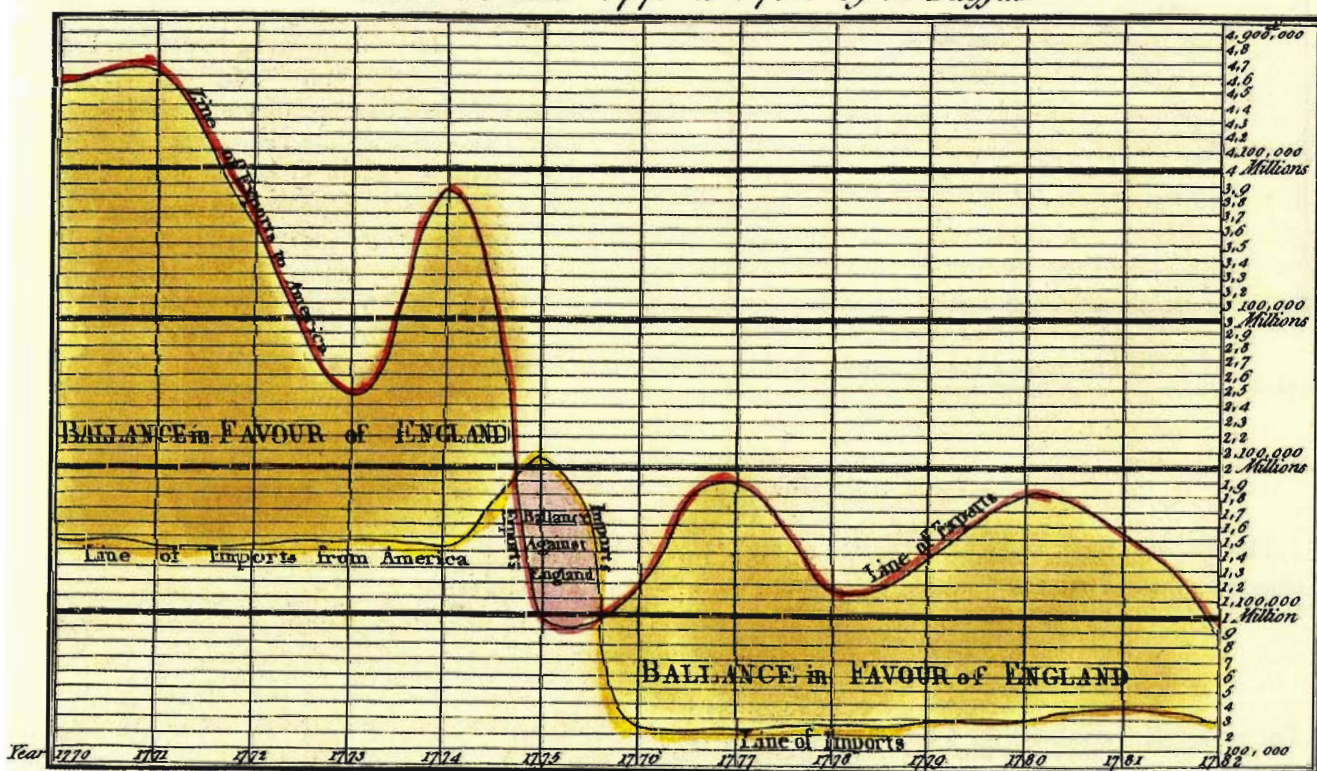


4 Data-Ink and Graphical Redesign

Data graphics should draw the viewer's attention to the sense and substance of the data, not to something else. The data graphical form should present the quantitative contents. Occasionally artfulness of design makes a graphic worthy of the Museum of Modern Art, but essentially statistical graphics are instruments to help people reason about quantitative information.

