M I N I  T U F T E

Excerpts from *The Visual Display of Quantitative Information* by Edward Tufte

I 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.

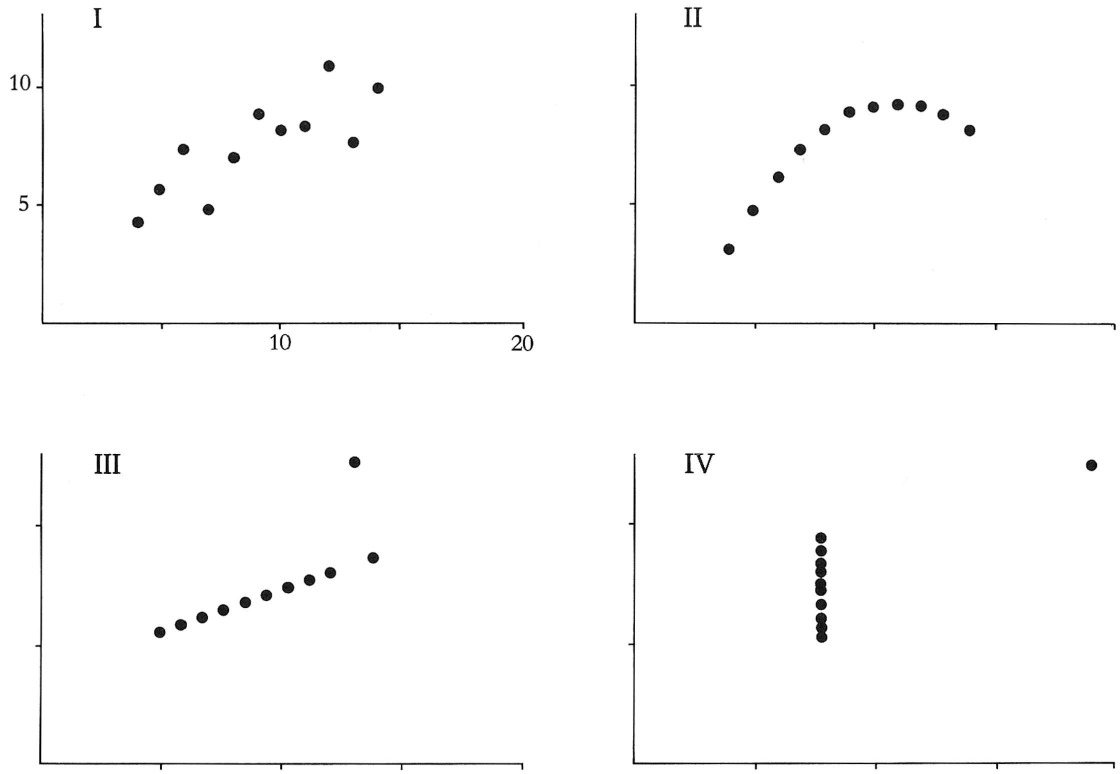
Graphics *reveal* data. Indeed graphics can be more precise and revealing than conventional statistical computations. Consider Anscombe's quartet: all four of these data sets are described by exactly the same linear model (at least until the residuals are examined).

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

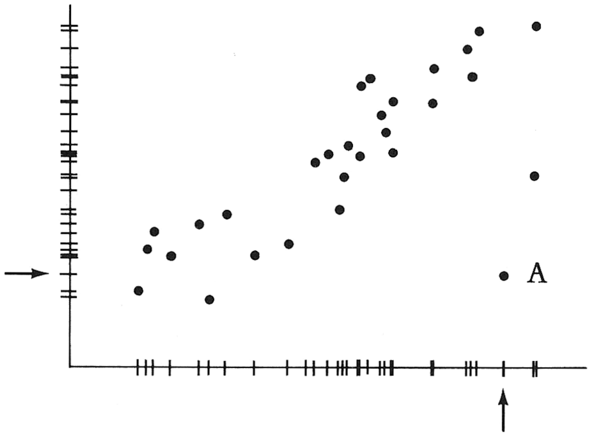
$N = 11$
mean of X's = 9.0
mean of Y's = 7.5
equation of regression line: $Y = 3 + 0.5X$
standard error of estimate of slope = 0.118
$t = 4.24$
sum of squares $X - \overline{X} = 110.0$
regression sum of squares = 27.50
residual sum of squares of Y = 13.75
correlation coefficient = .82
$r^2 = .67$

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.



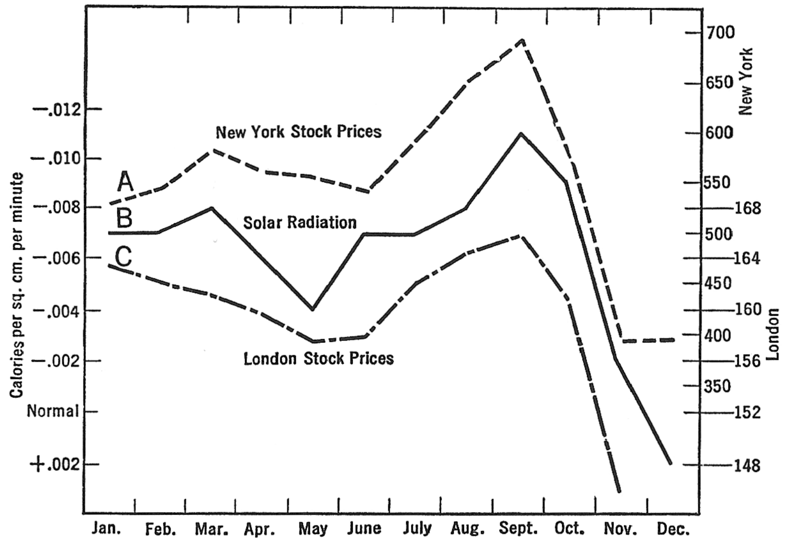
And likewise a graphic easily reveals point A, a wildshot observation that will dominate standard statistical calculations. Note that point A hides in the marginal distribution but shows up as clearly exceptional in the bivariate scatter.



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, D.C., 1980), p. 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), p. 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

[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 $7 \times 3{,}056$ entries in a data matrix sufficient to reproduce a map.

- 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.

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

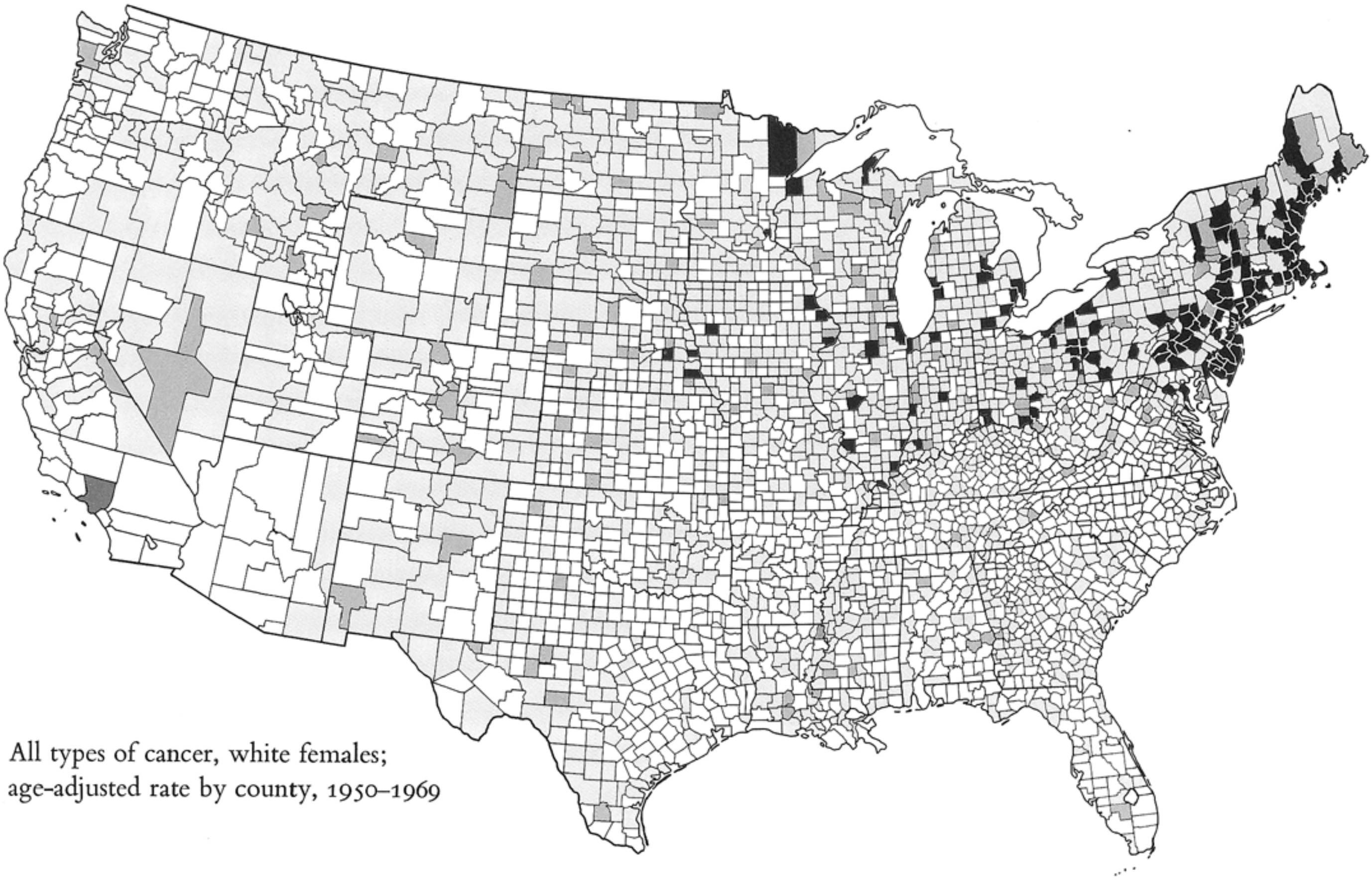
Significantly lower than U.S. as a whole

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

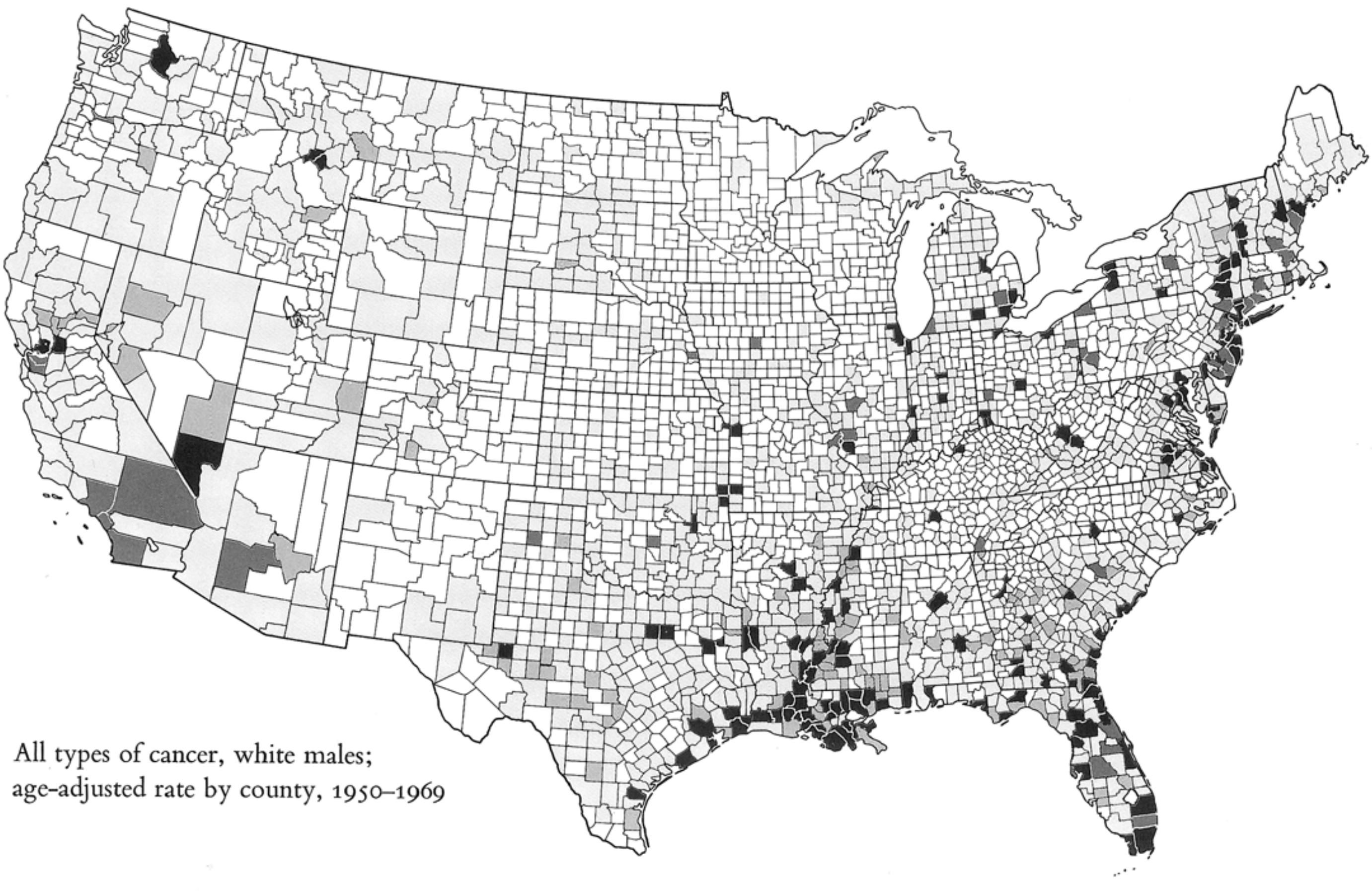
> In certain situations . . . the unusual experience of a county warrants further investigation. For example, Salem County, New Jersey, leads the nation in bladder cancer mortality among white men. We attribute this excess risk to occupational exposures, since about 25 percent of the employed persons 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]

[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, D.C.: Public Health Service, National Institutes of Health, 1975). The six maps shown here were redesigned and redrawn by Lawrence Fahey and Edward Tufte.

