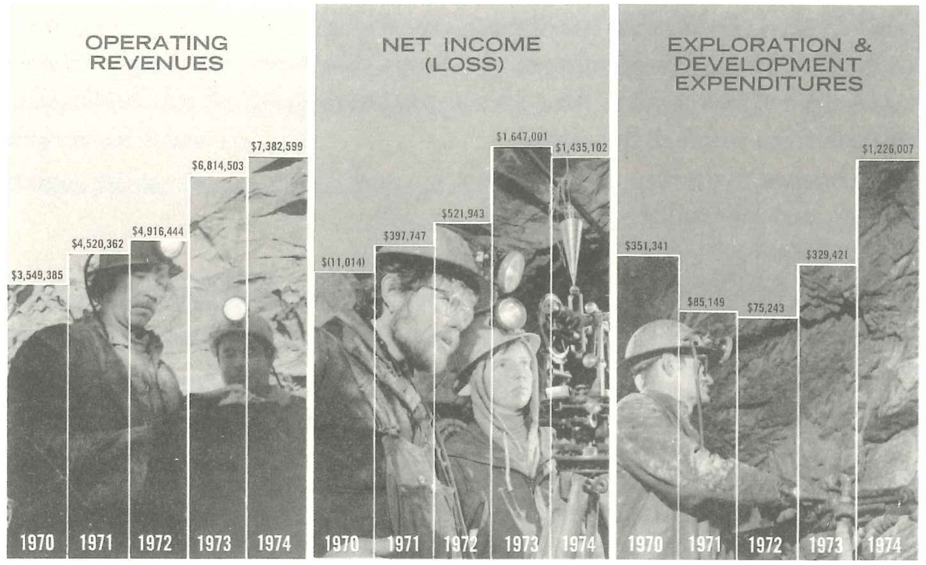
Then, in the late 1960s, John Tukey made statistical graphics respectable, putting an end to the view that graphics were only for decorating a few numbers. For here was a world-class data analyst spinning off half a dozen new designs and, more importantly, using them effectively to explore complex data.[1] Not a word about deception; no tortured attempts to construct more "graphical standards" in a hopeless effort to end all distortions. Instead, graphics were used as instruments for reasoning about quantitative information. With this good example, graphical work has come to flourish.

Of course false graphics are still with us. Deception must always be confronted and demolished, even if lie detection is no longer at the forefront of research. Graphical excellence begins with telling the truth about the data.

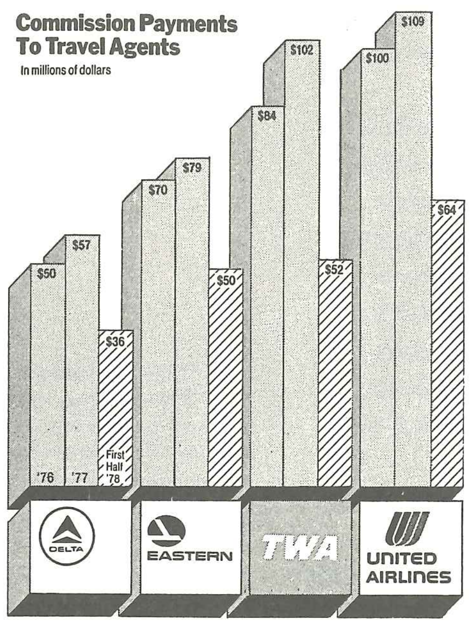
[1] John W. Tukey and Martin B. Wilk, "Data Analysis and Statistics: Techniques and Approaches," in Edward R. Tufte, ed., *The Quantitative Analysis of Social Problems* (Reading, Mass., 1970), 370–390; and John W. Tukey, "Some Graphic and Semigraphic Displays," in T. A. Bancroft, ed., *Statistical Papers in Honor of George W. Snedecor* (Ames, Iowa, 1972), 293–316.

Here are several graphics that fail to tell the truth. First, the case of the disappearing baseline in the annual report of a company that would just as soon forget about 1970. A careful look at the middle panel reveals a negative income in 1970, which is disguised by having the bars begin at the bottom at approximately minus $4,200,000:

Day Mines, Inc., *1974 Annual Report*, 1.

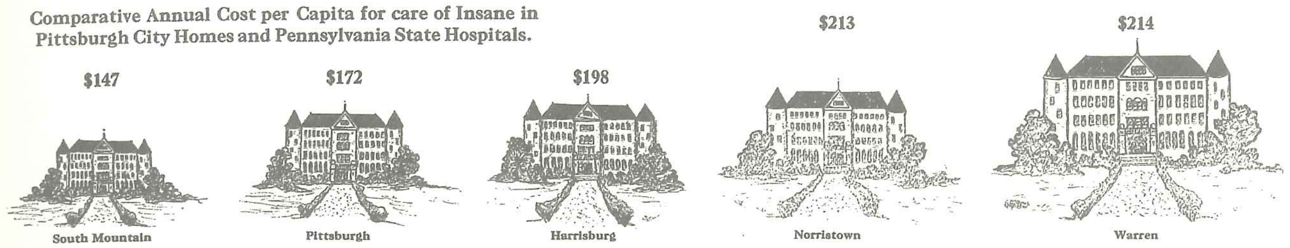


This pseudo-decline was created by comparing six months' worth of payments in 1978 to a full year's worth in 1976 and 1977, with the lie repeated four times over.



New York Times, August 8, 1978, D-1.

And sometimes the fact that numbers have a magnitude as well as an order is simply forgotten:

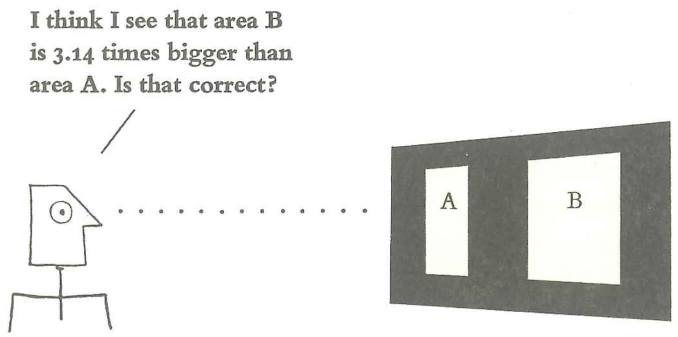


Pittsburgh Civic Commission, *Report on Expenditures of the Department of Charities* (Pittsburgh, 1911), 7.

What is Distortion in a Data Graphic?

A graphic does not distort if the visual representation of the data is consistent with the numerical representation. What then is the "visual representation" of the data? As physically measured on the surface of the graphic? Or the *perceived* visual effect? How do we know that the visual image represents the underlying numbers?

One way to try to answer these questions is to conduct experiments on the visual perception of graphics—having people look at lines of varying length, circles of different areas, and then recording their assessments of the numerical quantities.



Such experiments have discovered very approximate power laws relating the numerical measure to the reported perceived measure. For example, the perceived area of a circle probably grows somewhat more slowly than the actual (physical, measured) area: the reported perceived area = (actual area)^x, where $x = .8 \pm .3$, a discouraging result. Different people see the same areas somewhat differently; perceptions change with experience; and perceptions are context-dependent.[2] Particularly disheartening is the securely established finding that the reported perception of something as clear and simple as line length depends on the context and what other people have already said about the lines.[3]

Misperception and miscommunication are certainly not special to statistical graphics,

Drawing by CEM; copyright 1961, *The New Yorker*.

but what is a poor designer to do? A different graphic for each perceiver in each context? Or designs that correct for the visual transformations of the average perceiver participating in the average psychological experiment?

One satisfactory answer to these questions is to use a table to show the numbers. Tables usually outperform graphics in reporting on small data sets of 20 numbers or less. The special power of graphics comes in the display of large data sets.

At any rate, given the perceptual difficulties, the best we can hope for is some uniformity in graphics (if not in the perceivers) and some assurance that perceivers have a fair chance of getting the numbers right. Two principles lead toward these goals and, in consequence, enhance graphical integrity:

> The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.
>
> 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.

[2] The extensive literature is summarized in Michael Macdonald-Ross, "How Numbers are Shown: A Review of Research on the Presentation of Quantitative Data in Texts," *Audio-Visual Communication Review*, 25 (1977), 359–409. In particular, H. J. Meihoefer finds great variability among perceivers; see "The Utility of the Circle as an Effective Cartographic Symbol," *Canadian Cartographer*, 6 (1969), 105–117; and "The Visual Perception of the Circle in Thematic Maps: Experimental Results," ibid., 10 (1973), 63–84.

[3] S. E. Asch, "Studies of Independence and Submission to Group Pressure. A Minority of One Against a Unanimous Majority," *Psychological Monographs* (1956), 70.

Violations of the first principle constitute one form of graphic misrepresentation, measured by the

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

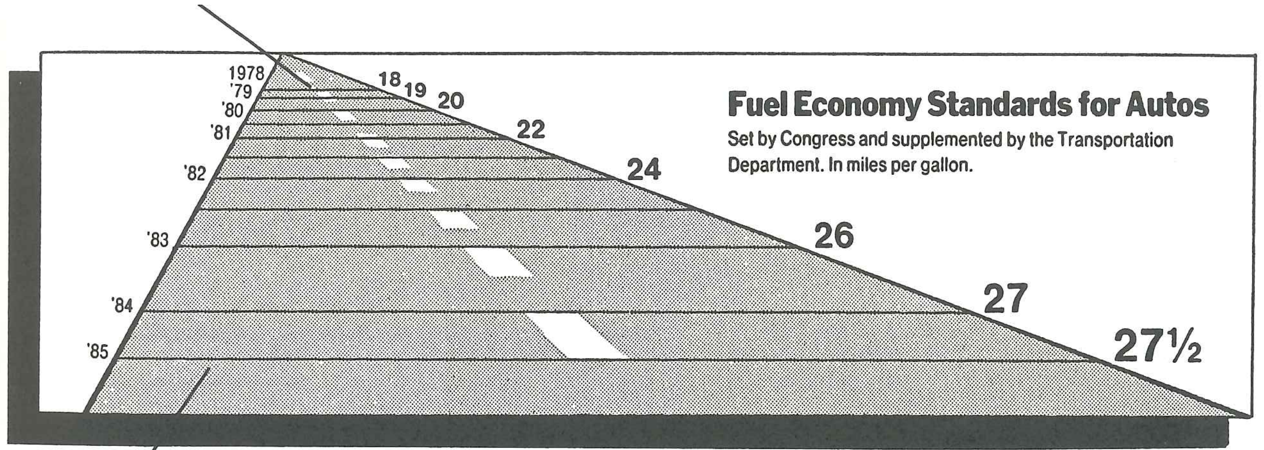
If the Lie Factor is equal to one, then the graphic might be doing a reasonable job of accurately representing the underlying numbers. Lie Factors greater than 1.05 or less than .95 indicate substantial distortion, far beyond minor inaccuracies in plotting. The logarithm of the Lie Factor can be taken in order to compare overstating (log LF > 0) with understating (log LF < 0) errors. In practice almost all distortions involve overstating, and Lie Factors of two to five are not uncommon.

Here is an extreme example. A newspaper reported that the U.S. Congress and the Department of Transportation had set a series of fuel economy standards to be met by automobile manufacturers, beginning with 18 miles per gallon in 1978 and moving in steps up to 27.5 by 1985, an increase of 53 percent:

$$\frac{27.5 - 18.0}{18.0} \times 100 = 53\%$$

These standards and the dates for their attainment were shown:

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.

New York Times, August 9, 1978, D-2.