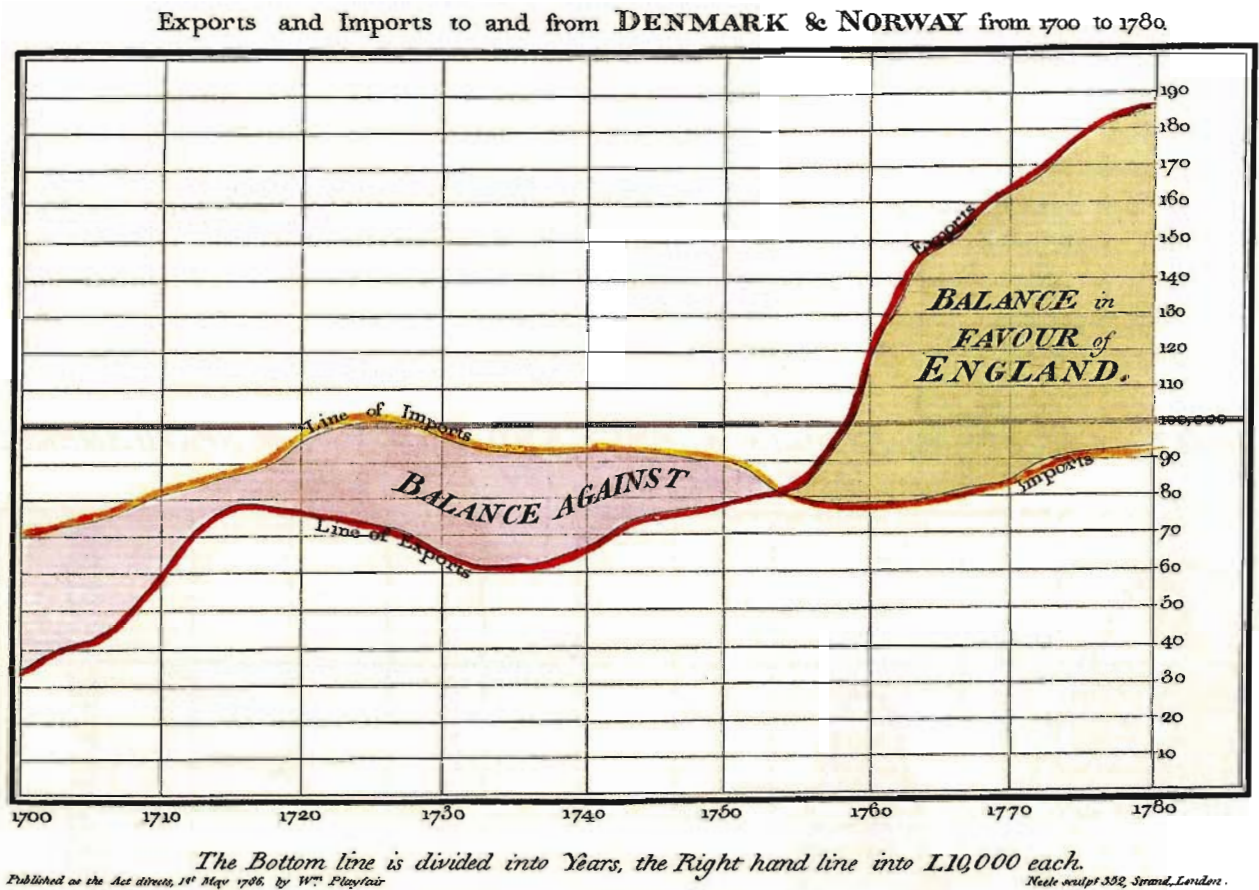
Playfair's very first charts devoted too much of their ink to graphical apparatus, with elaborate grid lines and detailed labels. This time-series, engraved in August 1785, is from the early pages of *The Commercial and Political Atlas*:

*CHART of IMPORTS and EXPORTS of ENGLAND to and from all NORTH AMERICA
From the Year 1770 to 1782 by W. Playfair*



The Bottom Line is divided into Years the right-hand Line into HUNDRED THOUSAND POUNDS

Within a year Playfair had eliminated much of the non-data detail in favor of cleaner design that focused attention on the time-series itself. He then began working with a new engraver and was soon producing clear and elegant displays:



This improvement in graphical design illustrates the fundamental principle of good statistical graphics:

Above all else show the data.