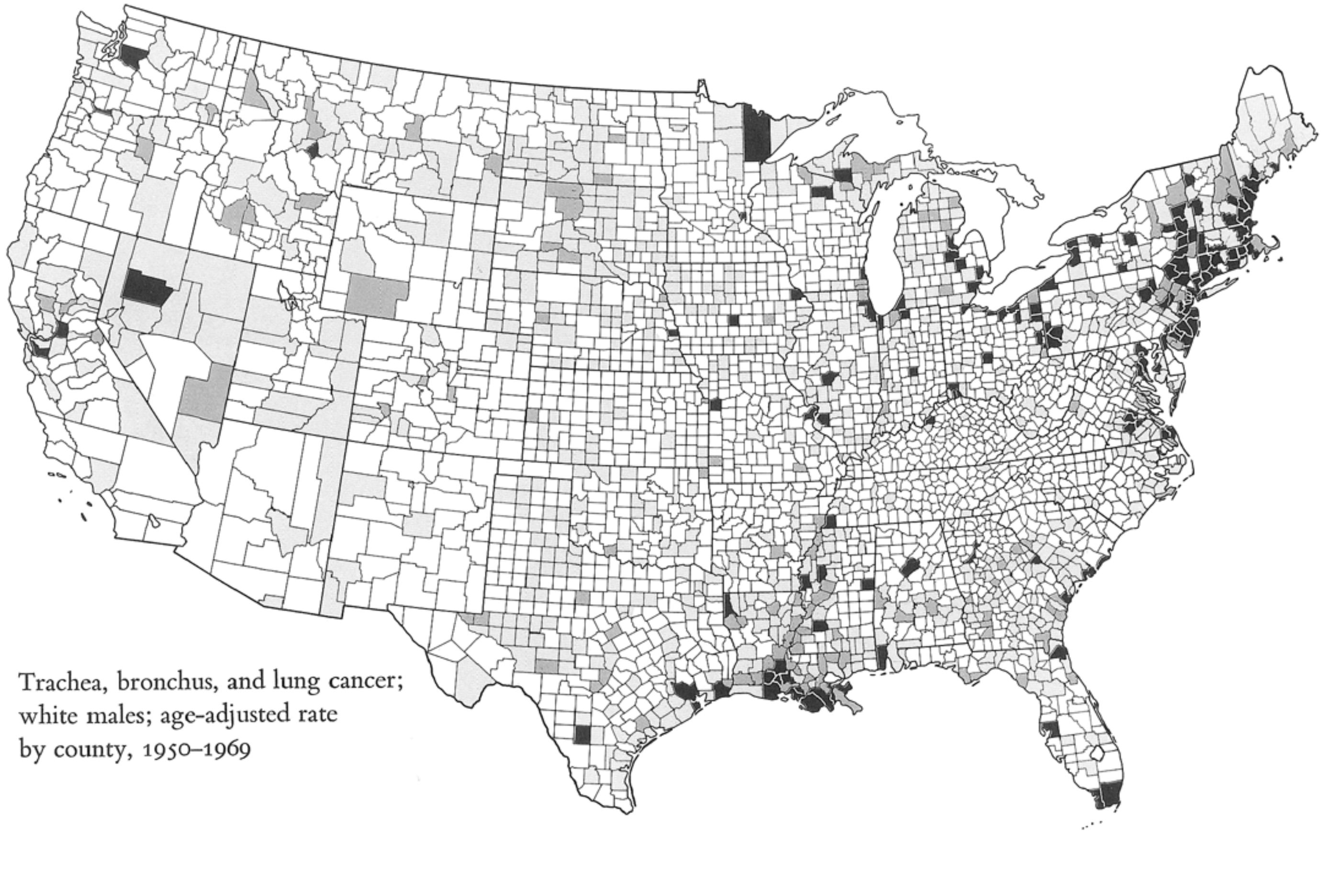


All types of cancer, white females;
age-adjusted rate by county, 1950–1969

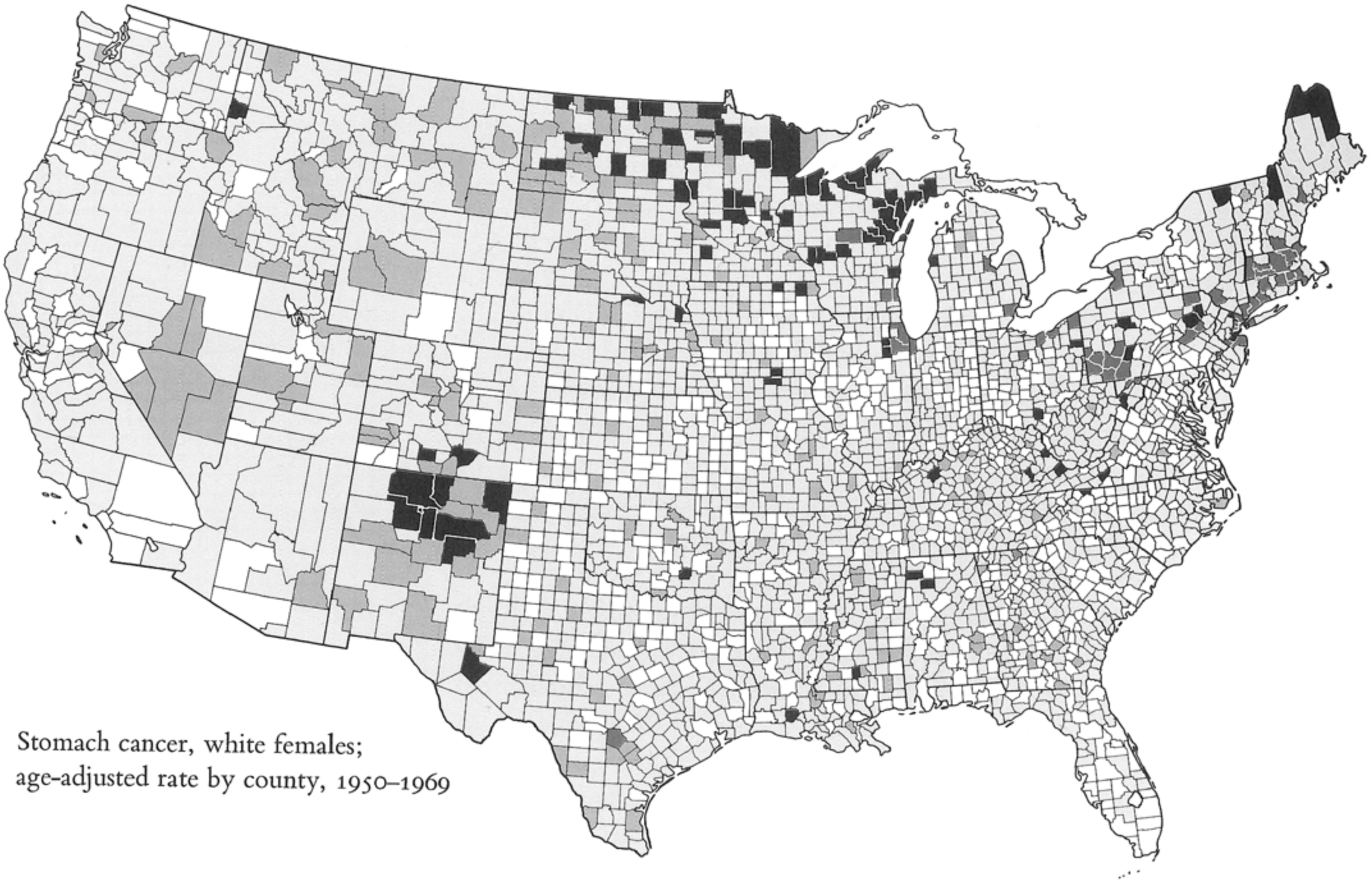


All types of cancer, white males;
age-adjusted rate by county, 1950–1969

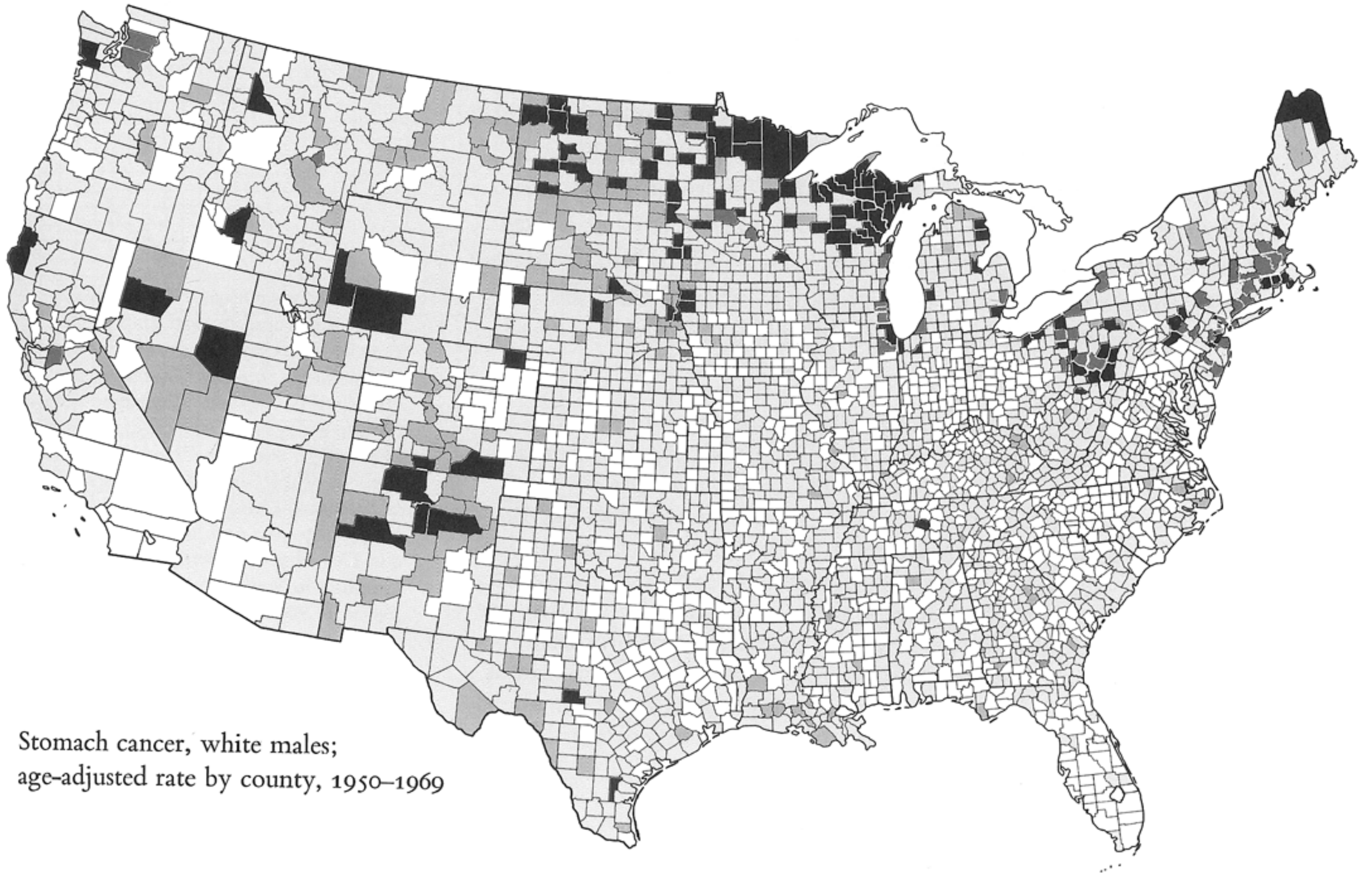
Trachea, bronchus, and lung cancer; white females; age-adjusted rate by county, 1950–1969



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

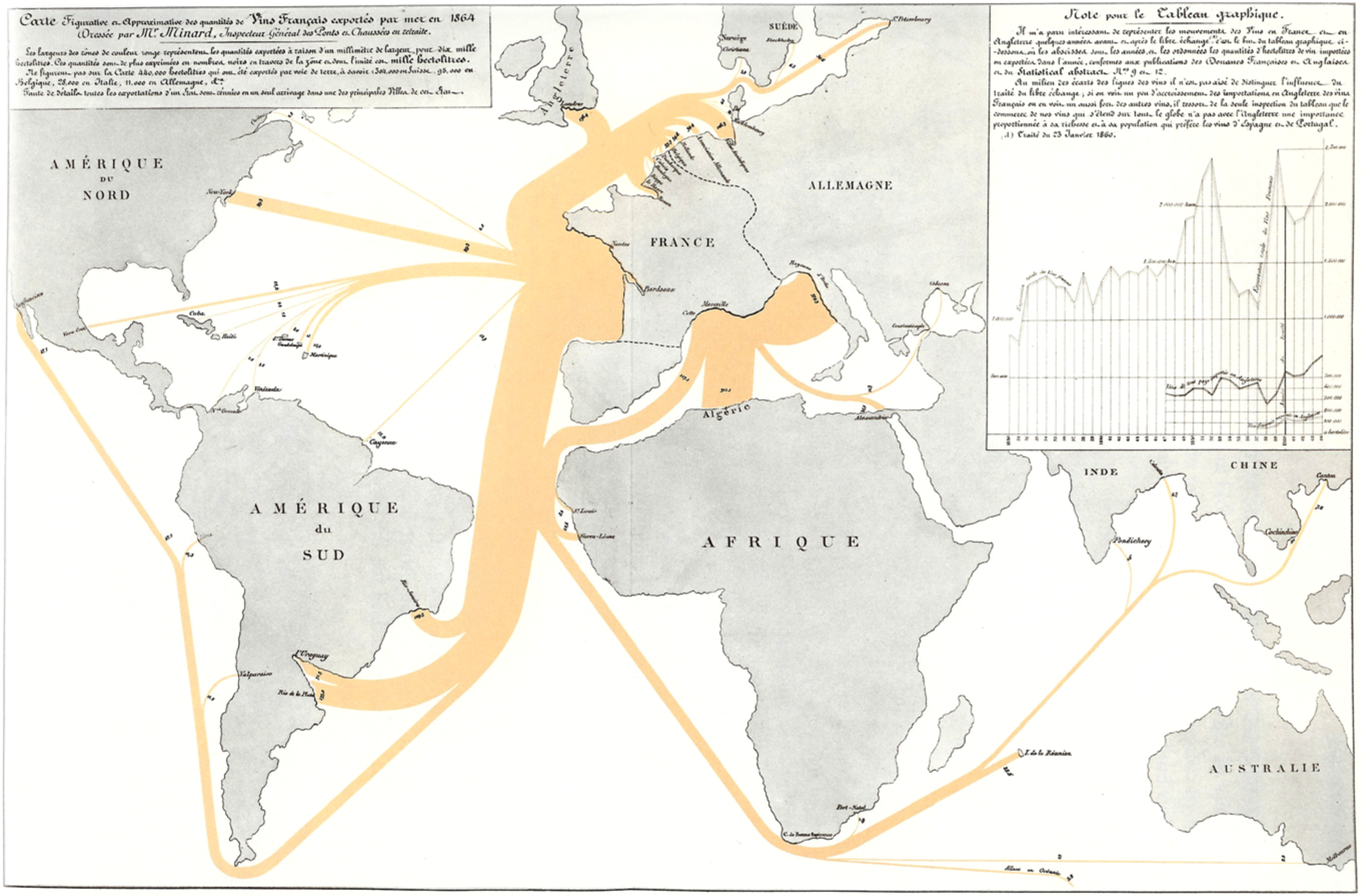
The maps repay careful study. Notice how quickly and naturally our attention has been directed toward exploring the substantive content of the data rather than toward questions of methodology and technique. Nonetheless the maps do have their flaws. They wrongly equate the visual importance of each county 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.