The magnitude of the change from 1978 to 1985 is shown in the graph by the relative lengths of the two lines:

$$\frac{5.3 - 0.6}{0.6} \times 100 = 783\%$$

Thus the numerical change of 53 percent is presented by some lines that changed 783 percent, yielding

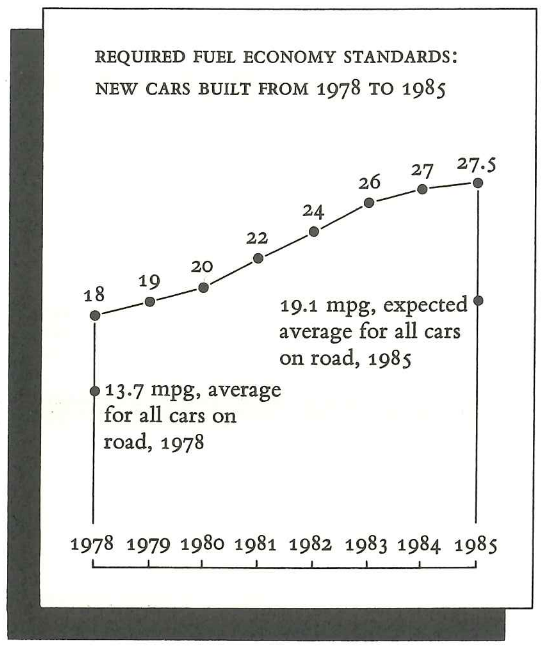
$$\text{Lie Factor} = \frac{783}{53} = 14.8$$

which is too big.

The display also has several peculiarities of perspective:

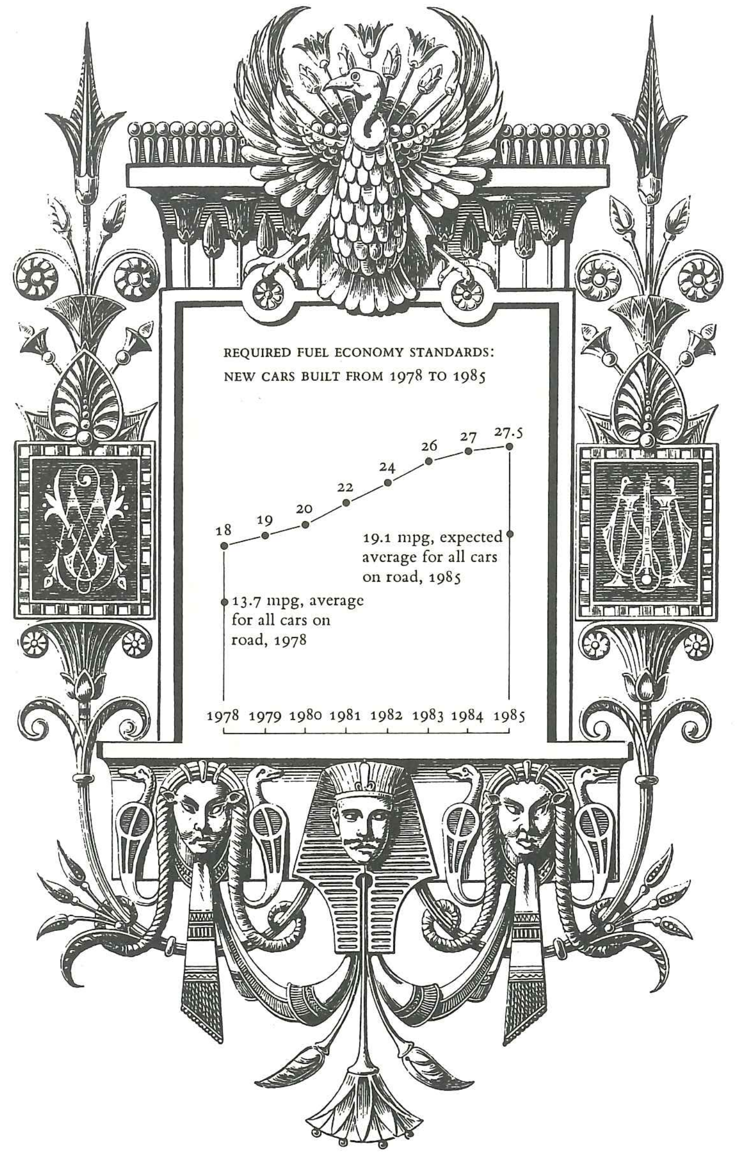
- On most roads the future is in front of us, toward the horizon, and the present is at our feet. This display reverses the convention so as to exaggerate the severity of the mileage standards.
- Oddly enough, the dates on the left remain a constant size on the page even as they move along with the road toward the horizon.
- The numbers on the right, as well as the width of the road itself, are shrinking because of two simultaneous effects: the change in the values portrayed and the change due to perspective. Viewers have no chance of separating the two.

It is easy enough to decorate these data without lying:



The non-lying version, in addition, puts the data in a context by comparing the new car standards with the mileage achieved by the mix of cars actually on the road. Also revealed is a side of the data disguised and mispresented in the original display: the fuel economy standards require gradual improvement at start-up, followed by a doubled rate from 1980 to 1983, and flattening out after that.

Sometimes decoration can help editorialize about the substance of the graphic. But it is wrong to distort the data measures—the ink locating values of numbers—in order to make an editorial comment or fit a decorative scheme. It is also a sure sign of the Graphical Hack at work. Here are many decorations but no lies:

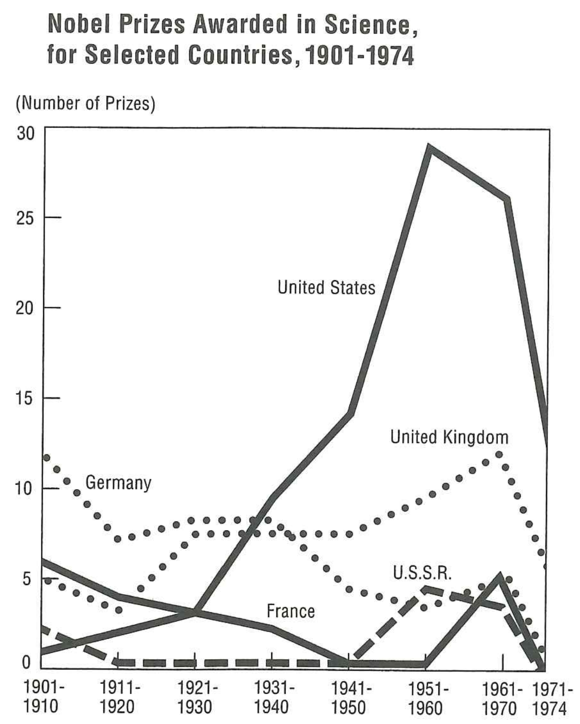


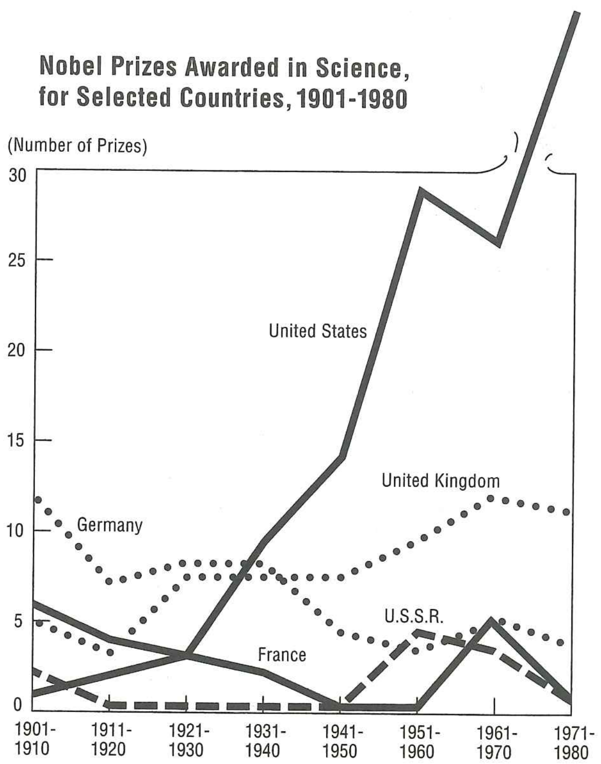
Design and Data Variation

Each part of a graphic generates visual expectations about its other parts and, in the economy of graphical perception, these expectations often determine what the eye sees. Deception results from the incorrect extrapolation of visual expectations generated at one place on the graphic to other places.

A scale moving in regular intervals, for example, is expected to continue its march to the very end in a consistent fashion, without the muddling or trickery of non-uniform changes. Here an irregular scale is used to concoct a pseudo-decline. The first seven increments on the horizontal scale are ten years long, masking the rightmost interval of four years. Consequently the conspicuous feature of the graphic is the apparent fall of curves at the right, particularly the decline in prizes won by people from the United States (the heavy, dark line) in the most recent period. This effect results solely from design variation. It is a big lie, since in reality (and even in extrapolation, scaling up each end-point by 2.5 to take the four years' worth of data up to a comparable decade), the U.S. curve turned sharply upward in the post-1970 interval. A correction, with the actual data for 1971–80, is at the right:

National Science Foundation, *Science Indicators, 1974* (Washington, DC, 1976), 15.

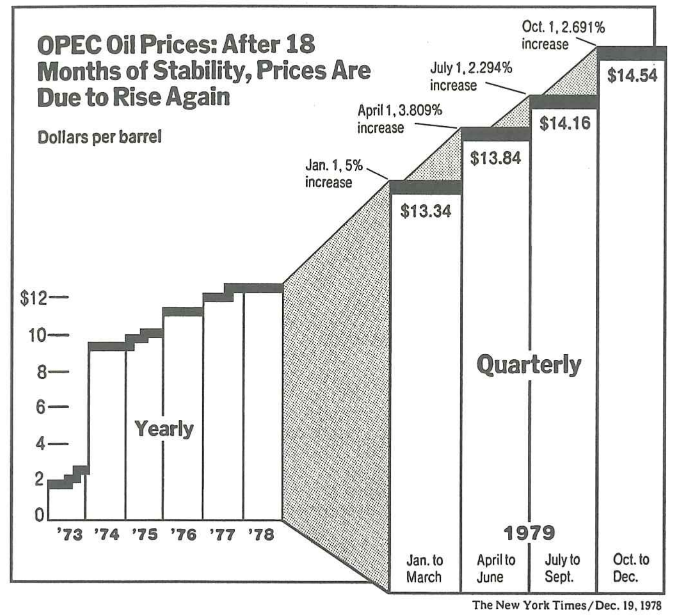




The confounding of *design variation* with *data variation* over the surface of a graphic leads to ambiguity and deception, for the eye may mix up changes in the design with changes in the data. A steady canvas makes for a clearer picture. The principle is, then:

Show data variation, not design variation.

Design variation corrupts this display:



New York Times, December 19, 1978, D-7.