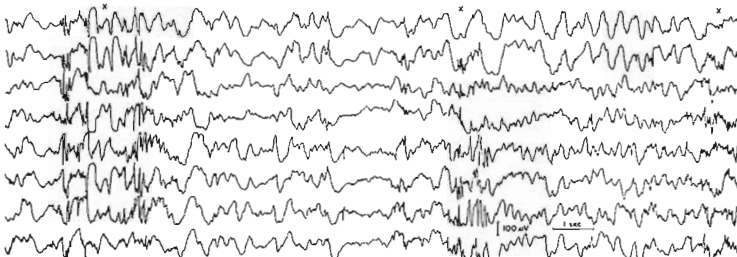
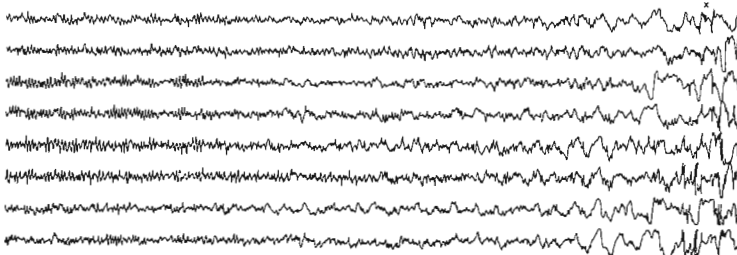
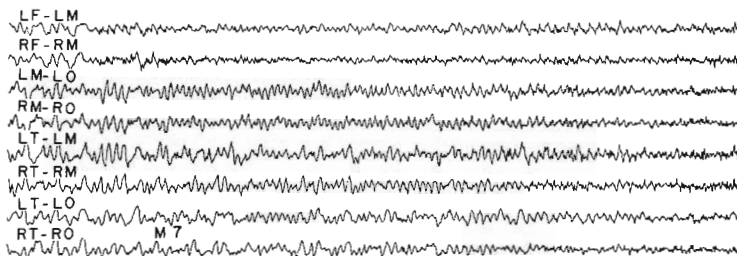
The principle is the basis for a theory of data graphics.

Data-Ink

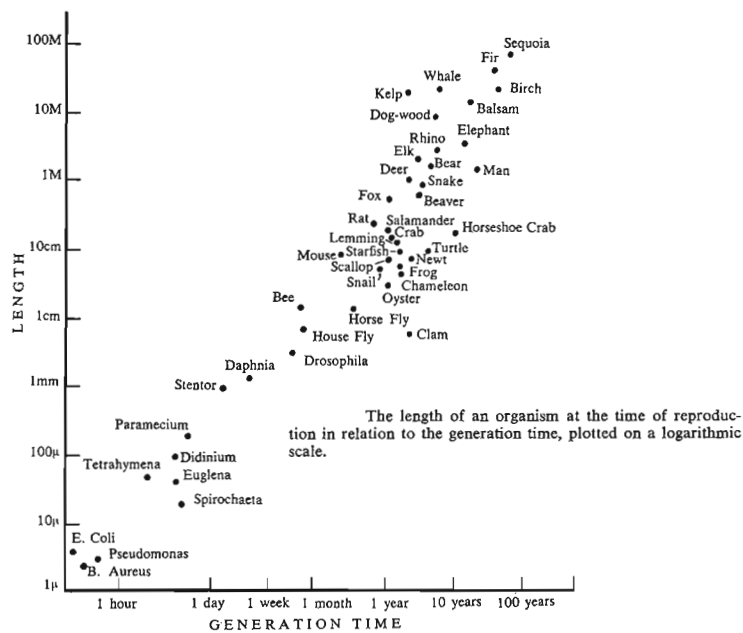
A large share of ink on a graphic should present data-information, the ink changing as the data change. *Data-ink* is the non-erasable core of a graphic, the non-redundant ink arranged in response to variation in the numbers represented. Then,

$$\begin{aligned} \text{Data-ink ratio} &= \frac{\text{data-ink}}{\text{total ink used to print the graphic}} \\ &= \text{proportion of a graphic's ink devoted to the} \\ &\quad \text{non-redundant display of data-information} \\ &= 1.0 - \text{proportion of a graphic that can be erased} \\ &\quad \text{without loss of data-information.} \end{aligned}$$