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.

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.

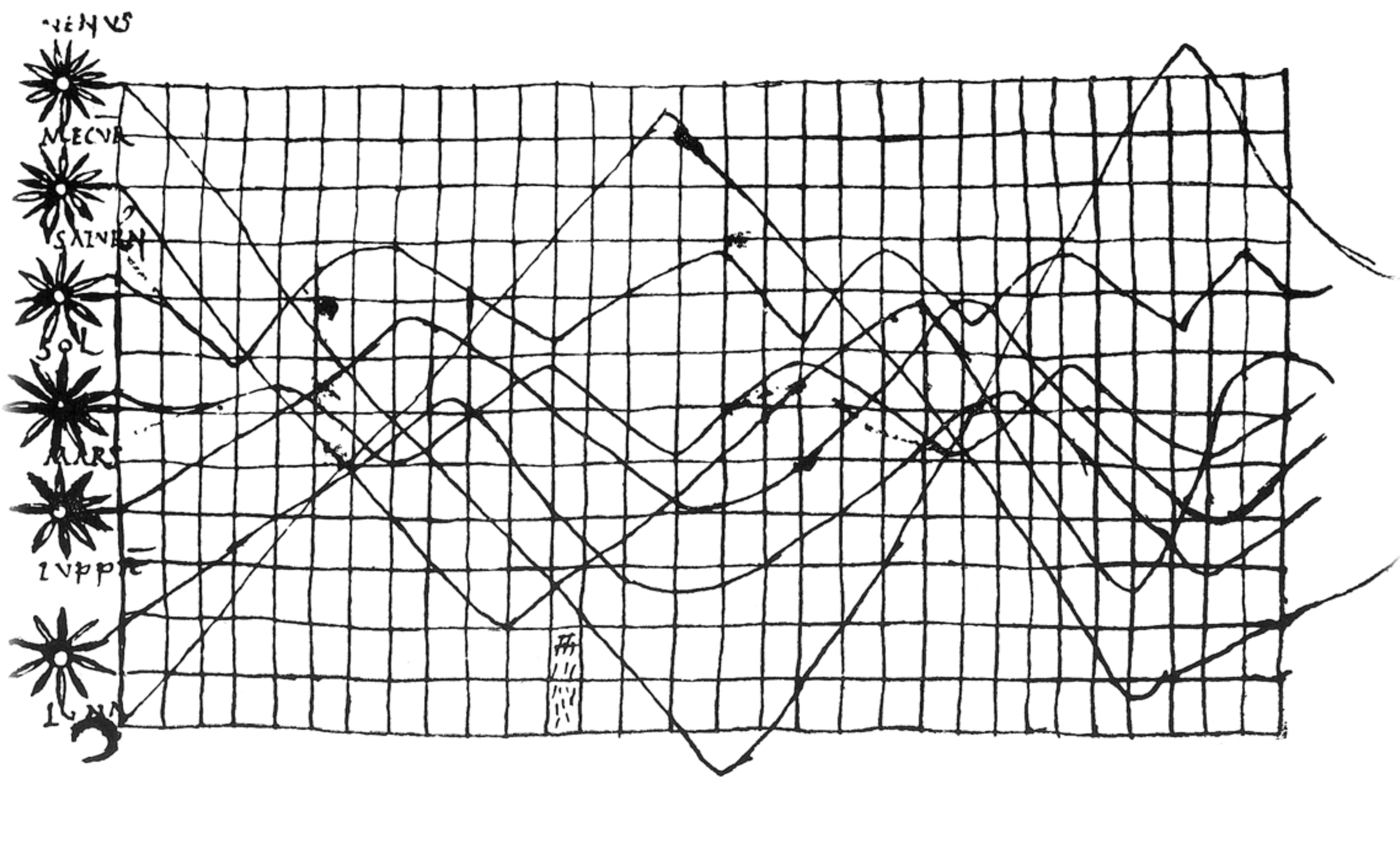
Time-Series

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.

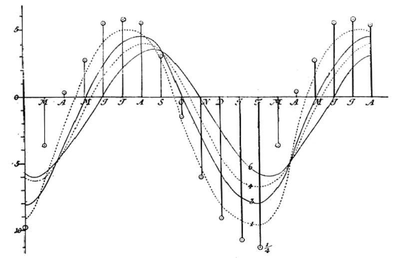
[8] A random sample of 4,000 graphics drawn from 15 of the world's newspapers and magazines published from 1974 to 1980 found that more than 75 percent of all the graphics published were time-series. Chapter 3 reports more on this.

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.

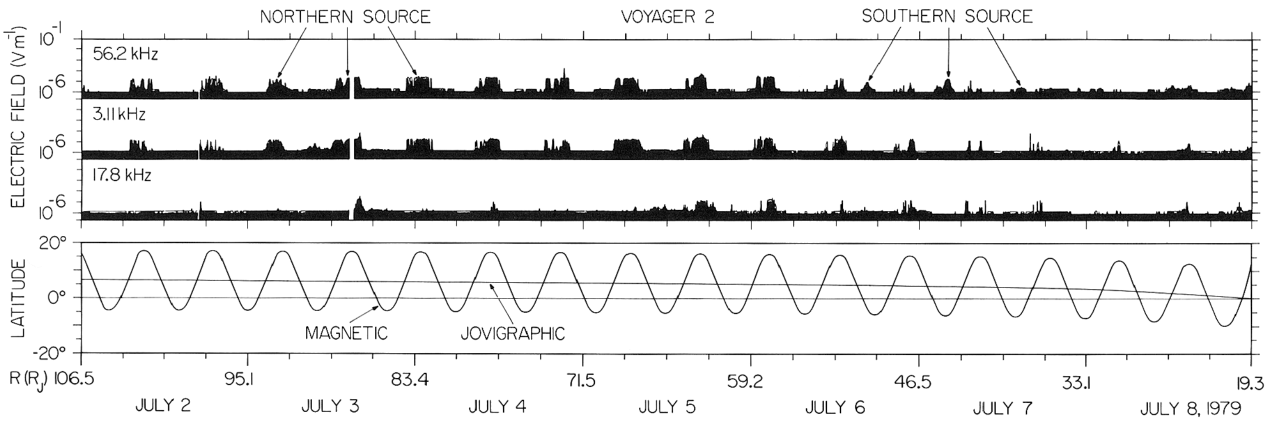
[9] H. Gray Funkhouser, "A Note on a Tenth Century Graph," *Osiris*, 1 (January 1936), 260–262.



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.



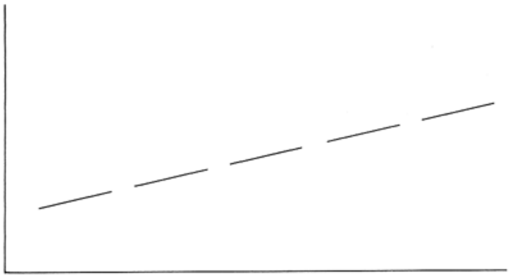
J. H. Lambert, *Pyrometrie* (Berlin, 1779).



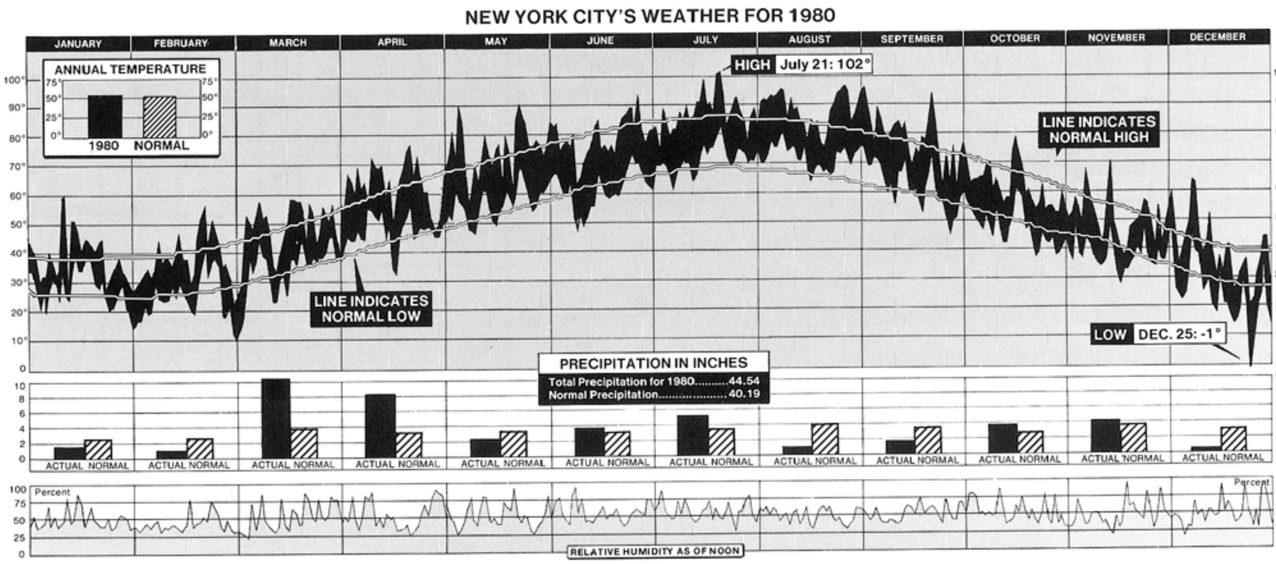
This plot of radio emissions from Jupiter is based on data collected by Voyager 2 in its pass close by the planet in July 1979. The radio intensity increases and decreases in a ten-hour cycle as Jupiter rotates. Maximum intensity occurs when the Jovian north magnetic pole is tipped toward the spacecraft, 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.

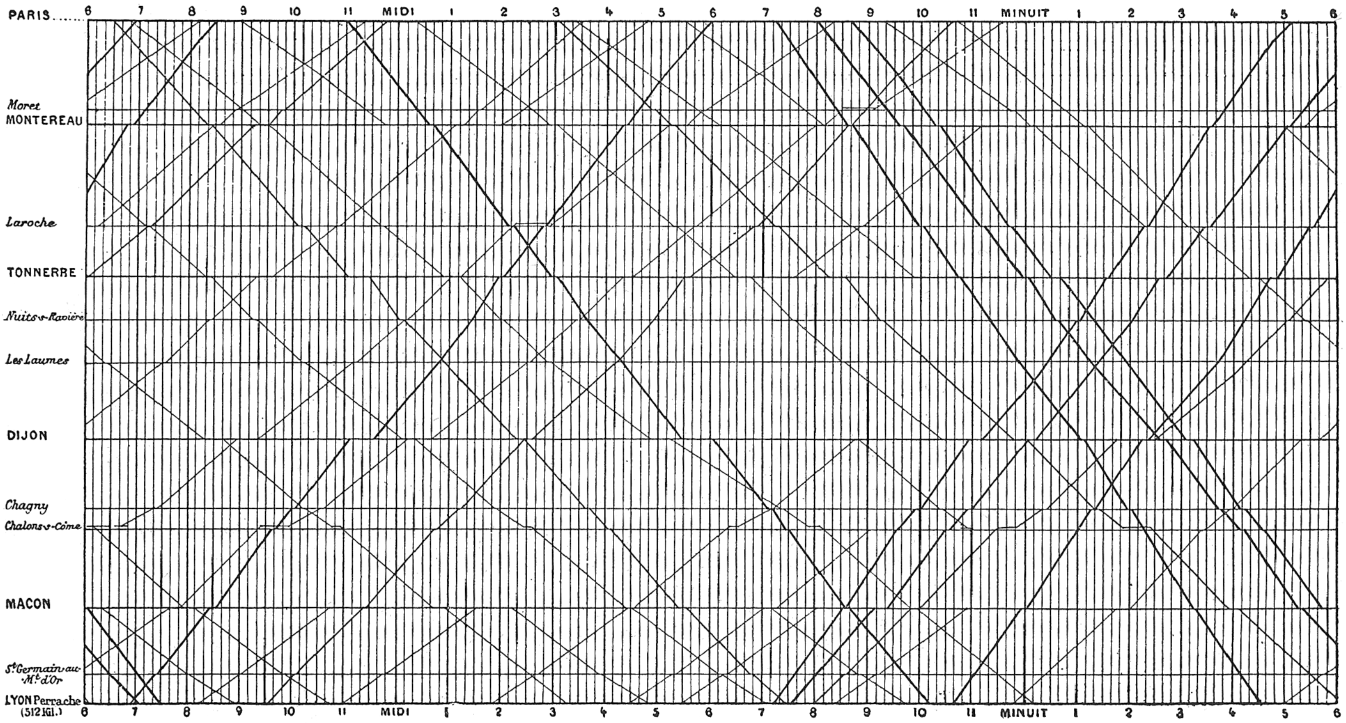
Time-series displays are at their best for big data sets with real variability. Why waste the power of data graphics on simple linear changes,



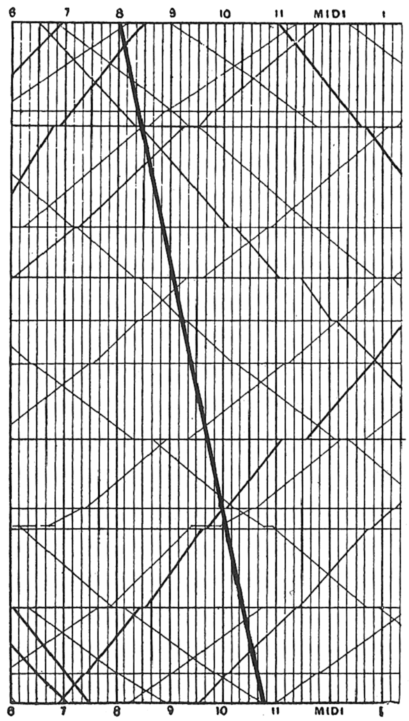
which can usually be better summarized in one or two numbers? Instead, graphics should be reserved for the richer, more complex, more difficult statistical material. This New York City weather summary for 1980 depicts 2,220 numbers. The daily high and low temperatures are shown in relation to the long-run 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 11, 1981, p. 32.