Five different vertical scales show the price:

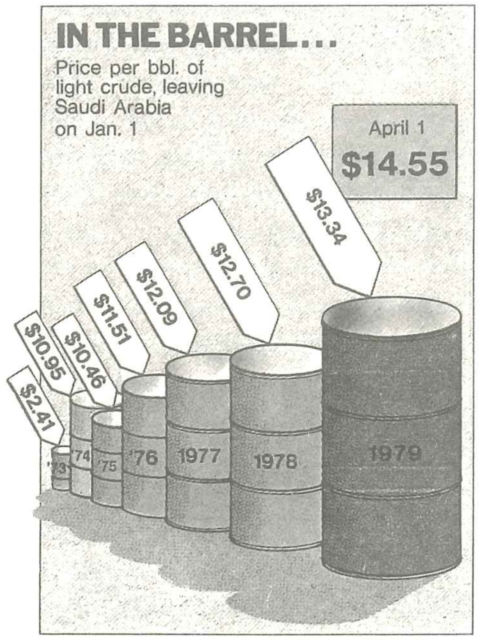
During this time	one vertical inch equals
1973–1978	$8.00
January–March 1979	$4.73
April–June 1979	$4.37
July–September 1979	$4.16
October–December 1979	$3.92

And two different horizontal scales show the passage of time:

During this time	one horizontal inch equals
1973–1978	3.8 years
1979	0.57 years

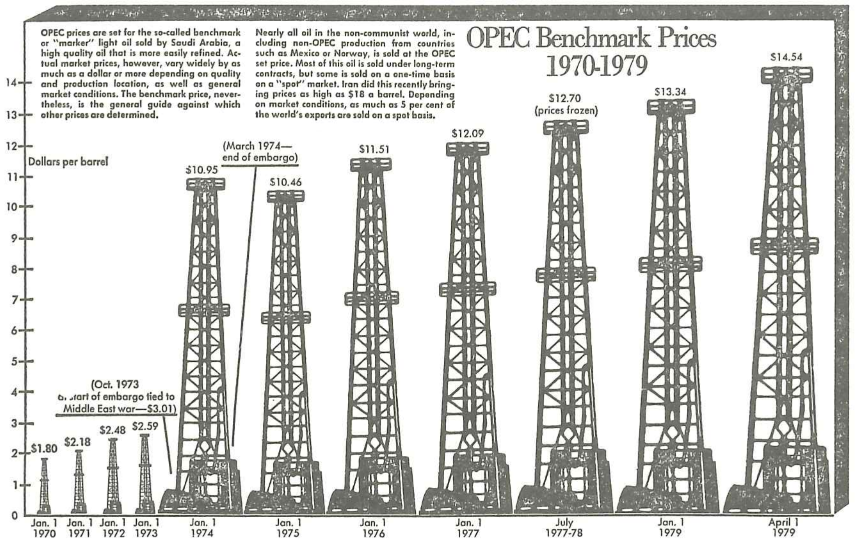
As the two scales shift simultaneously, the distortion takes on multiplicative force. On the left of the graph, a price of $10 for one year is represented by 0.31 square inches; on the right side, by 4.69 square inches. Thus exactly the same quantity is 4.69/0.31 = 15.1 times larger depending upon where it happens to fall on the surface of the graphic. *That* is design variation.

Design variation infected similar graphics in other publications. Here an increase of 454 percent is depicted as an increase of 4,280 percent, for a Lie Factor of 9.4:



Time, April 9, 1979, 57.

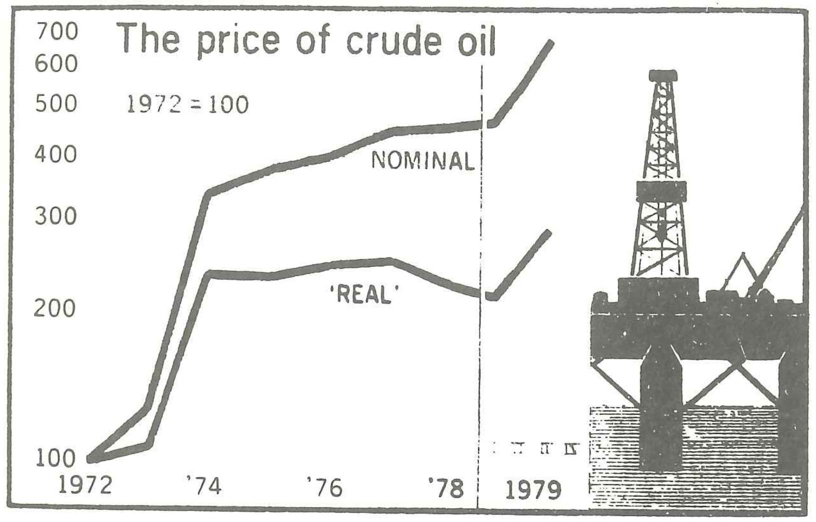
And an increase of 708 percent is shown as 6,700 percent, for a Lie Factor of 9.5:



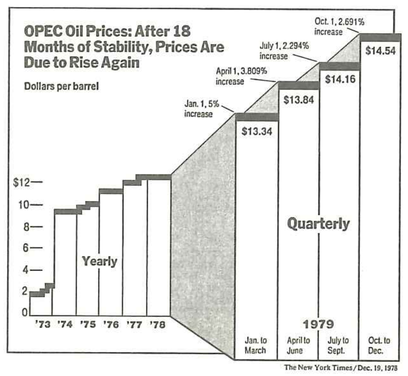
Washington Post, March 28, 1979, A-18.

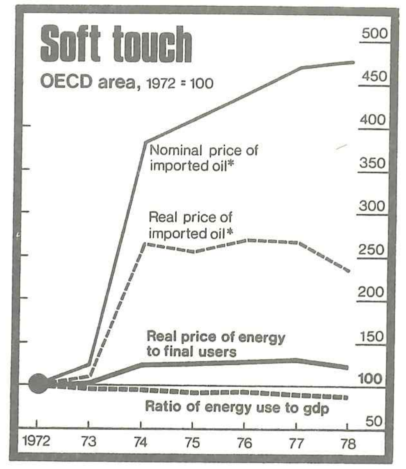
All these accounts of oil prices made a second error, by showing the price of oil in inflated (current) dollars. The 1972 dollar was worth much more than the 1979 dollar. Thus in sweeping from

left to right over the surface of the graphic, the vertical scale in effect changes—design variation—because the value of money changes over the years shown. The only way to think clearly about money over time is to make comparisons using inflation-adjusted units of money. Several distinguished graphic designers did express the price in real dollars—and they also avoided other sources of design variation. The stars were *Business Week*, the *Sunday Times* (London), and *The Economist*.



In the graphic we saw first, the two sources of design variation covered up an intriguing, non-obvious aspect of the data: in the four years prior to the 1979–1980 increases, the real price of oil had *declined*. Busy with decoration, the graphic had missed the news.

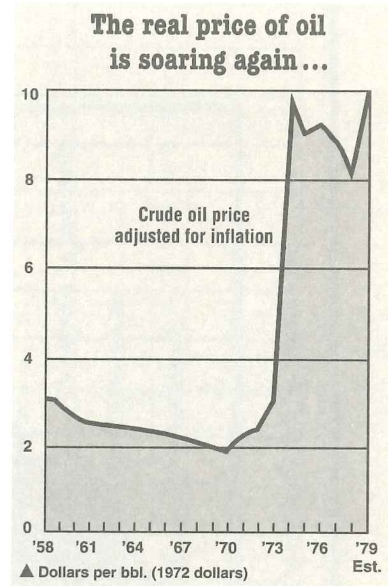


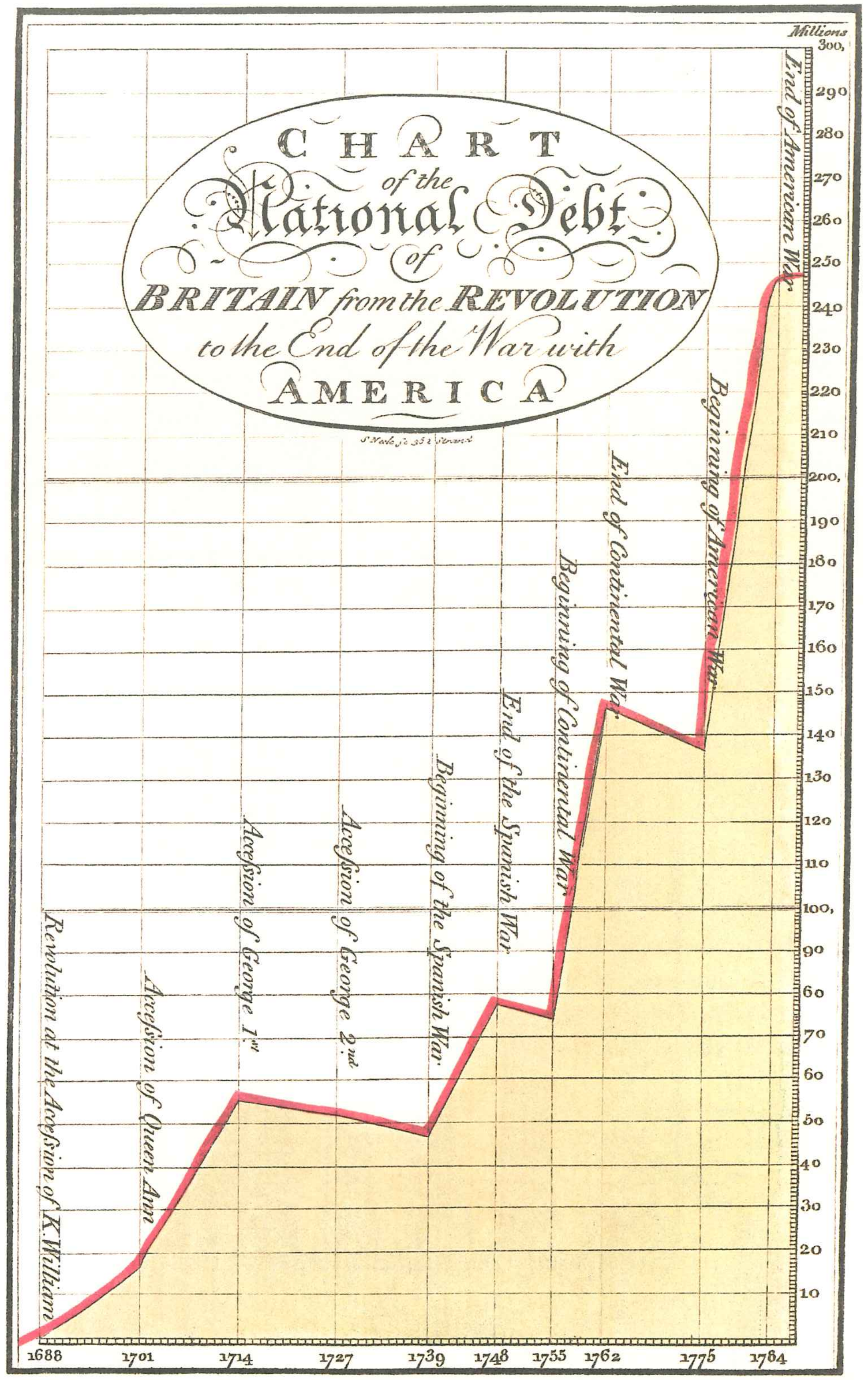


The Economist, December 29, 1979, 41.

Sunday Times (London), December 16, 1979, 54.

Business Week, April 9, 1979, 99.





The Divisions at the Bottom are Years, & those on the Right hand Money.

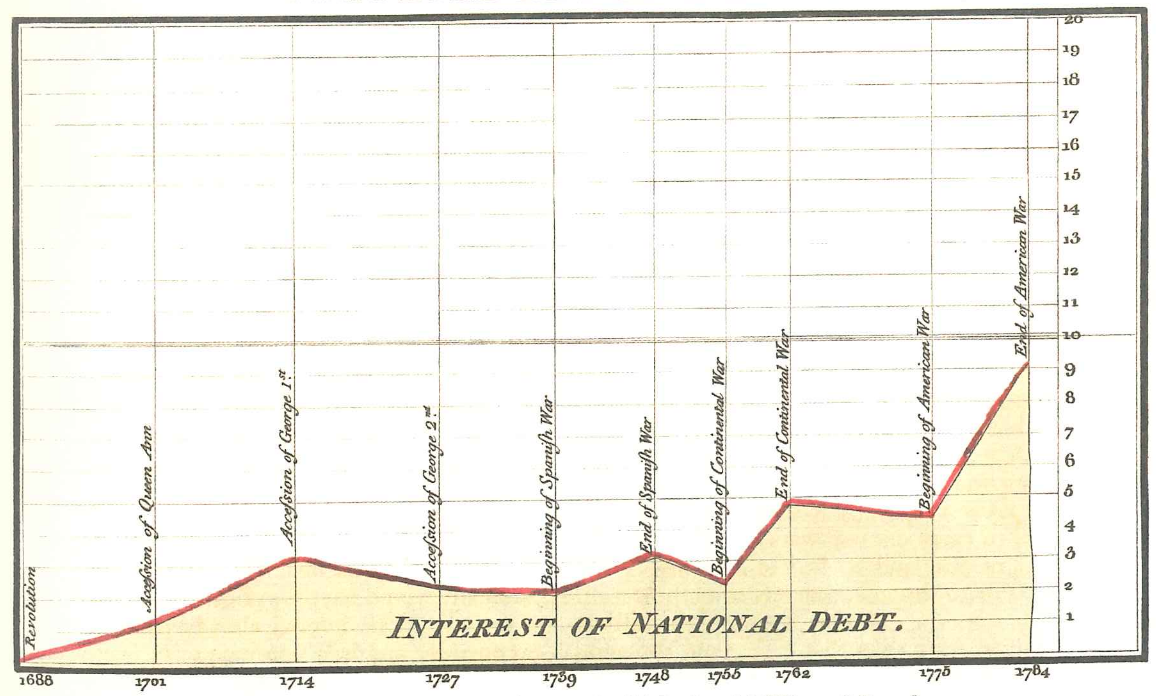
The Case of Skyrocketing Government Spending

Probably the most frequently printed graphic, other than the daily weather map and stock-market trend line, is the display of government spending and debt over the years. These arrays nearly always create the impression that spending and debt are rapidly increasing.