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:

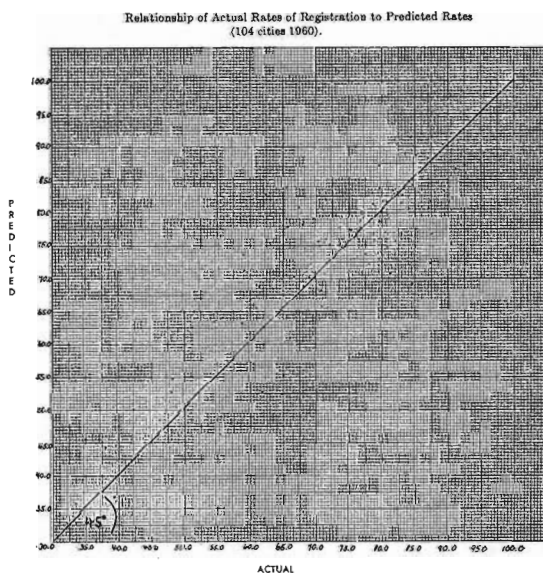


Most of the ink in this graphic is data-ink (the dots and labels on the diagonal), with perhaps 10–20 percent non-data-ink (the grid ticks and the frame):

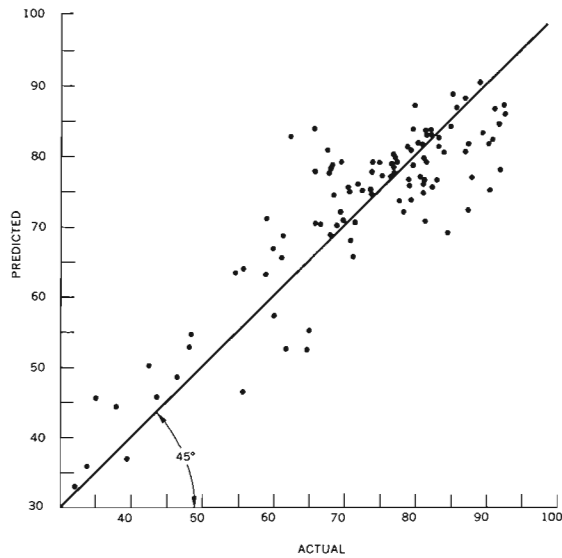


John Tyler Bonner, *Size and Cycle: An Essay on the Structure of Biology* (Princeton, 1965), p. 17.

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):



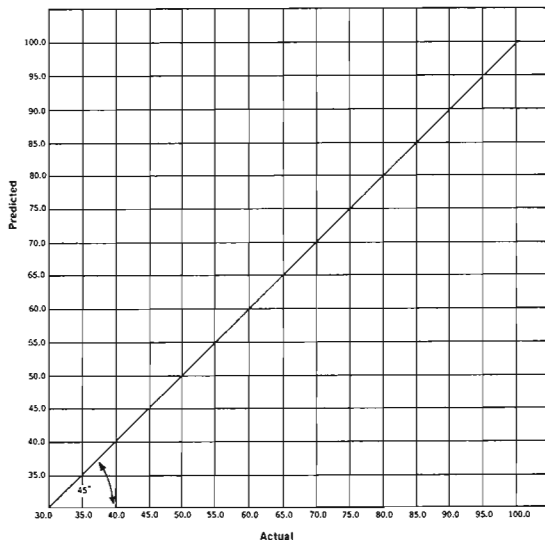
Another published version of the same data drove the share of data-ink up to about 0.7, an improvement:



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.

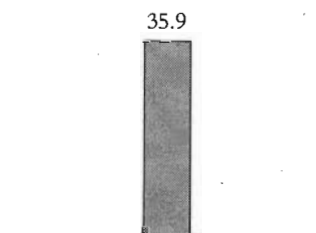
Two Erasing Principles

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

Erase non-data-ink, within reason.