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



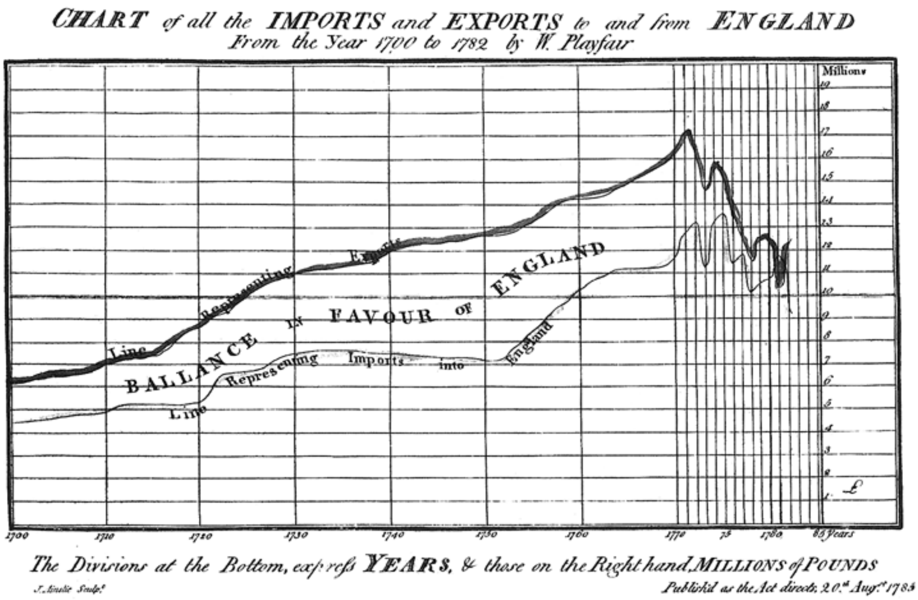
A design with similar strengths is Marey's graphical train schedule for Paris to Lyon in the 1880s. Arrivals and departures from a station are located along the horizontal; length of stop at a station is indicated by the length of the horizontal line. The stations are separated in proportion to their 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), an English 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-

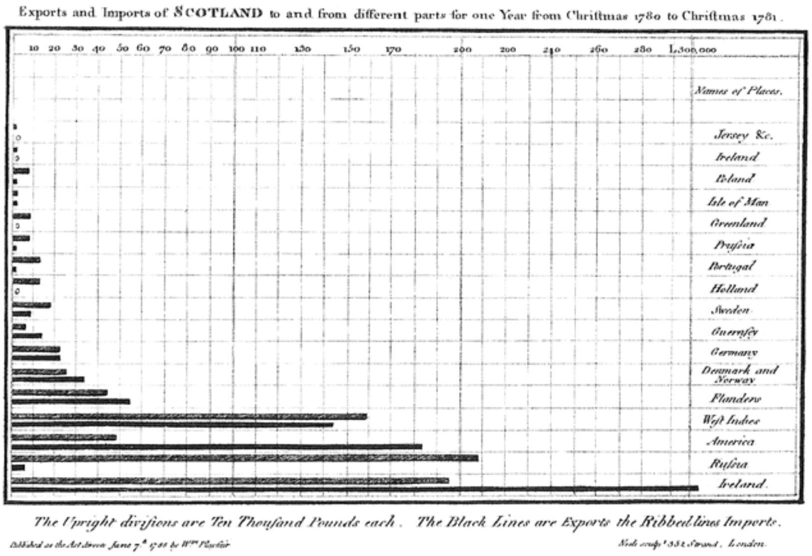


[10] Laura Tilling, "Early Experimental Graphs," *British Journal for the History of Science*, 8 (1975), 193–213.

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:

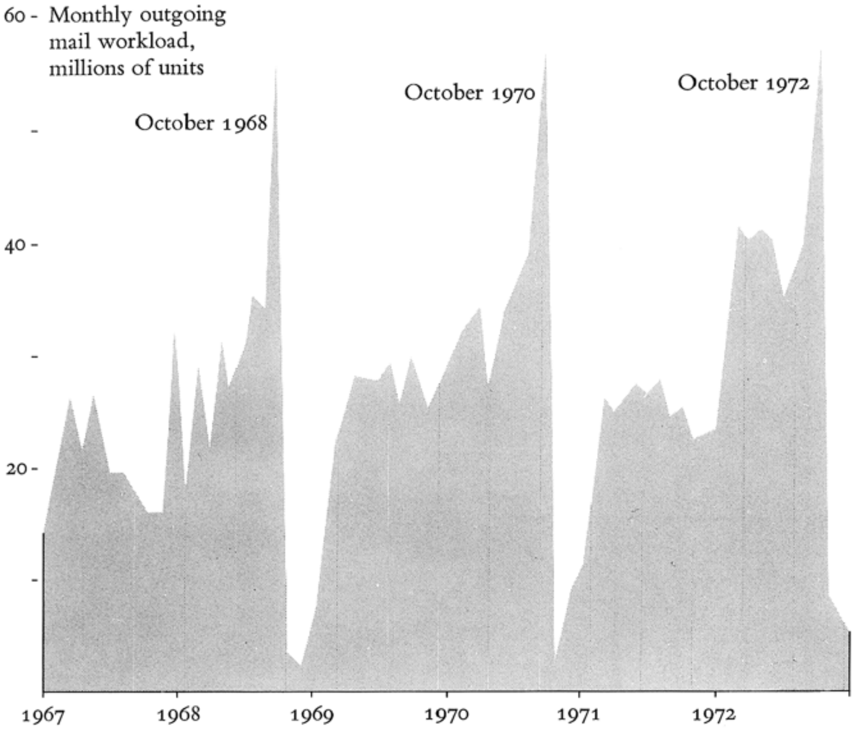
> This Chart is different from the others in principle, as it does not comprehend any portion of time, and it is much inferior in utility to those that do; for though it gives the extent of the different branches of trade, it does not compare the same branch of commerce with itself at different periods; 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 "0." 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).

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.

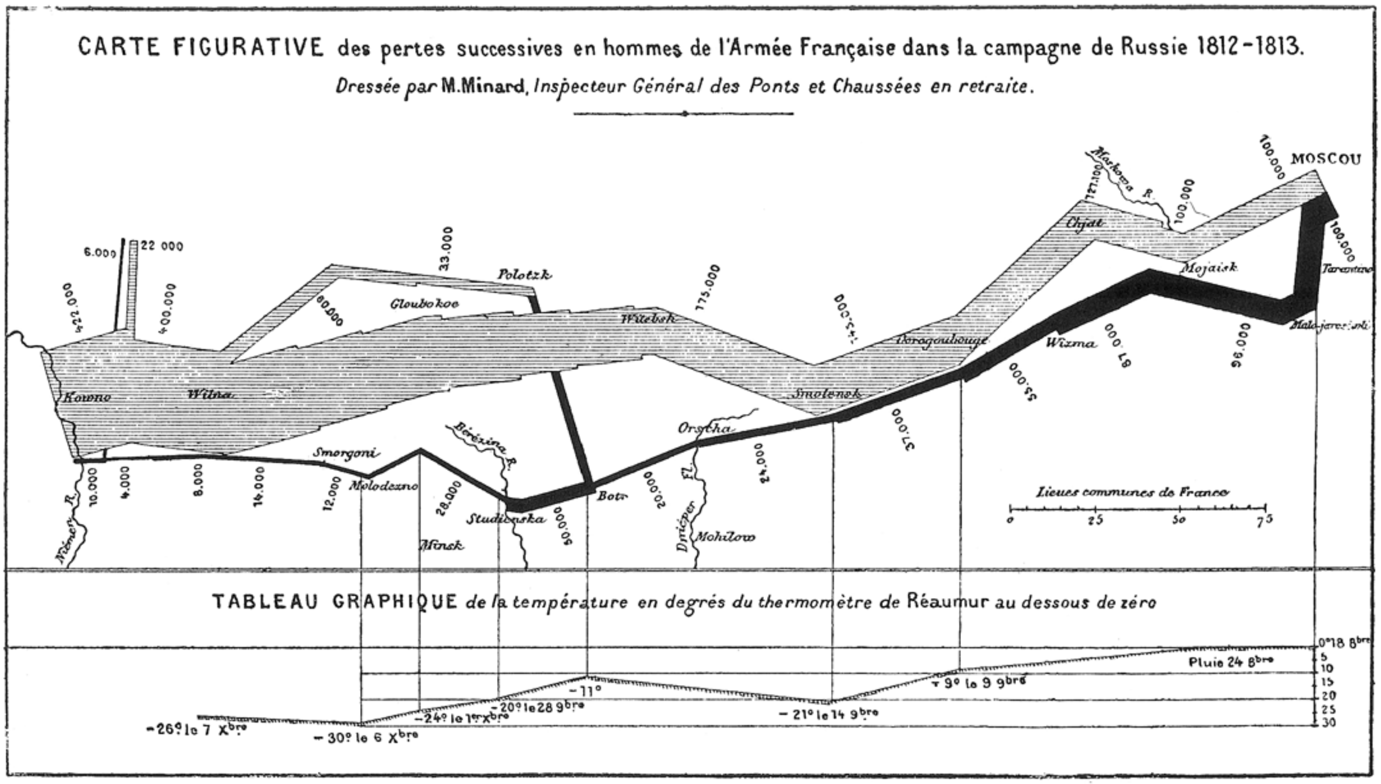
Narrative Graphics of Space and Time

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 1861, portrays the devastating losses suffered in Napoleon's Russian campaign of 1812. Beginning at the left on the Polish-Russian border near the Niemen River, the thick band shows the size of the army (422,000 men) as it invaded Russia in June 1812. The width of the 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.

It may well be the best statistical graphic ever drawn.

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



Xbre = December 9bre = November 8bre = October

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).

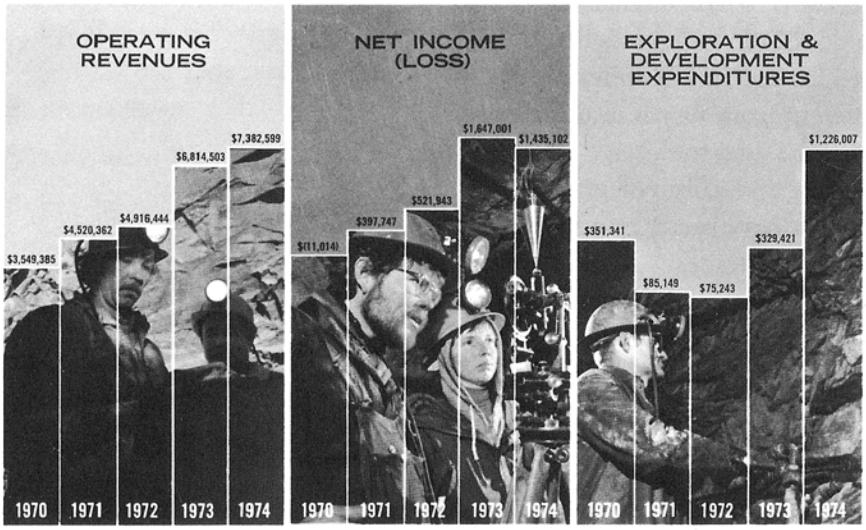
Then, in the late 1960s, John Tukey made statistical graphics respectable, putting an end to the view that graphics were only for decorating a few numbers. For here was a world-class data analyst spinning off half a dozen new designs and, more importantly, using them effectively to explore complex data.[1] 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.

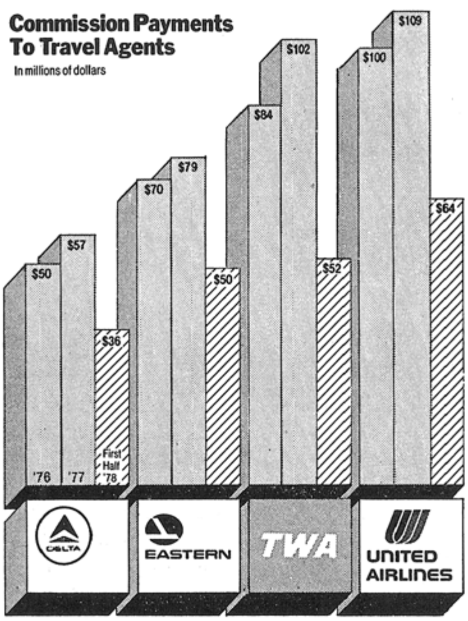
[1] John W. Tukey and Martin B. Wilk, "Data Analysis and Statistics: Techniques and Approaches," in Edward R. Tufte, ed., *The Quantitative Analysis of Social Problems* (Reading, Mass., 1970), 370–390; and John W. Tukey, "Some Graphic and Semigraphic Displays," in T. A. Bancroft, ed., *Statistical Papers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



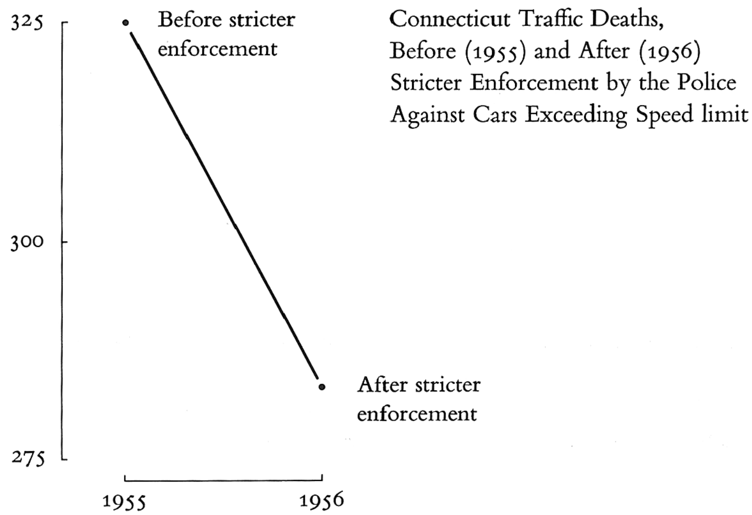
New York Times, August 8, 1978, p. D-1.