As usual, Playfair was the first, publishing this finely designed graphic in 1786. Accompanied by his polemic against the "ruinous folly" of the British government policy of financing its colonial wars through debt, it is surely the first skyrocketing government debt chart, beginning the now 200-year history of such displays. This is one of the few Playfairs that is taller than wide; less than one-tenth of all his graphics (about 90, drawn during 35 years of work) are longer on the vertical. The tall shape here serves to emphasize the picture of rapid growth. The money figures are not adjusted for inflation.

But Playfair had the integrity to show an alternative version a few pages later in *The Commercial and Political Atlas*. The interest on the national debt was plotted on a broad horizontal scale, diminishing the skyrocket effect. And, furthermore, "This is in real and not in nominal millions" (page 129):

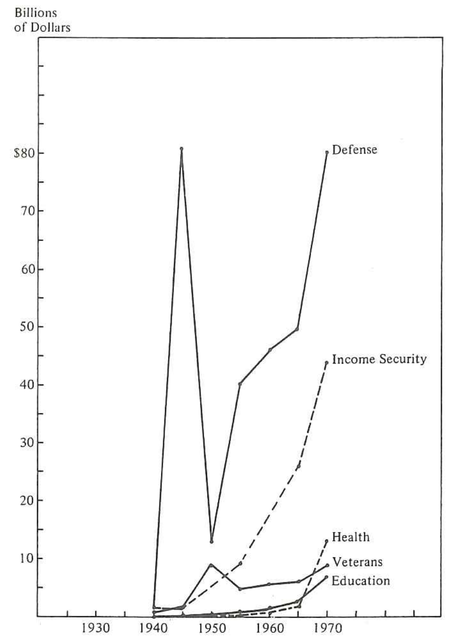
Interest of the NATIONAL DEBT from the Revolution.



The Bottom line is Years, those on the Right hand Millions of Pounds.

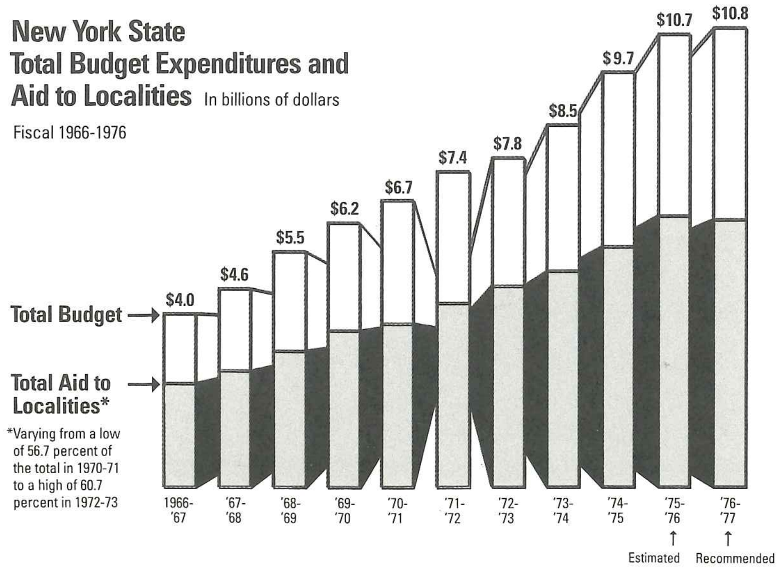
Although Playfair deflated money units over time in his work of 1786, the matter has proved difficult for many, eluding even modern scholars. This display helps its political point along by failing to discount for inflation and population growth and by using a tall and thin shape (the area covered by the data is 2.7 times taller than wide):

Figure A3. The Growth of Government: Federal Spending in Selected Domestic Areas



Morris Fiorina, *Congress: Keystone of the Washington Establishment* (New Haven, 1977), 92.

Let us look, in detail, at another graphic on government spending:

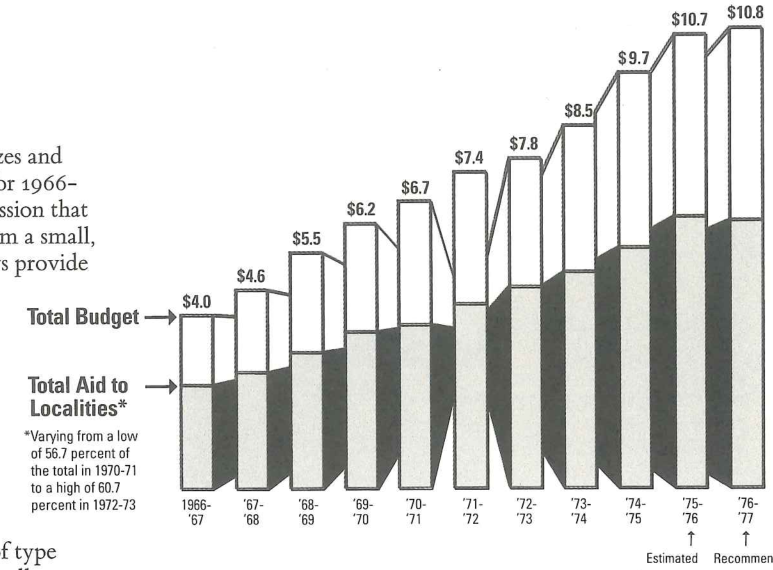


New York Times, February 1, 1976, IV-6.

Despite the appearance created by the hyperactive design, the state budget actually did not increase during the last nine years shown. To generate the thoroughly false impression of a substantial and continuous increase in spending, the chart deploys several visual and statistical tricks—all working in the same direction, to exaggerate the growth in the budget. These graphical gimmicks:

These three parallelepipeds have been placed on an optical plane *in front* of the other eight, creating the image that the newer budgets tower over the older ones.

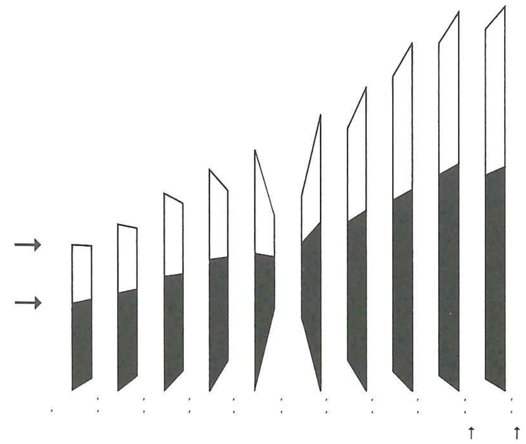
This cluster of type emphasizes and stretches out the low value for 1966–1967, encouraging the impression that recent years have shot up from a small, stable base. Horizontal arrows provide similar emphasis.

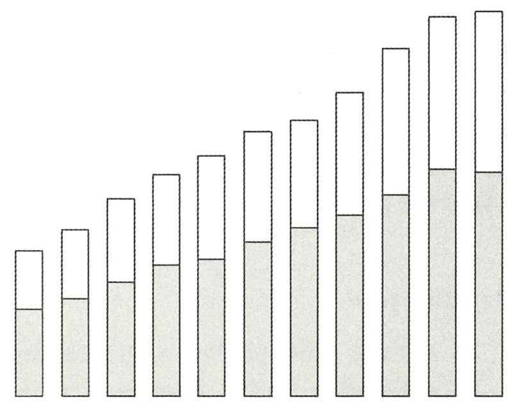


This squeezed-down block of type contributes to an image of small, squeezed-down budgets back in the good old days.

Arrows pointing straight up emphasize recent growth. Compare with horizontal arrows at left.

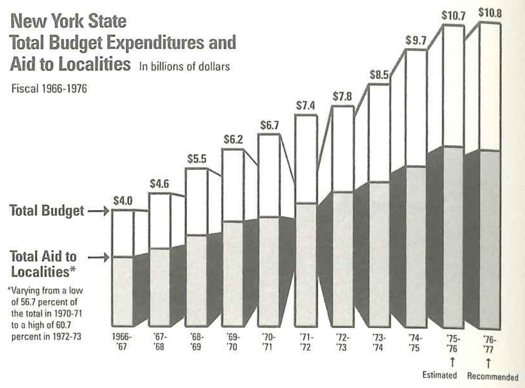
Leaving behind the distortion in the chartjunk heap at the left yields a calmer view:

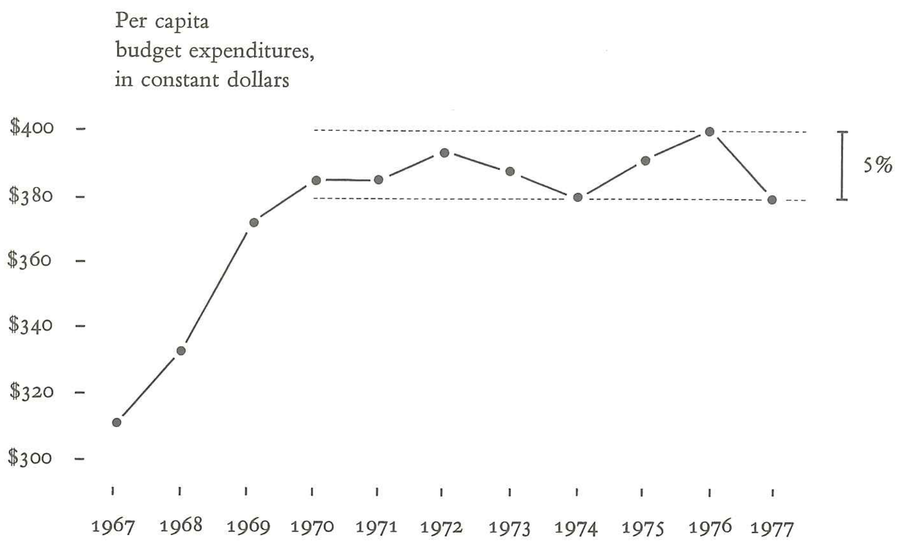




Two statistical lapses also bias the chart. First, during the years shown, the state's population increased by 1.7 million people, or 10 percent. Part of the budget growth simply paralleled population growth. Second, the period was a time of substantial inflation; those goods and services that cost state and local governments \$1.00 to purchase in 1967 cost \$2.03 in 1977. By not deflating, the graphic mixes up changes in the value of money with changes in the budget.