Context is Essential for Graphical Integrity

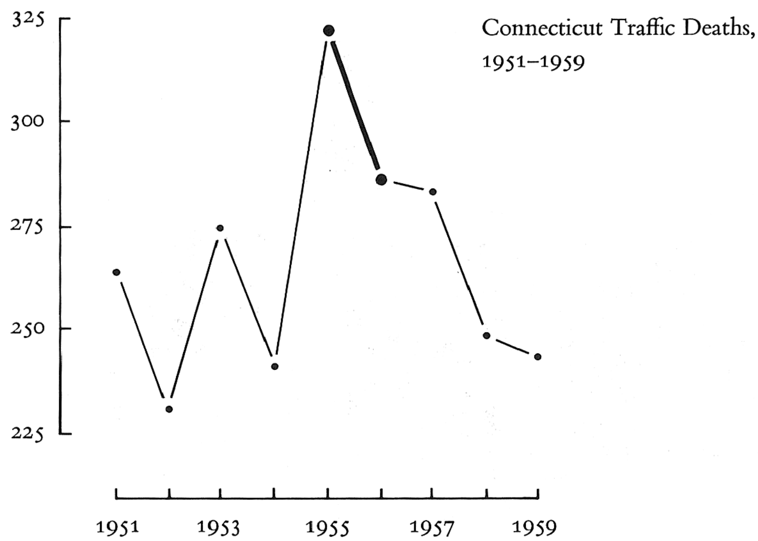
To be truthful and revealing, data graphics must bear on the question at the heart of quantitative thinking: "Compared to what?" The emaciated, data-thin design should always provoke suspicion, for graphics often lie by omission, leaving out data sufficient for comparisons. The principle:

Graphics must not quote data out of context.

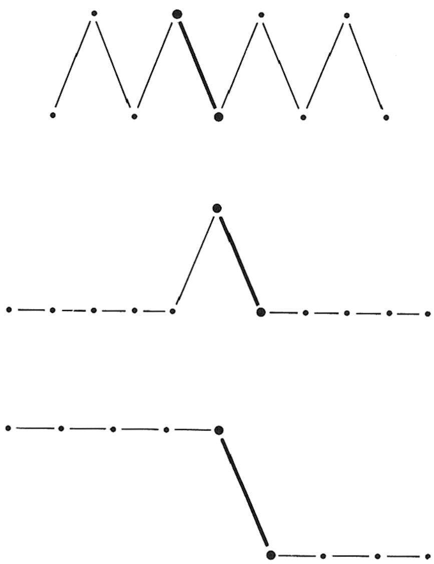
Nearly all the important questions are left unanswered by this display:



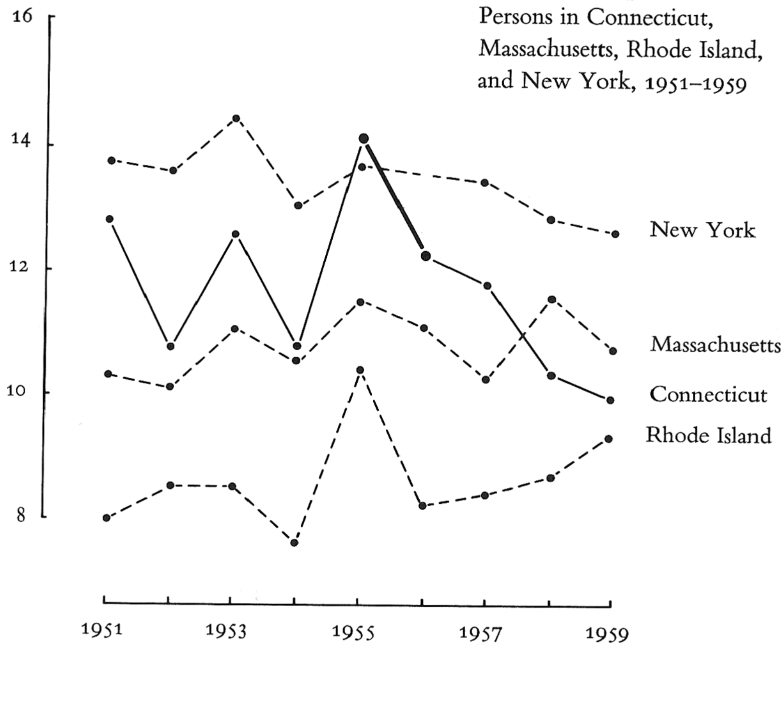
A few more data points add immensely to the account:



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:



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

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, Mass., 1970), 110–125.

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 then 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 1930's 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), p. 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, p. 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), pp. 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]

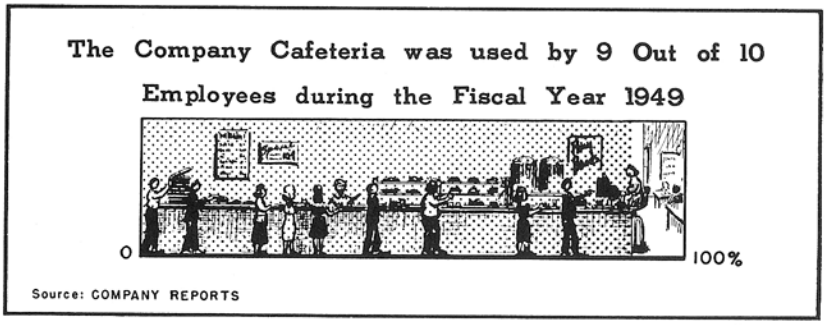
[5] *Consumer Reports*, 45 (July 1980), 408.

[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), p. 5, who appropriately describes this as an "unnecessary chart."

The Consequences

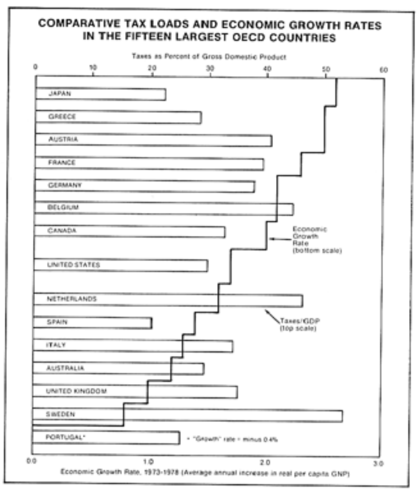
What E. B. White said of writing is also true of statistical graphics: "No one can write decently who is distrustful of the reader's intelligence, or whose attitude is patronizing."[8] Contempt for graphics and their audience, along with the lack of quantitative skills among illustrators, has deadly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

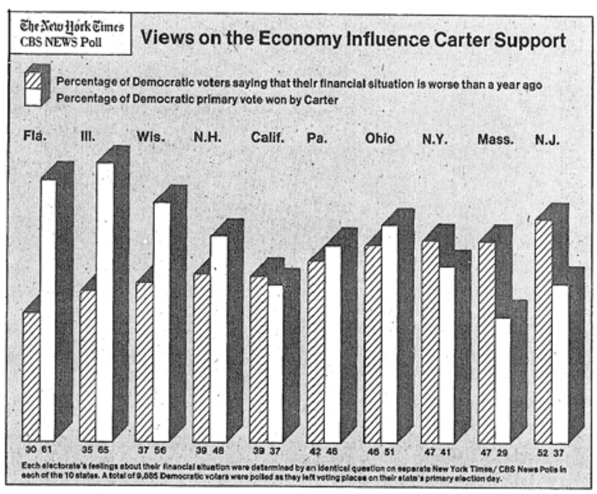
[8] In William Strunk, Jr., and E. B. White, *The Elements of Style* (New York, 1959), p. 70.

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, p. A-18.

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





Data-Ink

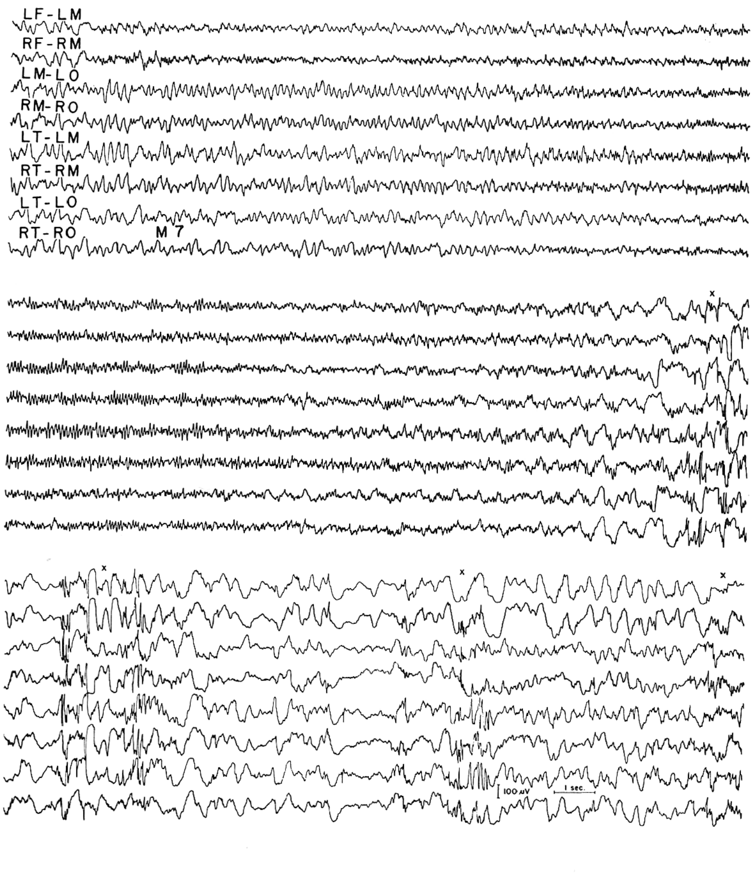
A large share of ink on a graphic should present data-information, the ink changing as the data change. *Data-ink* is the non-erasable core of a graphic, the non-redundant ink arranged in response to variation in the numbers represented. Then,

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

$$= \text{proportion of a graphic's ink devoted to the non-redundant display of data-information}$$

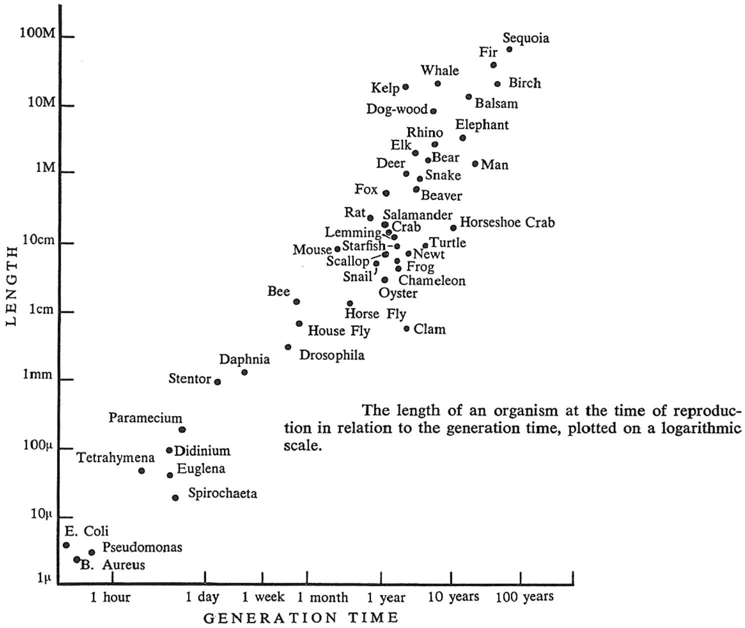
$$= 1.0 - \text{proportion of a graphic that can be erased without loss of data-information.}$$

A few graphics use every drop of their ink to convey measured quantities. Nothing can be erased without losing information in these continuous eight tracks of an electroencephalogram. The data change from background activity to a series of polyspike bursts. Note the scale in the bottom block, lower right:



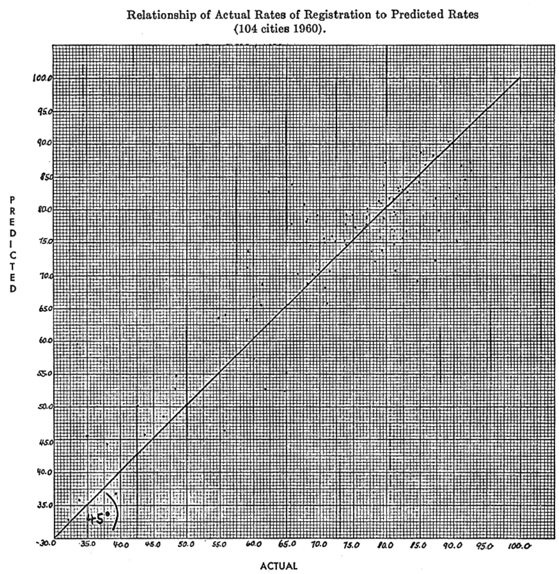
Kenneth A. Kooi, *Fundamentals of Electroencephalography* (New York, 1971), p. 110.

Most of the ink in this graphic is data-ink (the dots and labels on the diagonal), with perhaps 10–20 percent non-data-ink (the grid ticks and the frame):

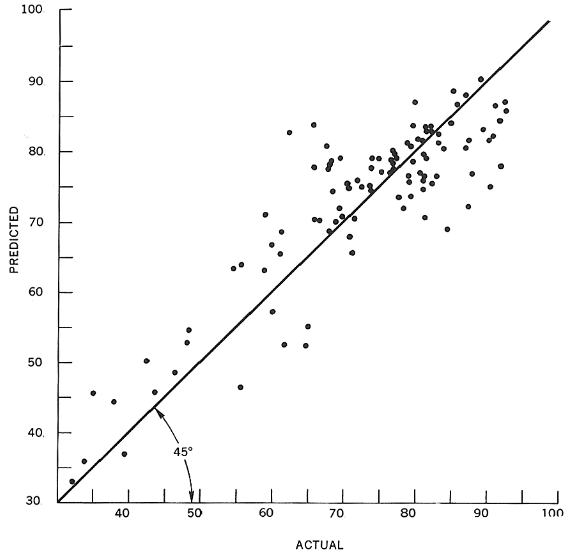


John Tyler Bonner, *Size and Cycle: An Essay on the Structure of Biology* (Princeton, 1965), p. 17.

In this display with nearly all its ink devoted to matters other than data, the grid sea overwhelms the numbers (the faint points scattered about the diagonal):



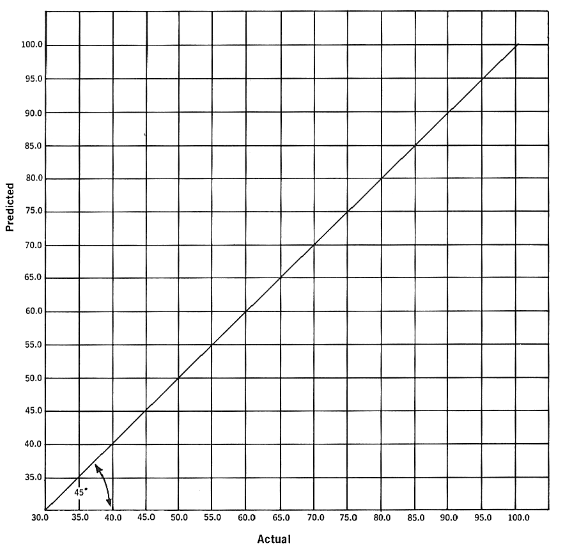
Another published version of the same data drove the share of data-ink up to about 0.7, an improvement:



Relationship of Actual Rates of Registration to Predicted Rates (104 cities 1960).