Application of arithmetic makes it possible to take population and inflation into account. Computing expenditures in *constant (real) dollars per capita* reveals a quite different—and far more accurate—picture:





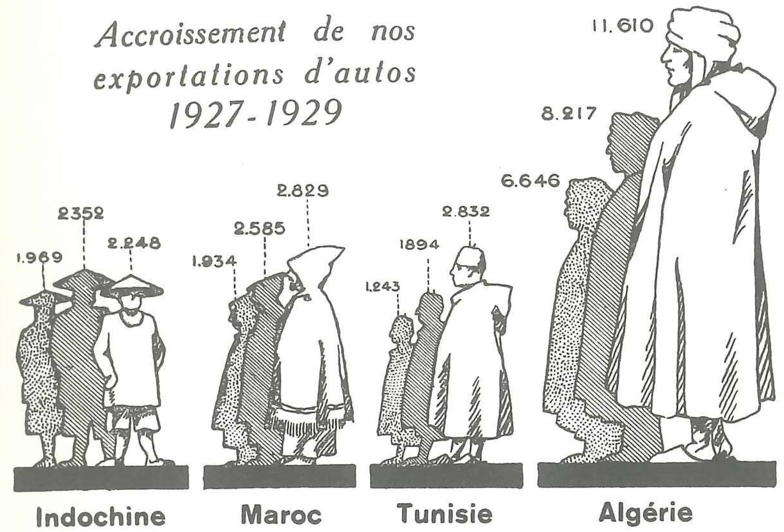
Thus, in terms of real spending per capita, the state budget increased by about 20 percent from 1967 to 1970 and remained relatively constant from 1970 through 1976. And the 1977 budget represents a substantial *decline* in expenditures. That is the real news story of these data, and it was completely missed by the Graph of the Magical Parallelepipeds. Of course no small set of numbers is going to capture the complexities of a large budget—but, at any rate, why tell lies?

The principle:

> In time-series displays of money, deflated and standardized units of monetary measurement are nearly always better than nominal units.

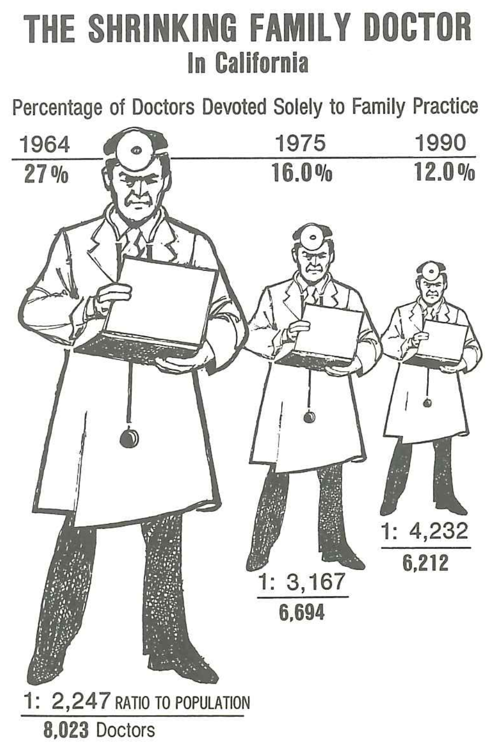
Visual Area and Numerical Measure

Another way to confuse data variation with design variation is to use areas to show one-dimensional data:



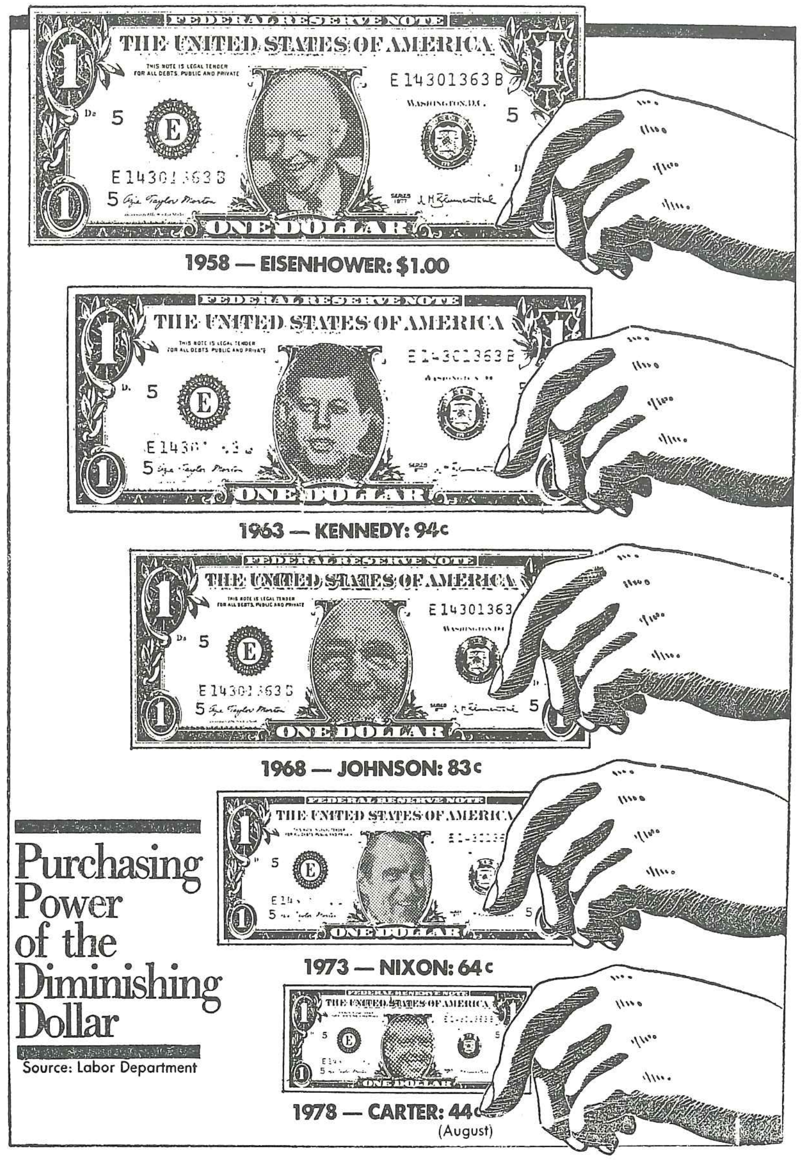
R. Satet, *Les Graphiques* (Paris, 1932), 12.

And here is the incredible shrinking doctor, with a Lie Factor of 2.8, not counting the additional exaggeration from the overlaid perspective and the incorrect horizontal spacing of the data:



Los Angeles Times, August 5, 1979, 3.

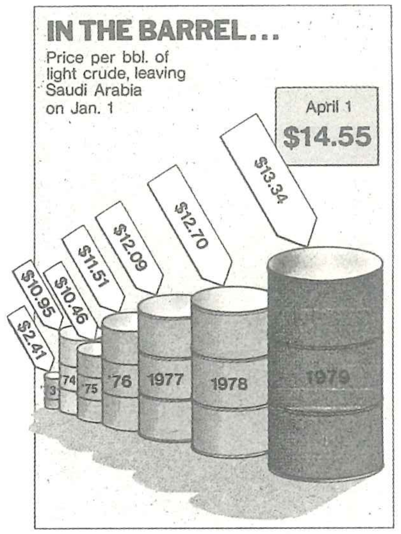
Many published efforts using areas to show magnitudes make the elementary mistake of varying both dimensions simultaneously in response to changes in one-dimensional data. Typical is the shrinking dollar fallacy. To depict the rate of inflation, graphs show currency shrinking on two dimensions, even though the value of money is one-dimensional. Here is one of hundreds of such charts:



Washington Post, October 25, 1978, 1.

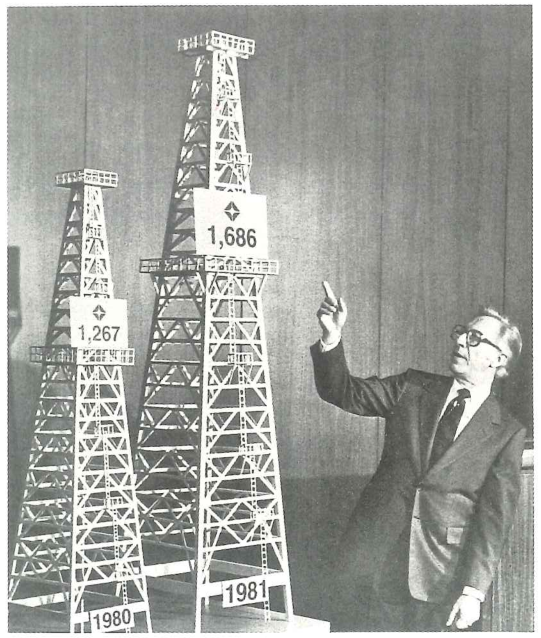
If the area of the dollar is accurately to reflect its purchasing power, then the 1978 dollar should be about twice as big as that shown.

There are considerable ambiguities in how people perceive a two-dimensional surface and then convert that perception into a one-dimensional number. Changes in physical area on the surface of a graphic do not reliably produce appropriately proportional changes in perceived areas. The problem is all the worse when the areas are tricked up into three dimensions:



By surface area, the Lie Factor for this graphic is 9.4. But, if one takes the barrel metaphor seriously and assumes that the *volume* of the barrels represents the price change, then the volume from 1973 to 1979 increases 27,000 percent compared to a data increase of 454 percent, for a Lie Factor of 59.4, which is a record.

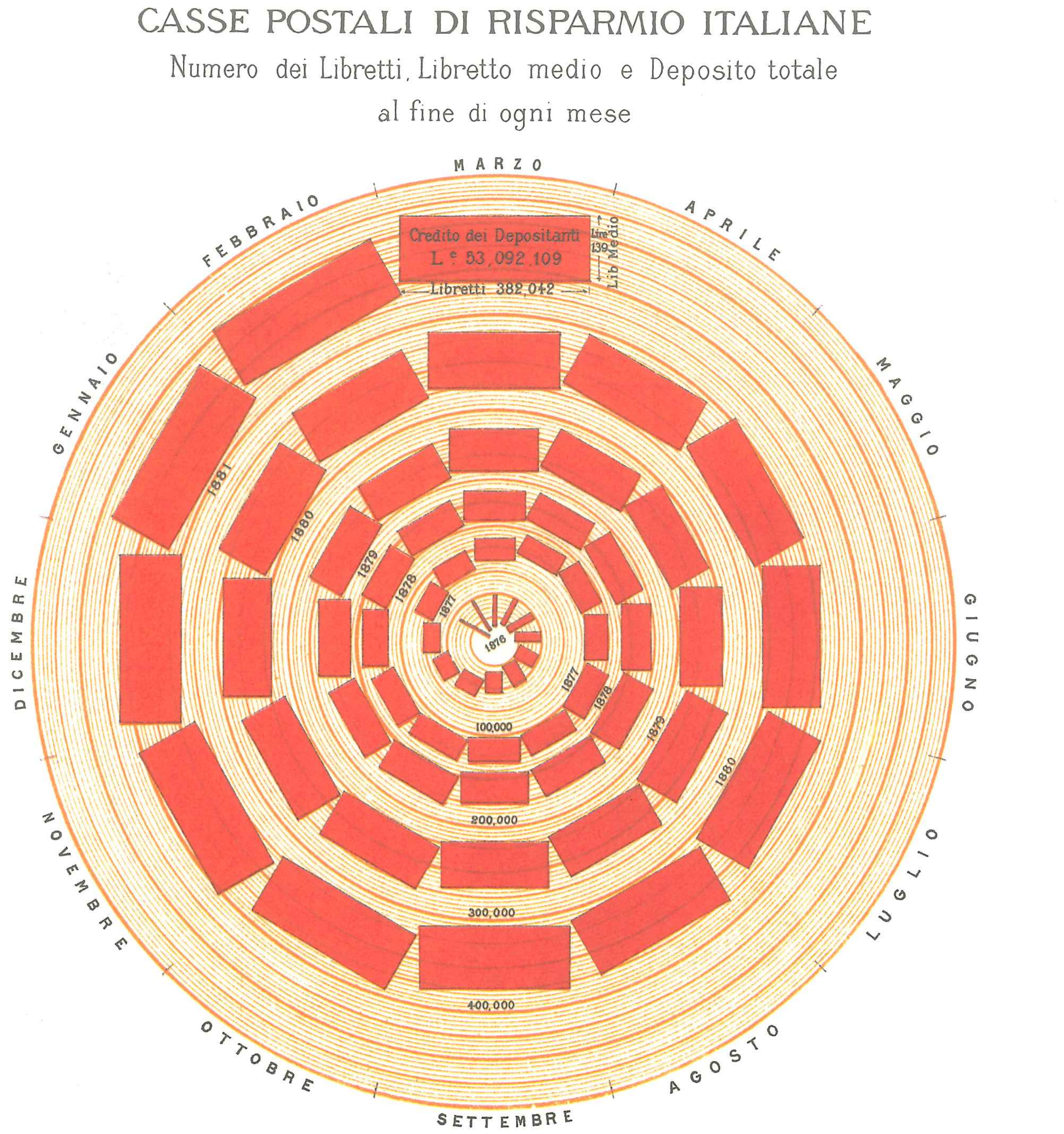
Similarly, a three-dimensional representation puffing up one-dimensional data:



New York Times, January 27, 1981, D-1.

Conclusion: The use of two (or three) varying dimensions to show one-dimensional data is a weak and inefficient technique, capable of handling only very small data sets, often with error in design and ambiguity in perception. These designs cause so many problems that they should be avoided:

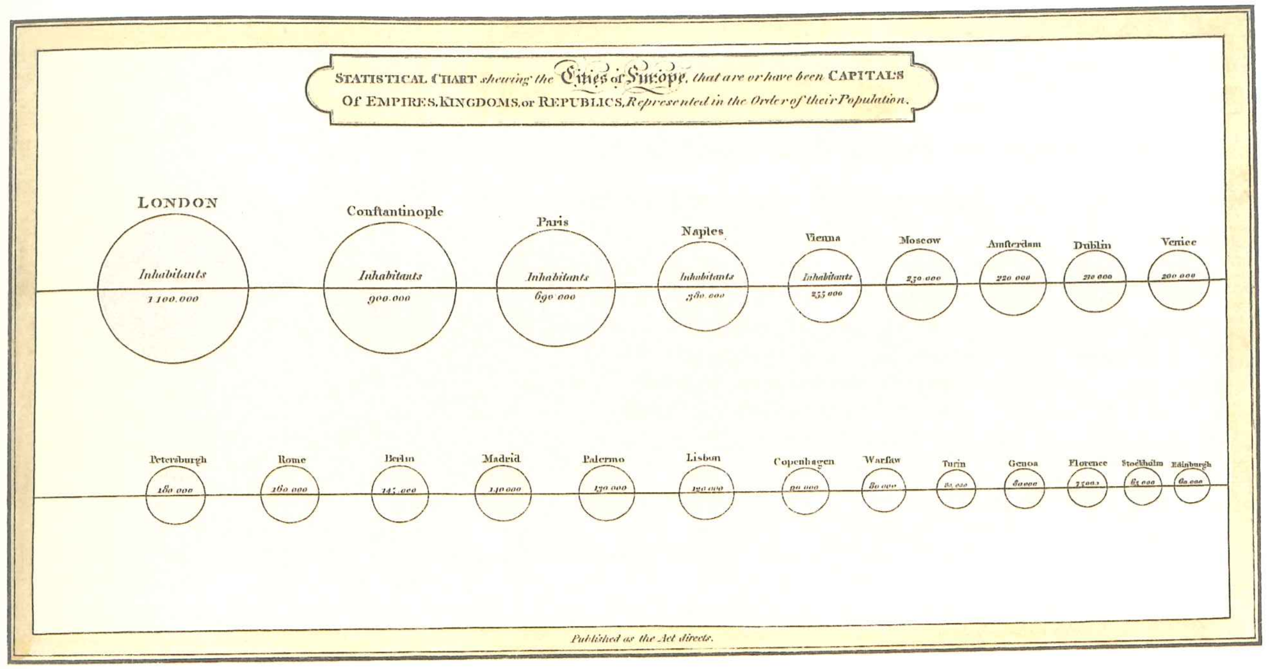
> The number of information-carrying (variable) dimensions depicted should not exceed the number of dimensions in the data.



This multivariate history of the Italian post office uses two dimensions in a way nearly consistent with this principle, with the number of postal savings books issued and the average size of deposits multiplying up to total deposits at the end of each month from 1876 to 1881.

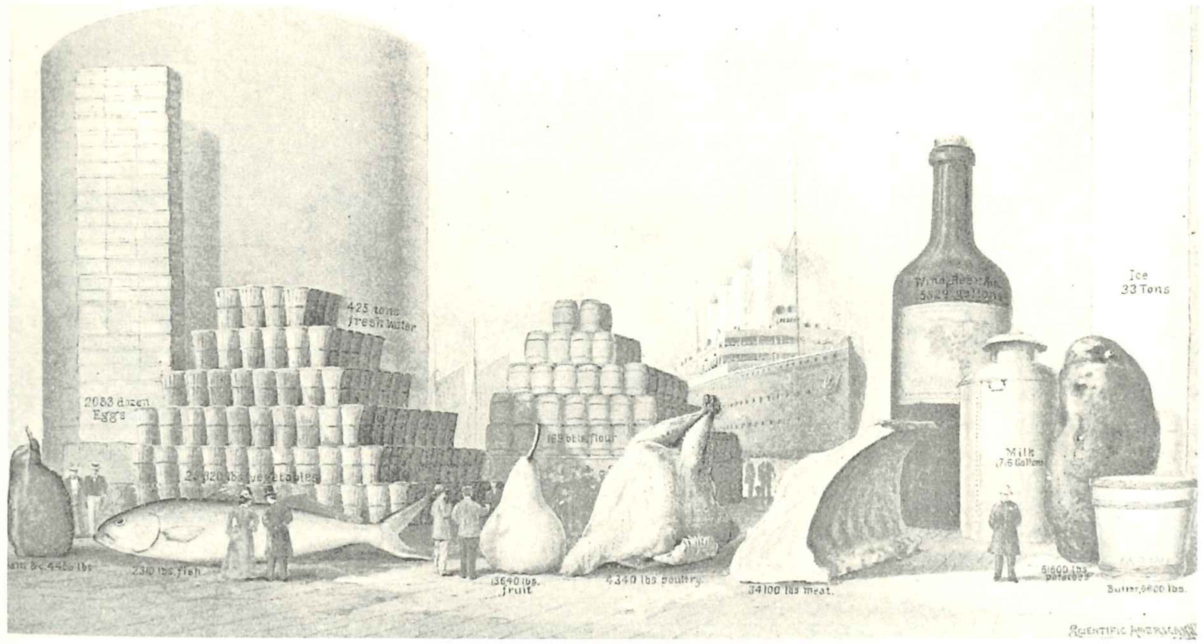
Antonio Gabaglio, *Teoria Generale della Statistica* (Milan, second edition, 1888).

But Playfair's circles, an early use of area to show magnitude, are not consistent with the principle, since the one-dimensional data (city populations) are represented by area:



Perhaps graphics that border on cartoons should be exempt from the principle. We certainly would not want to forgo the 4,340 pound chicken:

Scientific American Reference Book (New York, 1909), 280.

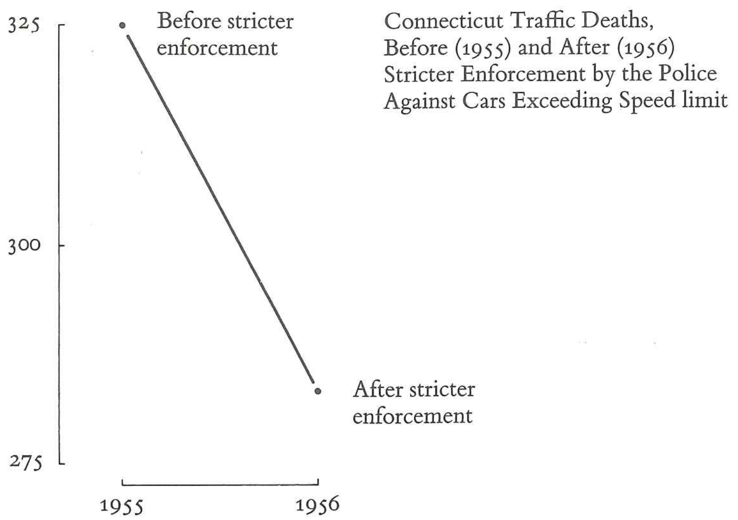


Context is Essential for Graphical Integrity

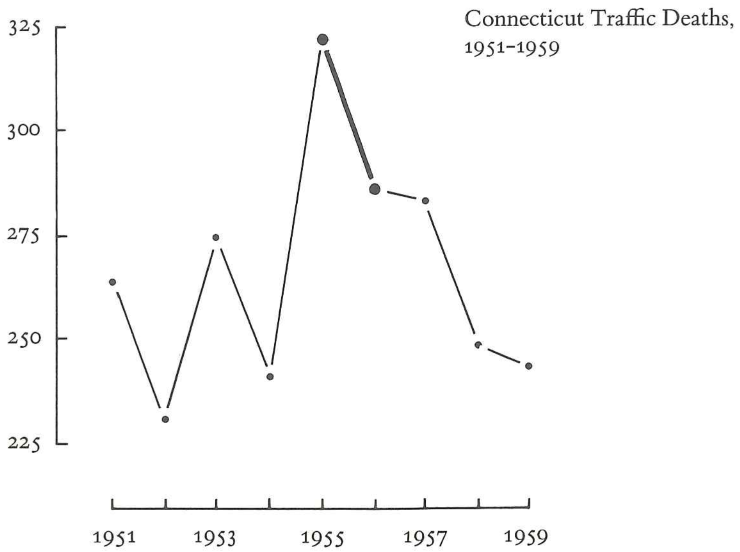
To be truthful and revealing, data graphics must bear on the question at the heart of quantitative thinking: "Compared to what?" The emaciated, data-thin design should always provoke suspicion, for graphics often lie by omission, leaving out data sufficient for comparisons. The principle:

Graphics must not quote data out of context.

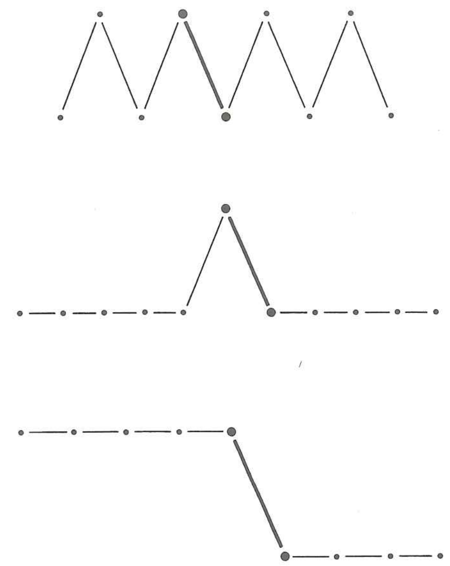
Nearly all the important questions are left unanswered by this display:



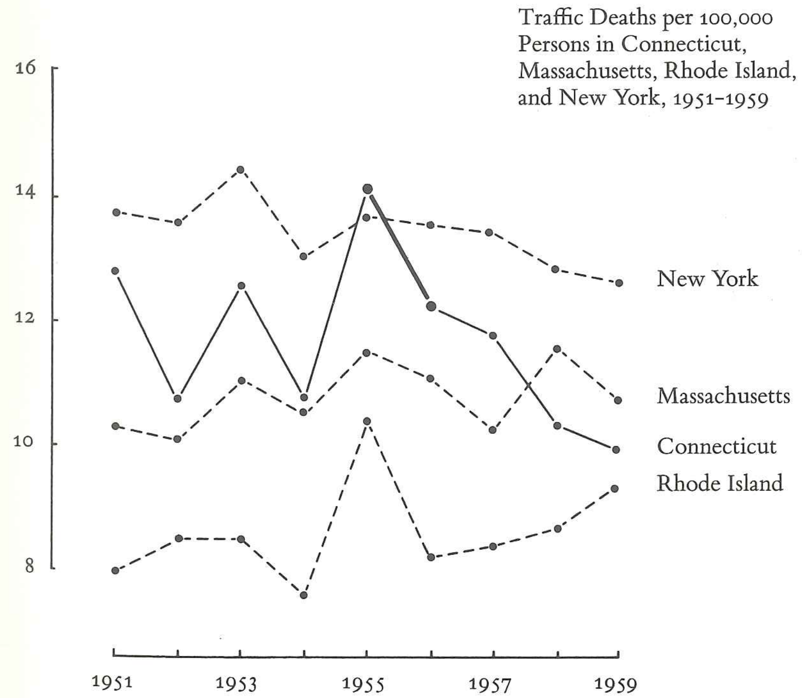
A few more data points add immensely to the account:



Imagine the very different interpretations other possible time-paths surrounding the 1955–1956 change would have:



Comparisons with adjacent states give a still better context, revealing it was not only Connecticut that enjoyed a decline in traffic fatalities in the year of the crackdown on speeding:

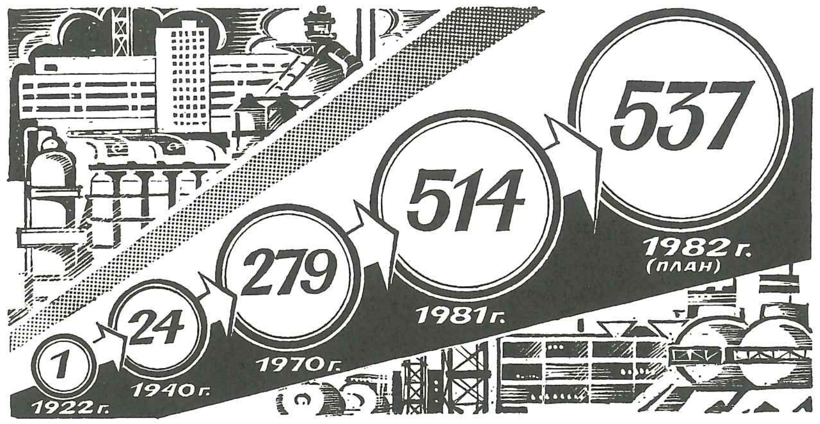


Donald T. Campbell and H. Laurence Ross, "The Connecticut Crackdown on Speeding: Time Series Data in Quasi-Experimental Analysis," in Edward R. Tufte, ed., *The Quantitative Analysis of Social Problems* (Reading, Massachusetts, 1970), 110–125.

Conclusion

Lying graphics cheapen the graphical art everywhere. Since the lies often show up in news reports, millions of images are printed. When a chart on television lies, it lies tens of millions of times over; when a *New York Times* chart lies, it lies 900,000 times over to a great many important and influential readers. The lies are told about the major issues of public policy—the government budget, medical care, prices, and fuel economy standards, for example. The lies are systematic and quite predictable, nearly always exaggerating the rate of recent change.

The main defense of the lying graphic is . . . "Well, at least it was approximately correct, we were just trying to show the general direction of change." But many of the deceptive displays we saw in this chapter involved fifteenfold lies, too large to be described as approximately correct. And in several cases the graphics were not even approximately correct by the most lax of standards, since they falsified the real news in the data. It is the special character of numbers that they have a magnitude as well as an order; numbers measure *quantity*. Graphics can display the quantitative size of changes as well as their direction. The standard of getting only the direction and not the magnitude right is the philosophy that informs the Pravda School of Ordinal Graphics. There, every chart has a crystal clear direction coupled with fantasy magnitudes.



Рост продукции промышленности (1922 г. = 1).

Pravda, May 24, 1982, 2.

A second defense of the lying graphic is that, although the design itself lies, the actual numbers are printed on the graphic for those picky folks who want to know the correct size of the effects displayed. It is as if not lying in one place justified fifteenfold lies elsewhere. Few writers would work under such a modest standard of integrity, and graphic designers should not either.

Graphical integrity is more likely to result if these six principles are followed:

The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.

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.

Show data variation, not design variation.

In time-series displays of money, deflated and standardized units of monetary measurement are nearly always better than nominal units.

The number of information-carrying (variable) dimensions depicted should not exceed the number of dimensions in the data.

Graphics must not quote data out of context.

3 *Sources of Graphical Integrity and Sophistication*

WHY do artists draw graphics that lie? Why do the world's major newspapers and magazines publish them?[1]

Although bias and stereotyping are the origin of more than a few graphical distortions, the primary causes of inept graphical work are to be found in the skills, attitudes, and organizational structure prevailing among those who design and edit statistical graphics.

[1] "It is difficult to know why these same errors are being repeated. In Playfair's original work these kinds of mistakes were not made; moreover, these errors were not as widespread in the 1930s as they are now. Perhaps the reason is an increase in the perceived need for graphs . . . without a concomitant increase in training in their construction. Evidence gathered by the committee on graphics of the American Statistical Association indicates that formal training in graphic presentation has had a marked decline at all levels of education over the last few decades." Howard Wainer, "Making Newspaper Graphs Fit to Print," in Paul A. Kolers, et al., eds., *Processing of Visible Language 2* (New York, 1980), 139.

Lack of Quantitative Skills of Professional Artists

Lurking behind the inept graphic is a lack of judgment about quantitative evidence. Nearly all those who produce graphics for mass publication are trained exclusively in the fine arts and have had little experience with the analysis of data. Such experience is essential for achieving precision and grace in the presence of statistics, but even textbooks of graphical design are silent on how to think about numbers. Illustrators too often see their work as an exclusively artistic enterprise—the words "creative," "concept," and "style" combine regularly in all possible permutations, a Big Think jargon for the small task of constructing a time-series a few data points long. Those who get ahead are those who beautify data, never mind statistical integrity.

The Doctrine That Statistical Data Are Boring

Inept graphics also flourish because many graphic artists believe that statistics are boring and tedious. It then follows that decorated graphics must pep up, animate, and all too often exaggerate what evidence there is in the data. For example:

- *Time*'s first full-time chart specialist, an art-school graduate, says that in his work, "The challenge is to present statistics as a visual idea rather than a tedious parade of numbers."[2]

[2] *Time*, February 11, 1980, 3.

- The opening sentence of the chapter on statistical charts in Jan White's *Graphic Idea Notebook*: "Why are statistics so boring?" Sample illustrations supposedly reveal "Dry statistics turned into symbolic graphics" and "Plain statistics embellished or humanized with pictures."[3]

- A fine book on graphics, Herdeg's *Graphis/Diagrams*, is described by its publisher: "An international review demonstrating convincingly that statistical and diagrammatic graphics do not necessarily have to be dull."[4]

[3] Jan V. White, *Graphic Idea Notebook* (New York, 1980), 148, 165.

[4] Walter Herdeg, ed., *Graphis/Diagrams* (Zurich, 1976).

The doctrine of boring data serves political ends, helping to advance certain interests over others in bureaucratic struggles for control of a publication's resources. For if the numbers are dull dull dull, then an artist, indeed many artists, indeed an Art Department and an Art Director are required to animate the data, lest the eyes of the audience glaze over. Thus the doctrine encourages placing data graphics under control of artists rather than in the hands of those who write the words and know the substance. As the art bureaucracy grows, style replaces content. And the word people, having lost space in the publication to data decorators, console themselves with thoughts that statistics are really rather tedious anyway.

If the statistics are boring, then you've got the wrong numbers. Finding the right numbers requires as much specialized skill—statistical skill—and hard work as creating a beautiful design or covering a complex news story.

The Doctrine That Graphics Are Only for the Unsophisticated Reader

Many believe that graphical displays should divert and entertain those in the audience who find the words in the text too difficult. For example:

- *Consumer Reports* describes the design of their new consumer magazine for children: "For the first test issue, CU's professional staff produced an article about sugar that was longer on graphics than on information. We had feared children might be overwhelmed by too many facts."[5]

- An art director with overall responsibility for the design of some 3,000 data graphics each year (yielding 2.5 billion printed images) said that graphics are intended more to lure the reader's attention away from the advertising than to explain the news in any detail. "Unlike the advertisements," he said, "at least we don't put naked women in our graphics."[6]

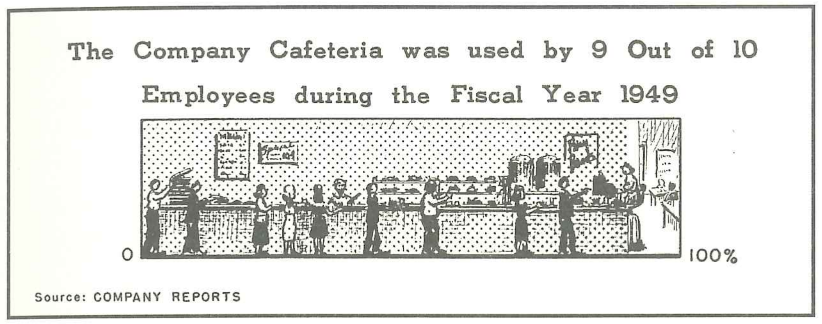
[5] *Consumer Reports*, 45 (July 1980), 408.

[6] Louis Silverstein, "Graphics at the *New York Times*," presentation at the First General Conference on Social Graphics, Leesburg, Virginia, October 23, 1978.

- A news director at a national television network said that graphics must be instantly understandable: "If you have to explain it, don't use it."[7]

[7] Interview with author, July 1980.

This kind of graphical thinking leads to



Mary Eleanor Spear, *Charting Statistics* (New York, 1952), 5, who appropriately describes this as an "unnecessary chart."

The Consequences

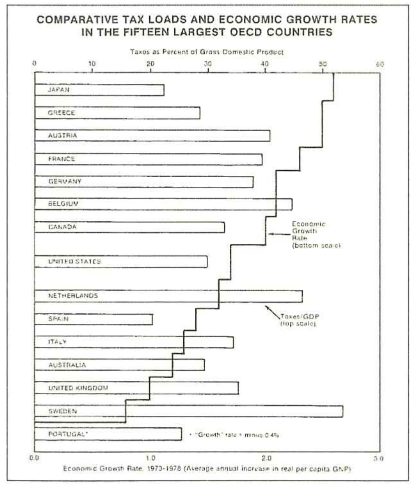
What E. B. White said of writing is also true of statistical graphics: "No one can write decently who is distrustful of the reader's intelligence, or whose attitude is patronizing."[8] Contempt for graphics and their audience, along with the lack of quantitative skills among illustrators, has deadly consequences for graphical work: over-decorated and simplistic designs, tiny data sets, and big lies.

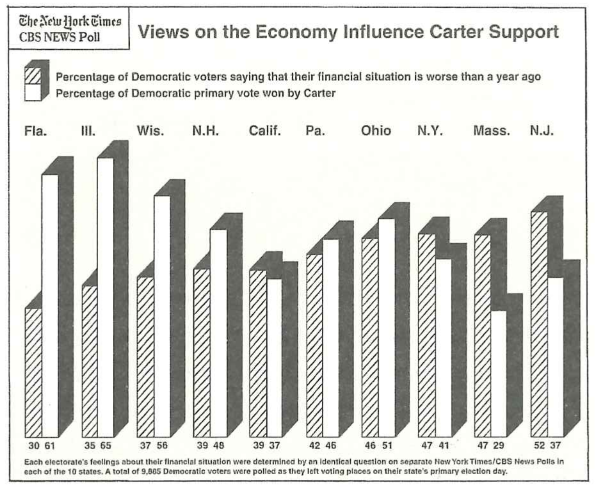
[8] In William Strunk, Jr., and E. B. White, *The Elements of Style* (New York, 1959), 70.

Like censorship, these constraints on graphical design lead to elliptical and eccentric communication. In seeking to avoid the subtleties of the scatterplot, artists drew up these convoluted specimens, forcing bivariate data into a univariate design:

New York Times, June 16, 1980, A-18.

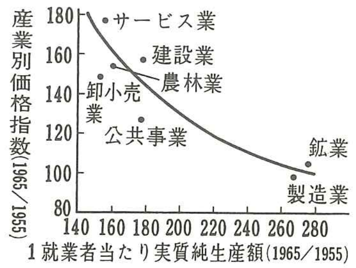
Allen D. Manvel, "Taxation and Economic Growth," *Taxation with Representation Newsletter*, 9 (June 1980), 3.