But a third reprint publication of the same figure forgot to plot the points and simply retraced the grid lines from the original, including the excess strip of grid along the top and right margins. The resulting figure achieves a graphical absolute zero, a null data-ink ratio:

Figure 19.1 Relationship of Actual Rates of Registration to Predicted Rates (104 cities, 1960)



The three graphics were published in, respectively, Stanley Kelley, Jr., Richard E. Ayres, and William G. Bowen, "Registration and Voting: Putting First Things First," *American Political Science Review*, 61 (1967), 371; then reprinted in Edward R. Tufte, ed., *The Quantitative Analysis of Social Problems* (Reading, Mass., 1970), p. 267; and reprinted again in William J. Crotty, ed., *Public Opinion and Politics: A Reader* (New York, 1970), p. 364.

Maximizing the Share of Data-Ink

The larger the share of a graphic's ink devoted to data, the better (other relevant matters being equal):

Maximize the data-ink ratio, within reason.

Every bit of ink on a graphic requires a reason. And nearly always that reason should be that the ink presents new information.

The principle has a great many consequences for graphical editing and design. The principle makes good sense and generates reasonable graphical advice—for perhaps two-thirds of all statistical graphics. For the others, the ratio is ill-defined or is just not appropriate. Most important, however, is that other principles bearing on graphical design follow from the idea of maximizing the share of data-ink.

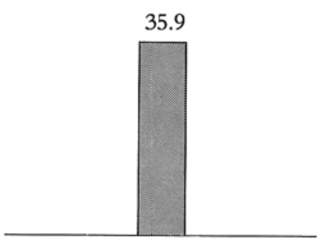
Two Erasing Principles

The other side of increasing the proportion of data-ink is an erasing principle:

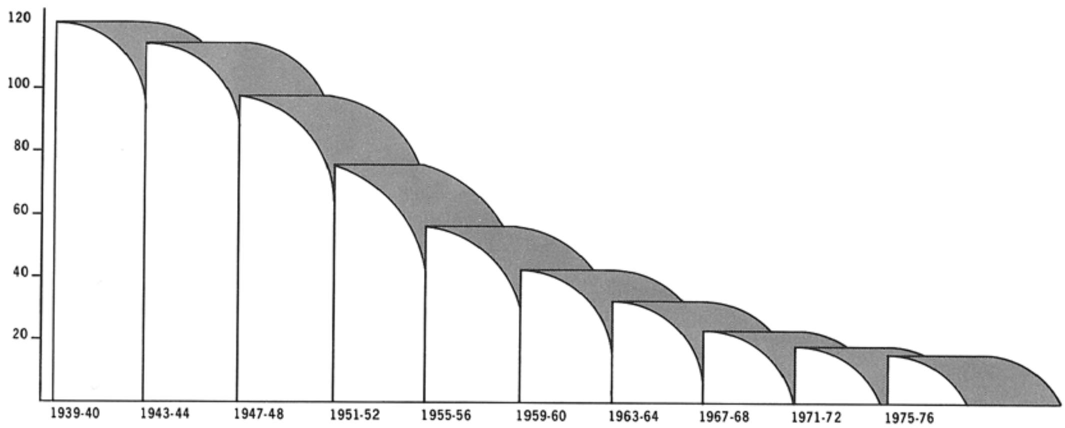
Erase non-data-ink, within reason.

Ink that fails to depict statistical information does not have much interest to the viewer of a graphic; in fact, sometimes such non-data-ink clutters up the data, as in the case of a thick mesh of grid lines. While it is true that this boring ink sometimes helps set the stage for the data action, it is surprising, as we shall see in Chapter 7, how often the data themselves can serve as their own stage.

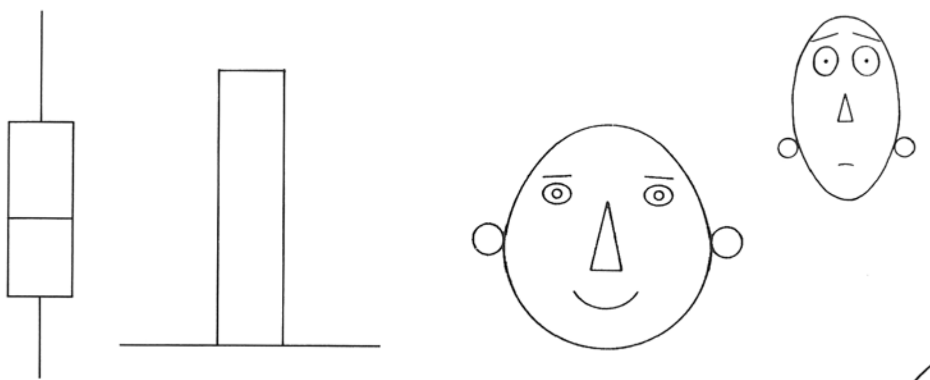
Redundant data-ink depicts the same number over and over. The labeled, shaded bar of the bar chart, for example,



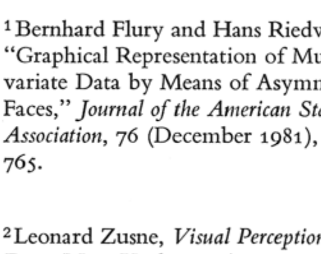
unambiguously locates the altitude in six separate ways (any five of the six can be erased and the sixth will still indicate the height): as the (1) height of the left line, (2) height of shading, (3) height of right line, (4) position of top horizontal line, (5) position (not content) of number at bar's top, and (6) the number itself. That is more ways than are needed. Gratuitous decoration and reinforcement of the data measures generate much redundant data-ink:



Bilateral symmetry of data measures also creates redundancy, as in the box plot, the open bar, and Chernoff faces:



Half-faces carry the same information as full faces. Halves may be easier to sort (by matching the right half of an unsorted face to the left half of a sorted face) than full faces. Or else an asymmetrical full face can be used to report additional variables.[1]

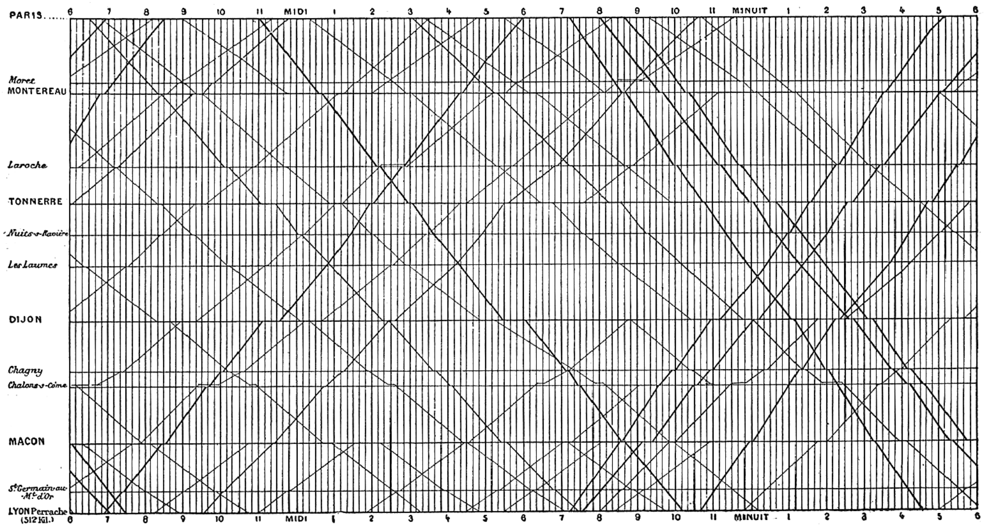


Bilateral symmetry doubles the space consumed by the design in a graphic, without adding new information. The few studies done on the perception of symmetrical designs indicate that "when looking at a vase, for instance, a subject would examine one of its symmetric halves, glance at the other half and, seeing that it was identical, cease his explorations. . . . The enjoyment of symmetry . . . lies not with the physical properties of the figure. At least eye movements suggest anything but symmetry, balance, or rest."[2]

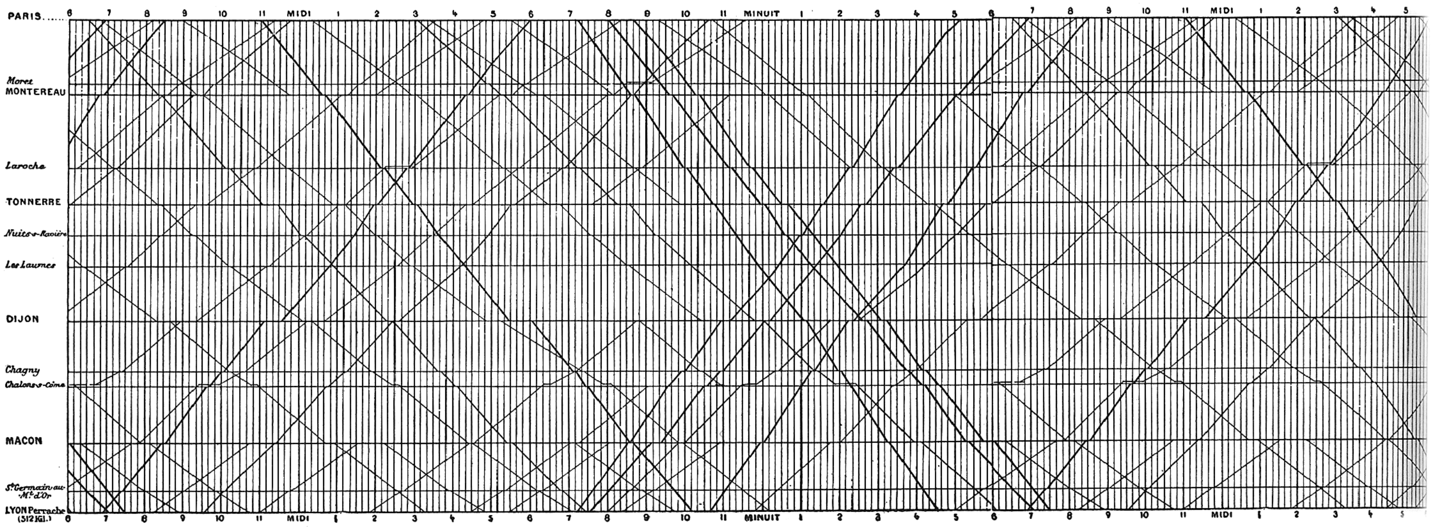
[1] Bernhard Flury and Hans Riedwyl, "Graphical Representation of Multivariate Data by Means of Asymmetrical Faces," *Journal of the American Statistical Association*, 76 (December 1981), 757–765.

[2] Leonard Zusne, *Visual Perception of Form* (New York, 1970), pp. 256–257.

Redundancy, upon occasion, has its uses: giving a context and order to complexity, facilitating comparisons over various parts of the data, perhaps creating an aesthetic balance. In cyclical time-series, for example, parts of the cycle should be repeated so that the eye can track any part of the cycle without having to jump back to the beginning. Such redundancy possibly improves Marey's 1880 train schedule. Those people leaving Paris or Lyon in the evening find that their trains run off the right-hand edge of the chart, to be picked up on the left again:

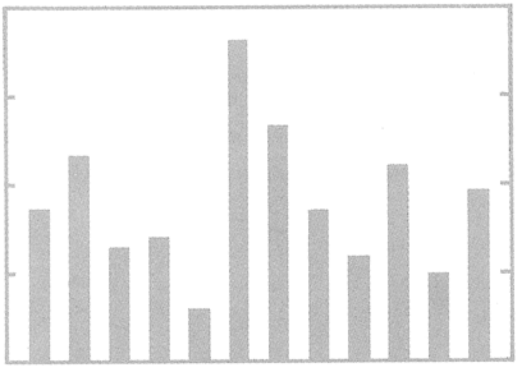


Attaching an extra half cycle makes every train in the first 24 hours of the schedule a continuous line (as would mounting the original on a cylinder):

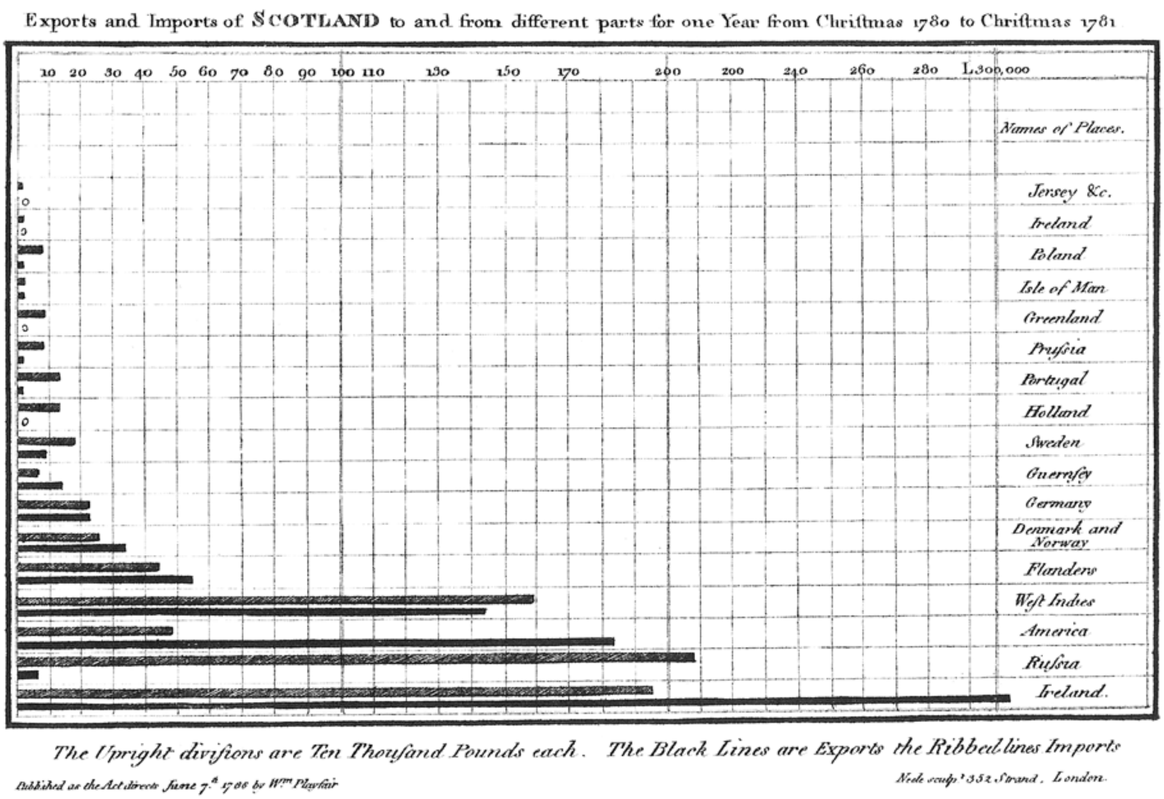


Redesign of the Bar Chart/Histogram

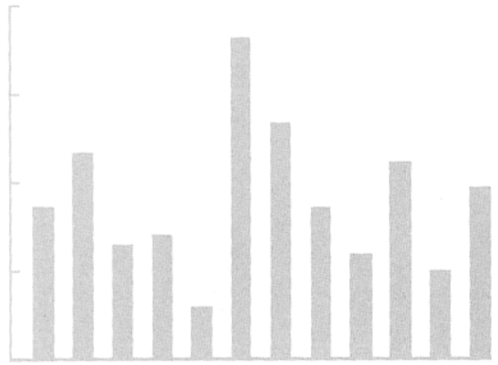
Here is the standard model bar chart, with the design endorsed by the practices and the style sheets of many statistical and scientific publications:



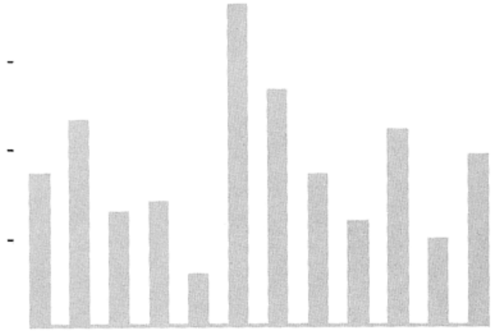
Its architecture differs little from Playfair's original design:



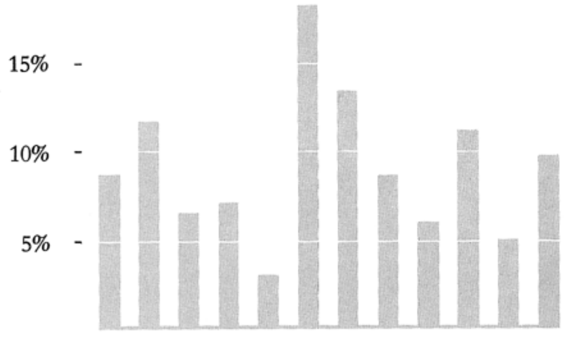
The box can be erased:



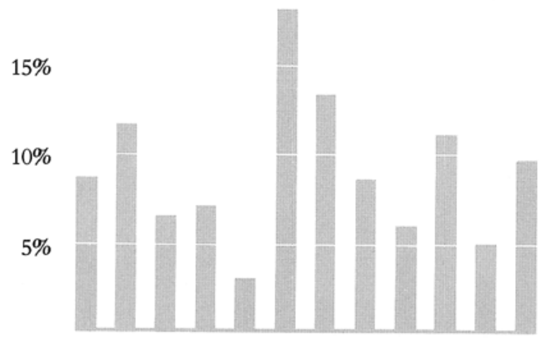
And the vertical axis, except for the ticks:



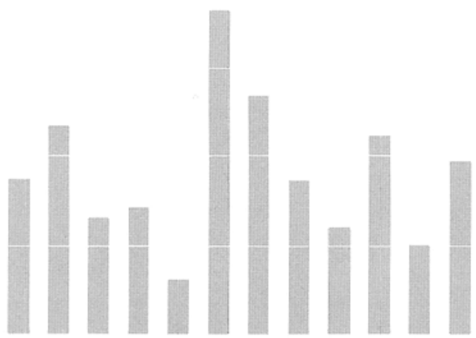
Even part of the data measures can be erased, making a *white grid*, which shows the coordinate lines more precisely than ticks alone:



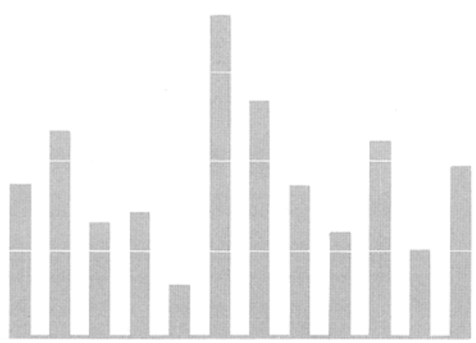
The white grid eliminates the tick marks, since the numerical labels on the vertical are tied directly to the white lines:



Although the intersection of the thicker bar with the thinner baseline creates an attractive visual effect (but also the optical illusion of gray dots at the intersections), the baseline can be erased since the bars define the end-point at the bottom:



Still, a thin baseline looks good:



7 *Multifunctioning Graphical Elements*

The same ink should often serve more than one graphical purpose. A graphical element may carry data information and also perform a design function usually left to non-data-ink. Or it might show several different pieces of data. Such *multifunctioning graphical elements*, if designed with care and subtlety, can effectively display complex, multivariate data.[1]

Consider, for example, the multifunctioning blot of the blot map. It simultaneously locates the geographic unit on a two-dimensional surface, describes the shape of the geographic unit, and indicates the level of the variable displayed by color or intensity of shading. That is a great deal of information for a small patch of ink—and the different pieces of information are not confounded and mixed together.

In contrast, the conventional graphical frame performs only a modest design function, the separation of the grid and data measures from the labels. And it is a place to hang the grid ticks. With all that ink doing so little, it is a prime candidate for mobilization as a double-functioning graphical element. Hence the range-frame, the quartile frame, and the dot-dash-plot.

The principle, then, is:

> Mobilize every graphical element, perhaps several times over, to show the data.

The danger of multifunctioning elements is that they tend to generate graphical puzzles, with encodings that can only be broken by their inventor. Thus design techniques for enhancing graphical clarity in the face of complexity must be developed along with multifunctioning elements.

[1] The idea of double-functioning elements appears in architectural criticism; see Robert Venturi, *Complexity and Contradiction in Architecture* (New York, second edition, 1977), ch. 5. Venturi in turn cites Wylie Sypher, *Four Stages of Renaissance Style* (Garden City, N.Y., 1955).

Data-Built Data Measures

The graphical element that actually locates or plots the data is the *data measure*. The bars of a bar chart, the dots of a scatterplot, the dots and dashes of a dot-dash-plot, the blots of a blot map are data measures. The ink of the data measure can itself carry data; for example, the dots of the scatterplot can take on different shadings in response to a third variable.

Building data measures out of the data increases the quantitative detail and dimensionality of a graphic. The stem-and-leaf plot constructs the distribution of a variable with numbers themselves:

0 | 9 = 900 feet

Stem-and-leaf displays:
heights of 218 volcanoes, unit 100 feet.

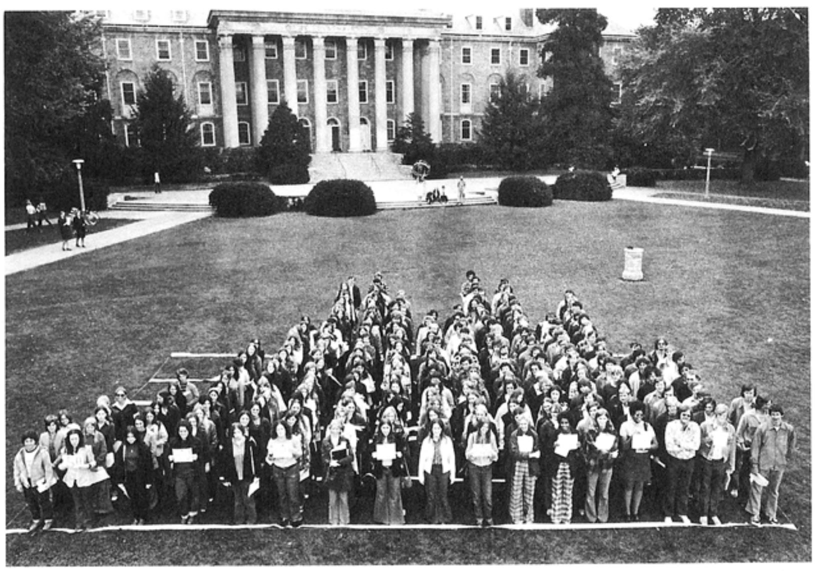
19 | 3 = 19,300 feet

0	98766562
1	97719630
2	69987766544422211009850
3	876655412099551426
4	9998844331929433361107
5	97666666554422210097731
6	898665441077761065
7	98855431100652108073
8	653322122937
9	377655421000493
10	0984433165212
11	4963201631
12	45421164
13	47830
14	00
15	676
16	52
17	92
18	5
19	39730

The idea of making every graphical element effective was behind the design of the stem-and-leaf plot. In presenting his invention, John Tukey wrote: "If we are going to make a mark, it may as well be a meaningful one. The simplest—and most useful—meaningful mark is a digit."[2]

[2] "Some Graphic and Semigraphic Displays," in T. A. Bancroft, ed., *Statistical Papers in Honor of George W. Snedecor* (Ames, Iowa, 1972), p. 296.

Here, too, the data form the data measure. Note the bimodal distribution in the histogram of college students arranged by height.



Brian L. Joiner, "Living Histograms," *International Statistical Review*, 43 (1975), 339–340.

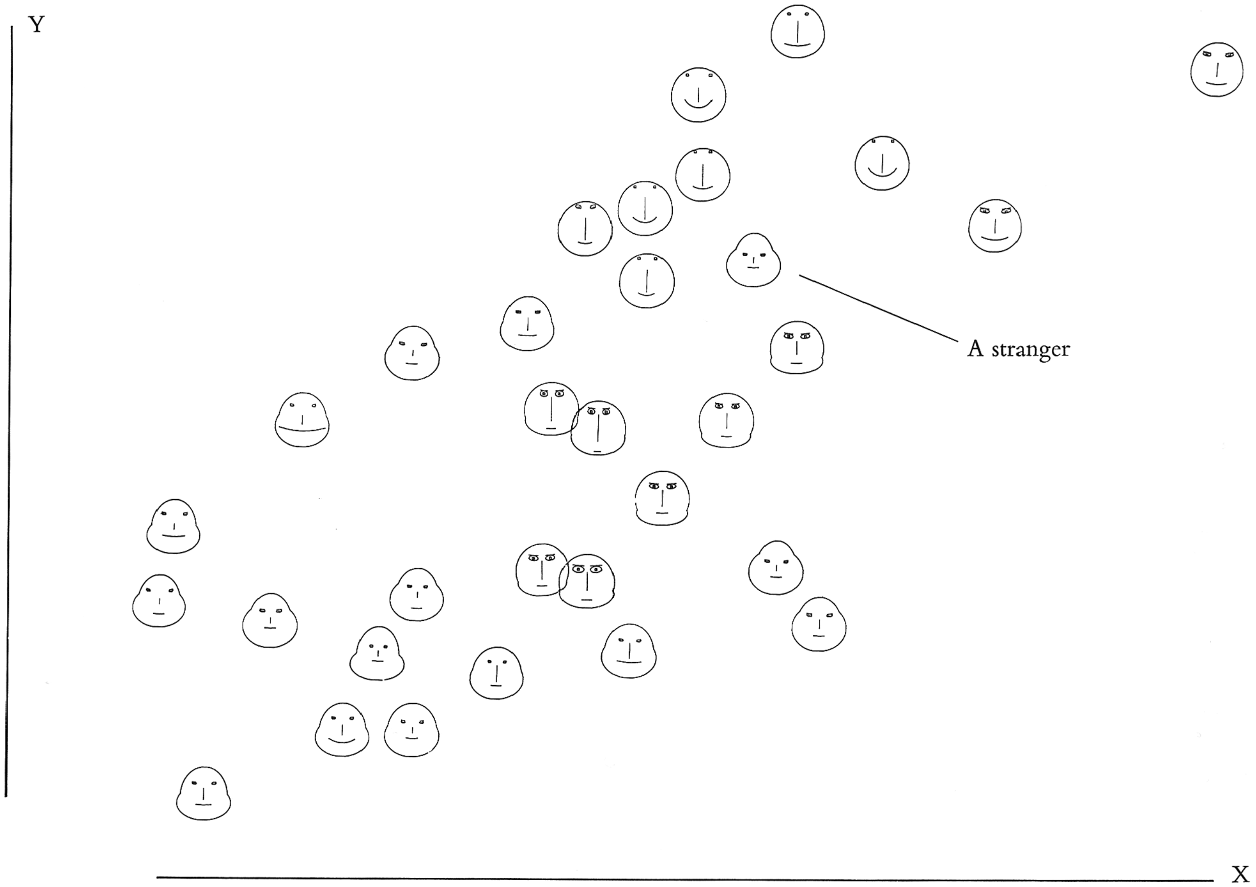
A distinguished graphic that builds data measures out of data was designed by Colonel Leonard P. Ayres for his statistical history of World War I, a book with several notable graphics all done by typewriter and rule. Constructing the data measures out of each American division's name (a numerical designation) turns what might have been a routine time-series into an elegant display. (Note that the cumulative design depends on the fact that none of the divisions returned before October 1918.) The triple-functioning data measure shows: (1) the number of divisions in France for each month, June 1917 to October 1918; (2) what particular divisions were in France in each month; and (3) the duration of each division's presence in France.

Leonard P. Ayres, *The War with Germany* (Washington, D.C., 1919), p. 102.

																8
																38
																31
															34	34
															86	86
															84	84
															87	87
														40	40	40
														39	39	39
														88	88	88
														81	81	81
														7	7	7
														85	85	85
													36	36	36	36
													91	91	91	91
													79	79	79	79
													76	76	76	76
												29	29	29	29	29
												37	37	37	37	37
												90	90	90	90	90
												92	92	92	92	92
												89	89	89	89	89
												83	83	83	83	83
												78	78	78	78	78
											80	80	80	80	80	80
											30	30	30	30	30	30
											33	33	33	33	33	33
											6	6	6	6	6	6
											27	27	27	27	27	27
											4	4	4	4	4	4
											28	28	28	28	28	28
											35	35	35	35	35	35
											82	82	82	82	82	82
										77	77	77	77	77	77	77
									3	3	3	3	3	3	3	3
									5	5	5	5	5	5	5	5
								32	32	32	32	32	32	32	32	32
						41	41	41	41	41	41	41	41	41	41	41
					42	42	42	42	42	42	42	42	42	42	42	42
			26	26	26	26	26	26	26	26	26	26	26	26	26	26
		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
			1917									1918				

Encoding of data measures can be far more elaborate. The plotted points here are Chernoff faces, which reduce well, maintaining legibility even with individual areas of .05 square inches as shown.[3] The analyst would observe the standard X-Y scatterplot and then turn to the within-scatter detail, seeking clusters of similar observations over the X-Y plane. Outlying faces and those inconsistent with others in the neighborhood—they are, of course, *strangers*—should be identified by observation number or name.

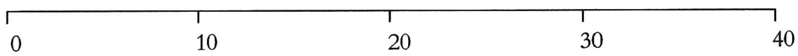
[3] Herman Chernoff, "The Use of Faces to Represent Points in k-Dimensional Space Graphically," *Journal of the American Statistical Association* 68 (June 1973), 361–368. For an application of faces located over two dimensions, see Howard Wainer and David Thissen, "Graphical Data Analysis," *Annual Review of Psychology*, 32 (1981), 191–241.



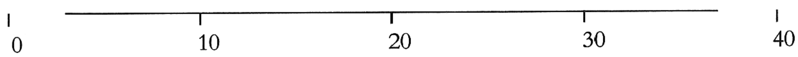
With cartoon faces and even numbers becoming data measures, we would appear to have reached the limit of graphical economy of presentation, imagination, and, let it be admitted, eccentricity.

Double-Functioning Labels

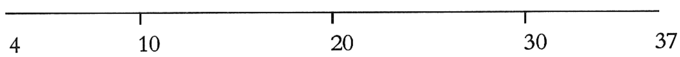
Data-based coordinate lines lead to *data-based labels*, as, for example, at the bottom of Playfair's debt graphic. Again, the issue is the same: why not use the ink to show data? Beginning with conventionally labeled frame



and erasing to the range-frame



leaves those lonely ticks and numbers out on the tails, working to help the eye get a better reading on where the line of the range-frame ends. But that job can be done better by investing the same ink in data: rather than showing the minimum round number and the maximum round number at the ends of the frame, show the actual minimum and maximum realized in the data:



With its greater precision and two tick-marks less of non-data-ink, the range-frame with range-labels is superior to the range-frame with round number labels. Both improve on the standard, passive frame.

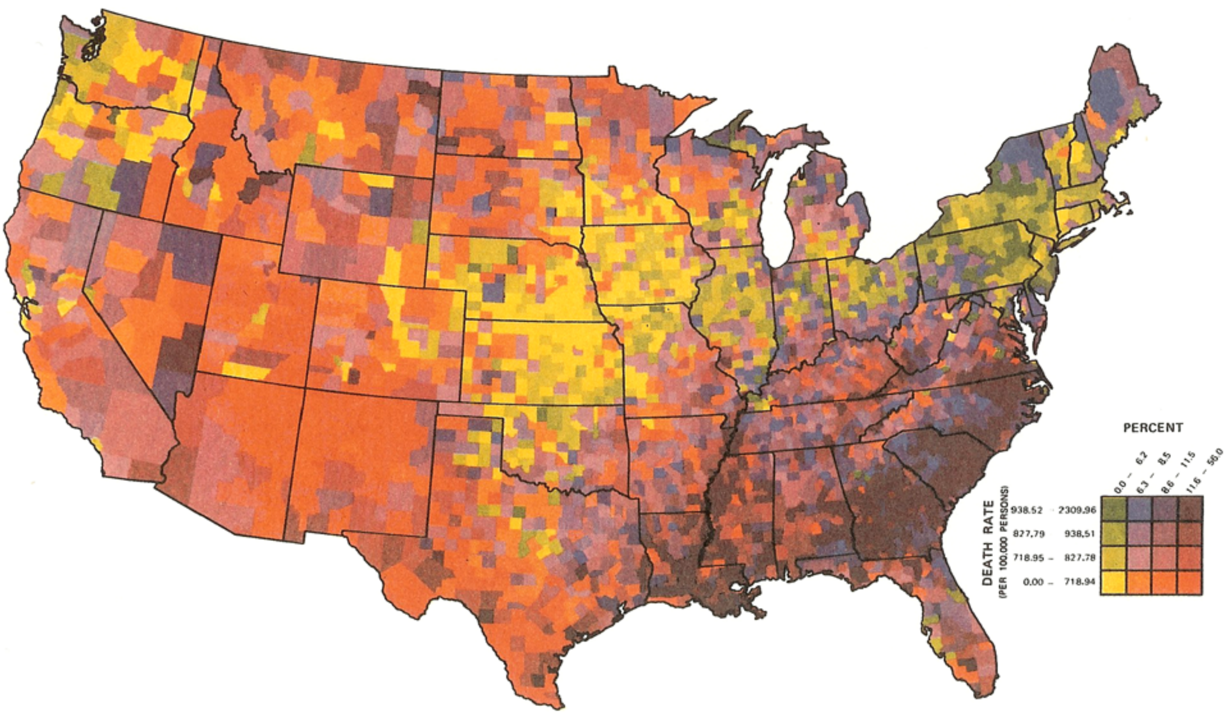
Numbers also double-function when used both to name things (like an identification number) and to reflect an ordering. In this graphic (in which the circled numbers fail to double-function), each number identifies a particular study of the thermal conductivity of tungsten, ordered alphabetically by the last name of the first author. If that list were ordered by date of publication instead, then the code would also indicate the time order in which

Puzzles and Hierarchy in Graphics

The complexity of multifunctioning elements can sometimes turn data graphics into visual puzzles, crypto-graphical mysteries for the viewer to decode. A sure sign of a puzzle is that the graphic must be interpreted through a verbal rather than a visual process.

For example, despite its clever and multifunctioning data measure, formed by crossing two four-color grids, this is a puzzle graphic. Deployed here, in a feat of technological virtuosity, are 16 shades of color spread on 3,056 counties, a monument to a sophisticated computer graphics system.[4] But it is surely a graphic experienced verbally, not visually. Over and over, the viewers must run little phrases through their minds, trying to maintain the right pattern of words to make sense out of the visual montage: "Now let's see, purple represents counties where there are both high levels of male cardiovascular disease mortality *and* 11.6 to 56.0 percent of the households have more than 1.01 persons per room. . . . What does that mean anyway? . . . And the yellow-green counties. . . ." By contrast, in a non-puzzle graphic, the translation of visual to verbal is quickly learned, automatic, and implicit—so that the visual image flows right *through* the verbal decoder initially necessary to understand the graphic. As Paul Valéry wrote, "Seeing is forgetting the name of the thing one sees."

[4] The technique is described in Vincent P. Barabba and Alva L. Finkner, "The Utilization of Primary Printing Colors in Displaying More than One Variable," in Bureau of the Census, Technical Paper No. 43, *Graphical Presentation of Statistical Information* (Washington, D.C., 1978), 14–21. The maps are assessed in Howard Wainer and C. M. Francolini, "An Empirical Inquiry Concerning Human Understanding of Two-Variable Color Maps," *American Statistician*, 34 (1980), 81–93.



Color often generates graphical puzzles. Despite our experiences with the spectrum in science textbooks and rainbows, the mind's eye does not readily give a visual ordering to colors, except possibly for red to reflect higher levels than other colors, as in the hot spots of the cancer map. Attempts to give colors an order result in those verbal decoders and the mumbling of little mental phrases again—indeed, even mnemonic phrases *about* the phrases required for graphical decoding:

> A method of coloring ingenious in idea but not very satisfactory in practice was used by L. L. Vauthier. It was called the mountain-to-the-sea method. White was used for the representation of the greatest intensity of the fact because it indicated the summit of a mountain with its eternal snow, next came green representing the forests farther down the slopes, then yellow for the grain of the plains, and finally for the minimum the blue of the waters at sea level.[5]

[5] H. Gray Funkhouser, "Historical Development of the Graphical Representation of Statistical Data," *Osiris*, 3 (1937), 326, who cites É. Cheysson, "Les méthodes de statistique graphique à l'Exposition universelle de 1878," *Journal de la Société de Statistique de Paris*, 19 (1878), 331.

Because they do have a natural visual hierarchy, varying shades of gray show varying quantities better than color. Ten gray shades worked effectively in the galaxies map:

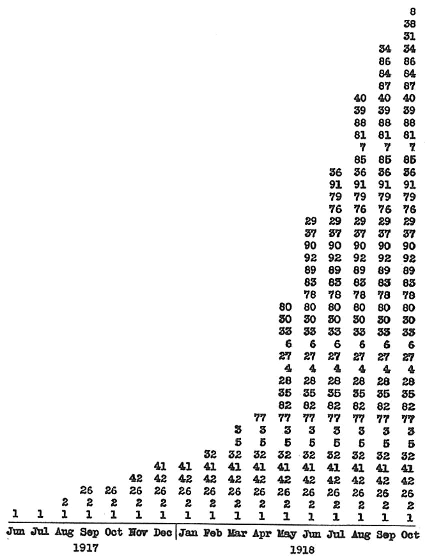
The success of gray compared to the visually more spectacular color gives us a lead on how multifunctioning graphical elements can communicate complex information without turning into puzzles. The shades of gray provide an easily comprehended order to the data measures. This is the key. Central to maintaining clarity in the face of the complex are graphical methods that *organize and order the flow of graphical information* presented to the eye.

How can graphical architecture promote the ordered, sequenced, hierarchical flow of information from the graphic to the mind's eye? How can the data-information be arranged so that the viewer is able to peel back layer after layer of data from a graphic?

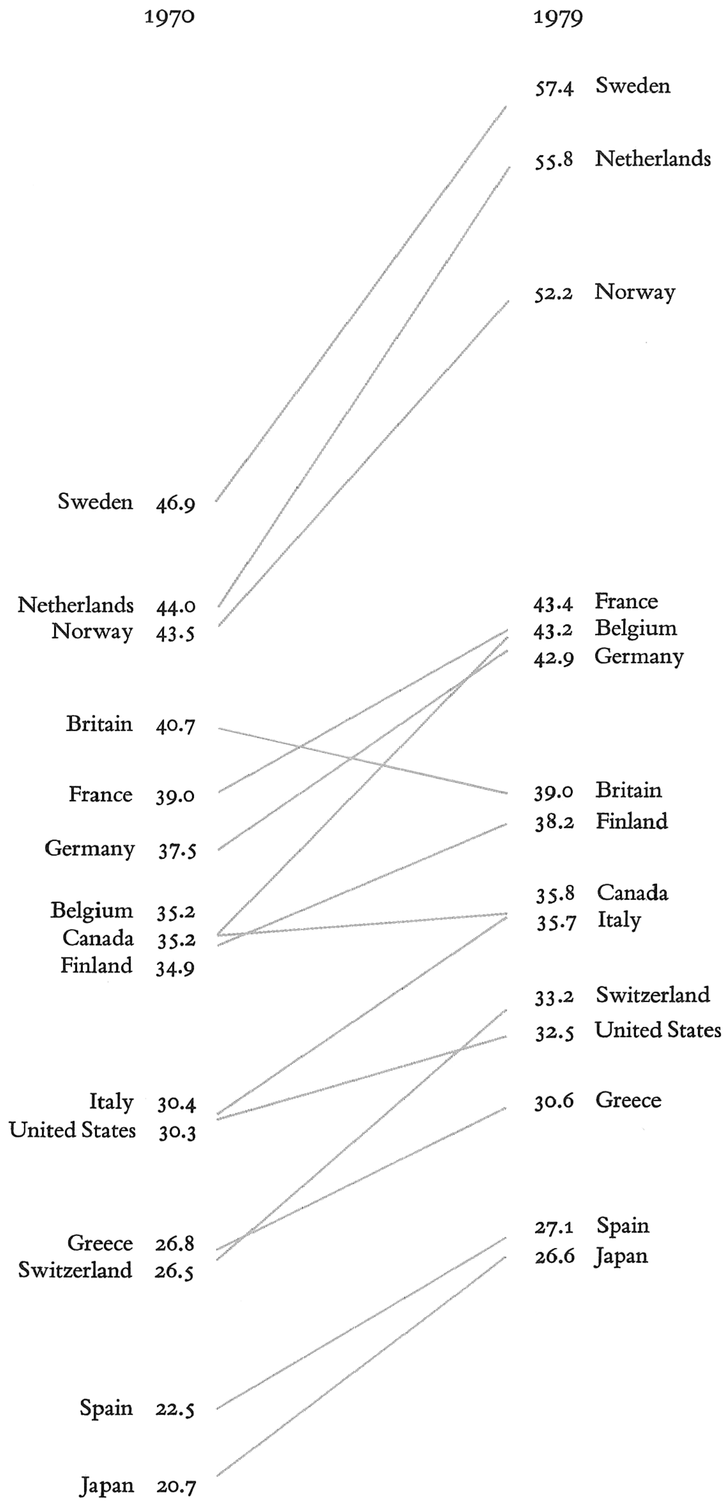
Multiple layers of information are created by *multiple viewing depths* and *multiple viewing angles*.

Graphics can be designed to have at least three viewing depths: (1) what is seen from a distance, an overall structure usually aggregated from an underlying microstructure; (2) what is seen up close and in detail, the fine structure of the data; and (3) what is seen implicitly, underlying the graphic—that which is behind the graphic. Look at all the different levels of detail created by this population density map of the United States, a glory of modern cartography prepared by the Bureau of the Census. Each dot, except in urban centers, represents 500 people. Note the corridors connecting the major urban complexes; the effects of landforms on the population distribution (the central valley of California, the valleys and ridges of Appalachia, and the clusters along rivers); and the small towns along the highways, linked like a string of pearls. The map arrays, in effect, some 400,000 points on its implicit grid.

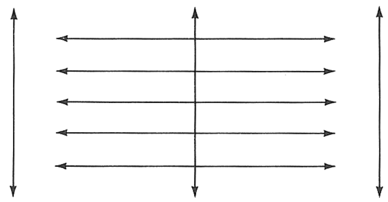
Different visual angles for different aspects of the data also organize graphical information. Each separate line of sight should remain unchanging (preferably horizontal or vertical) as the eye watches for data variation off the flat of the line of sight. For multivariate work, several clear lines can be created. Recall Ayres' display of American divisions in France. Even with its complex, interwoven data, the graphic is not a puzzle. Three separate visual angles make the flow of information coherent: the profile of the horizon for the upward-moving time-series, the vertical for the composition of the bar, and the horizontal for each division's stay. Thus while every drop of ink serves three different data display functions, each of the three comes to the eye with its own independence and integrity.



Current Receipts of Government as a Percentage of Gross Domestic Product, 1970 and 1979



Similarly, this table-graphic organizes data for viewing in several directions. The chart, when read vertically, ranks 15 countries by government tax collections in 1970 and again in 1979, with the names spaced in proportion to the percentages. Across the columns, the paired comparisons show how the numbers changed over the years. The slopes are also compared by reading down the collection of lines, and lines of unusual slope stand out from the overall upward pattern. The information shown is both integrated and separated: integrated through its connected content, separated in that the eye follows several different and uncluttered paths in looking over the data:



Such an analysis of the *viewing architecture* of a graphic will help in creating and evaluating designs that organize complex information hierarchically.