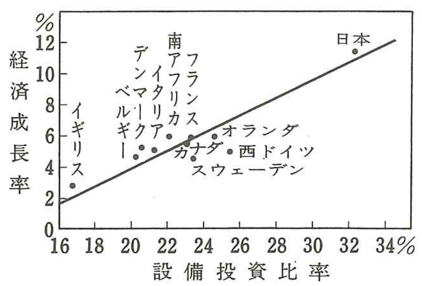




But beyond reviewing a few examples, let us look more systematically at the level of graphical sophistication prevailing at different publications. In order to make comparisons among a variety of newspapers, magazines, scientific journals, and books, I have compiled a rough measure of graphical sophistication—the share of a publication's graphics that are *relational*. Such a design links two or more variables but is not a time-series or a map. Relational graphics are essential to competent statistical analysis since they confront statements about cause and effect with evidence, showing how one variable affects another. The design idea is a simple one, although not quite as simple as the bar chart, time-series plot, or data map. Relational graphics have been used since 1765 and are printed billions of times and ways every year; and there is evidence that twelve-year-old children understand the design.[9]

All these graphics count as sophisticated by our hardly demanding measure:[10]



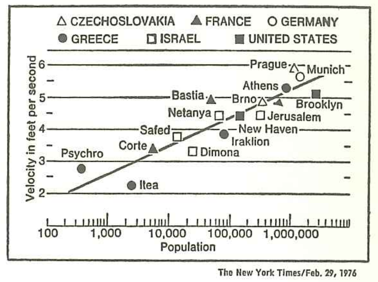


Isao Sato and Miyohei Shinohara, *New Politics and Economics* (Tokyo, 1974), 113; a Japanese high school textbook.

The frequency of use of relational designs was counted for randomly selected issues from 1974 to 1980 of each of 15 news publications. A total of about 4,000 graphics were examined in sampled issues. Scaling up the observed data by the frequency and circulation of the publication indicates that the sample represents a population of 250 to 300 billion printed graphical images.

[9] Clara Francis Bamberger, "Interpretation of Graphs at the Elementary School Level," *Catholic University of America Educational Research Monographs*, 13 (May 1942). Additional data from textbooks and standardized tests are presented shortly.

[10] A variety of measures of graphical intelligence and complexity are possible and another, data density, is discussed in Chapter 8.



Pace of City Life Found 2.8 Feet per Second Faster

By BOYCE RENSBERGER

The pace of life in big cities is faster than it is in small towns—about 2.8 feet per second faster, according to a study by a Princeton University psychologist and his wife, who is an anthropologist.

By measuring how fast people walk along the main streets of municipalities of varying sizes, they have confirmed what most people have sensed informally. The bigger the city, the faster its inhabitants walk.

They found, for example, that on Flatbush Avenue in Brooklyn, people walk at a brisk 5 feet per second, only a little slower than their counterparts on Wenceslas Square in Prague, who bustle along at 5.8 feet per second.

In contrast to Brooklyn and Prague, both of which have a population of more than a million, the 365 citizens of Psychro, Greece, amble along at 2.7 feet per second and the people of Corte, France (population 5,500, move at 3.3 feet per second.

New York Times, February 29, 1976, 46.

Table 1 shows the results, ranking the 15 news publications by graphical sophistication. Seven of the papers, from *Pravda* to the *Wall Street Journal*, produced no relational graphics among those sampled and usually limited themselves to time-series. Other papers published more advanced graphics: the Japanese *Asahi* (a mass circulation daily), *Akahata* ("Red Flag," a Communist party paper that appears, from the data, to have employed a sophisticated and talented graphical designer in 1979), and *Nihon Keizai* (a financial daily), as well as *Der Spiegel* and *The Economist*. Although none reached the level of sophistication found in displays of scientific data (a random sample of 220 graphics from *Science* 1978–1980 had 42 percent of relational design), it is clear that some graphical intelligence is possible in news work, at least in Japan and at a few European weeklies.

Table 1
Graphical Sophistication, World Press, 1974–1980

	Percentage of statistical graphics based on more than one variable, but not a time-series or a map	Number of graphics in sample
Akahata ("Red Flag") (Japan, daily, circulation 30,000)	9.3%	202
Asahi Shimbun (Japan, daily, 8,000,000)	7.6%	119
Der Spiegel (Germany, weekly, 1,000,000)	5.7%	454
The Economist (Britain, weekly, 170,000)	2.0%	342
Nihon Keizai Shimbun (Japan, daily financial paper, 1,700,000)	1.7%	297
Le Monde (French, daily, 440,000)	0.7%	144
Business Week (U.S., weekly, 800,000)	0.6%	726
New York Times (U.S., daily, 900,000; Sunday, 1,500,000)	0.5%	422
Pravda (USSR, daily, 10,500,000)	0.0%	54
Frankfurter Allgemeine (Germany, daily, 300,000)	0.0%	93
The Times (Britain, daily, 400,000)	0.0%	107
Washington Post (U.S., daily, 600,000; Sunday, 800,000)	0.0%	121
Time (U.S., weekly, 4,300,000)	0.0%	147
Die Zeit (Germany, weekly, 300,000)	0.0%	213
Wall Street Journal (U.S., daily, 2,000,000)	0.0%	449

Japanese graphical distinction is consistent with that country's heavy use of statistical techniques in the workplace and extensive quantitative training, even in the early years of school:

> . . . no nation ranks higher in its collective passion for statistics. In Japan, statistics are the subject of a holiday, local and national conventions, awards ceremonies and nationwide statistical collection and graph-drawing contests. "This year," said Yoshiharu Takahashi, a Government statistician, "we had almost 30,000 entries. Actually, we had 29,836."
>
> Entries in the [children's] statistical graph contest were screened three times by judges, who gave first prize this year to the work of five 7-year-olds. Their graph creation, titled "Mom, play with us more often," was the result of a survey of 32 classmates on the frequency that mothers play with their offspring and the reasons given for not doing so. . . . Other children's work examined the frequency of family phone usage and correlated the day's temperature with cicada singing.[11]

Note the relational design of the last children's graphic mentioned.

The five U.S. publications examined rank toward the bottom of the world list, along with *Pravda* and a few European papers. Note, in Table 1, the complete dominance of non-relational designs at the lower-ranked newspapers and magazines. This is unfortunate because the relational graphic, unlike the simpler designs, is an *explanatory* graphic—surely a natural for news reporting and analysis.

The statistical graphics found in college and even high school textbooks are more sophisticated than those in news publications. Indeed, grade school children may experience a greater density of relational graphics than someone who reads only *Business Week*, the *New York Times*, *Time*, the *Wall Street Journal*, and the *Washington Post*. Tables 2 and 3 record the graphical sophistication of textbooks and of a variety of standardized educational tests. A comparison between these data and Table 1 suggests that most news publications outside of Japan operate at a pre-adult level of intelligence in graphical design.[12]

[11] Andrew H. Malcolm, "Data-Loving Japanese Rejoice on Statistics Day," *New York Times*, October 28, 1977, A-1.

[12] Readers of news publications, particularly the elite press, have considerable educational and professional attainments, with the resulting graphical skills. About 80 percent of the 1.5 million readers of the Sunday *New York Times* attended college, according to a 1980 *Times* market survey. The audience for statistical graphics is smarter than many illustrators believe.

Table 2
Graphical Sophistication, College and High School Textbooks

	Percentage of statistical graphics based on more than one variable, but not a time-series or a map	Number of graphics
COLLEGE TEXTBOOKS:		
Medicine and public health: 11 articles in Judith Tanur, et al., *Statistics: A Guide to the Unknown*	82%	17
Introduction to Psychology, by Ernest Hilgard, et al.	68%	82
General Chemistry, by Linus Pauling	66%	53
Life on Earth, by Edward Wilson, et al.	47%	59
Weather, astronomy, engineering: 7 articles in Tanur, *Statistics: A Guide to the Unknown*	44%	9
Communication, work, education, economics: 20 articles in Tanur, *Statistics: A Guide to the Unknown*	43%	35
Political Behavior of the American Electorate, by William H. Flanigan and Nancy H. Zingale	42%	43
Economics, by Paul Samuelson	16%	57
Democracy in America, by Robert A. Dahl	8%	25
American Government, by James Q. Wilson	0%	39
HIGH SCHOOL TEXTBOOKS:		
Chemical Principles, by William Masterton and Emil Slowinski	77%	27
The Project Physics Course, by Harvard Project Physics	48%	33
New Politics and Economics, by Isao Sato and Miyohei Shinohara (Japanese)	27%	22
Biological Science: An Ecological Approach, Biological Sciences Curriculum Study	18%	28
The American Economy, by Roy J. Sampson, et al.	5%	132
Sociology: The Study of Human Relationships, by LaVerne Thomas and Robert Anderson	0%	3
New Ethics and Social Science, by Yokichi Yajima, et al. (Japanese)	0%	5
Rise of the American Nation, by Lewis Paul Todd and Merle Curti	0%	39
Magruder's American Government, revised by William McClenaghan	0%	70

Table 3
Graphical Sophistication, Educational Tests

	Percentage of statistical graphics based on more than one variable, but not a time-series or a map	Number of graphics
National university entrance examinations, Japan, 1979 and 1980	100%	16
Review materials, Law School Admission Test, United States 1975	48%	29
Standardized tests for grade school, high school, and college; United States, 1970s:*		
Science, 14 tests	67%	64
Arithmetic, mathematics, algebra, and analytic geometry; 21 tests	41%	37
Social studies, history, and government; 14 tests	24%	49
General ability, 5 tests	21%	47

*Graphics collected in James R. Beniger, compiler, *Selected Standardized Test Items that Measure Ability with Graphics* (Washington, DC: Bureau of Social Science Research, 1975).

And so, just as there is a double standard of integrity at a good many news publications—one for words, another for graphics—so there is a double standard of sophistication. The statistical graphics are stupid; the prose is often serious and sometimes even demanding of expertise, as can be seen in these sentences from a single issue of the *New York Times*:

> Recycling petrodollars may postpone the day of reckoning, but its effects would soon become intolerable without a steady depreciation in their purchasing power. Floating rates of exchange cannot restore even a semblance of equilibrium.
>
> Numerous facets of the performance seem decidedly unfashionable if not downright eccentric: the square-toed instrumental phrasing and the frequent plodding tempos in the arias, the Romanticized treatment of the chorales, the generous retards at every cadence, the often intrusively elaborate continuo improvisations and an inconsistent attitude toward expression which ranges from heaving Mahlerian emphases to mechanical literalism.
>
> The Court shows no sign of retreating from its view that a state government is protected by sovereign immunity against court orders to pay retroactive damages for past violations.
>
> And Dr. Garth Graham, a medical director with Smithkline Corp., makers of Thorazine, noted that neuroleptics produce no euphoria, and are therefore unlikely to be abused by patients with a history of drug or alcohol dependence. "They are, if anything, dysphorogenic," Dr. Graham said.

Conclusion

The conditions under which many data graphics are produced—the lack of substantive and quantitative skills of the illustrators, dislike of quantitative evidence, and contempt for the intelligence of the audience—guarantee graphic mediocrity. These conditions engender graphics that (1) lie; (2) employ only the simplest designs, often unstandardized time-series based on a small handful of data points; and (3) miss the real news actually in the data.

It wastes the tremendous communicative power of graphics to use them merely to decorate a few numbers. Moreover, much of the world these days is observed and assessed quantitatively—and well-designed graphics are far more effective than words in showing such observations.

How can graphic mediocrity be remedied?

Surely there is something to be said for rejecting once and for all the doctrines that data graphics are for the unintelligent and that statistics are boring. These doctrines blame the victims (the audience and the data) rather than the perpetrators.

Graphical competence demands three quite different skills: the substantive, statistical, and artistic. Yet now most graphical work, particularly at news publications, is under the direction of but a single expertise—the artistic. Allowing artist-illustrators to control the design and content of statistical graphics is almost like allowing typographers to control the content, style, and editing of prose. Substantive and quantitative expertise must also participate in the design of data graphics, at least if statistical integrity and graphical sophistication are to be achieved.