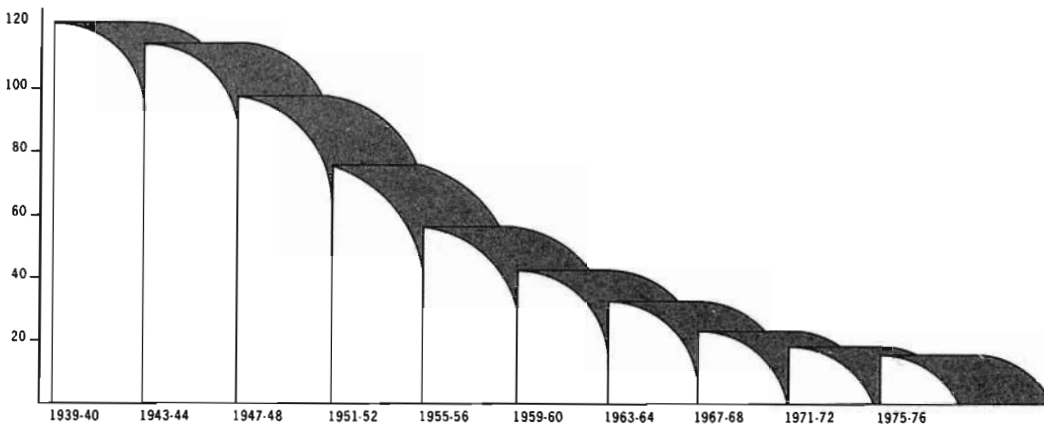
Ink that fails to depict statistical information does not have much interest to the viewer of a graphic; in fact, sometimes such non-data-ink clutters up the data, as in the case of a thick mesh of grid lines. While it is true that this boring ink sometimes helps set the stage for the data action, it 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,

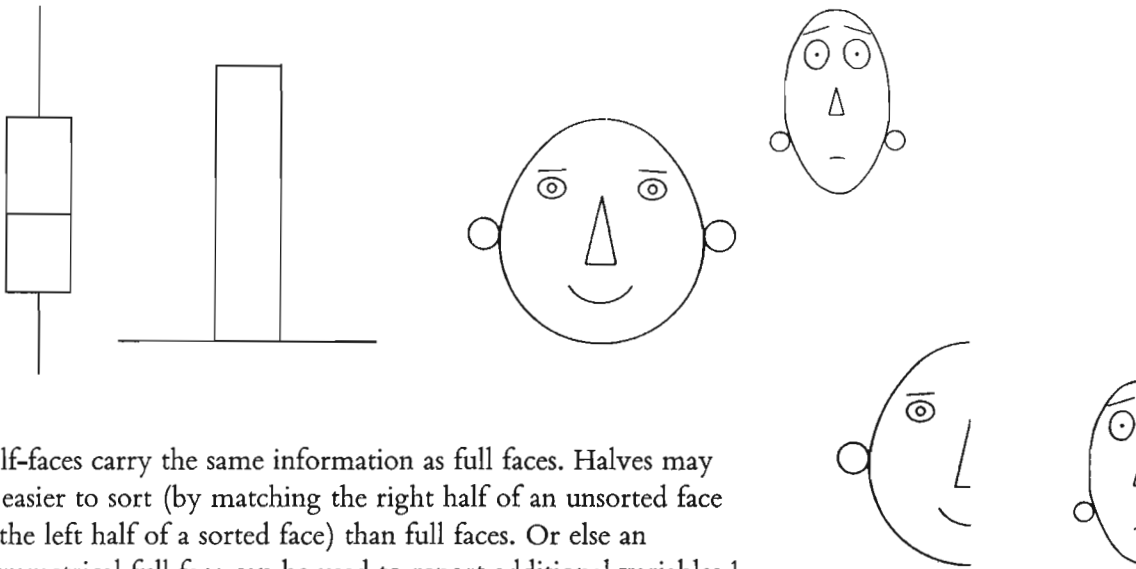


unambiguously locates the altitude in six separate ways (any five of the six can be erased and the sixth will still indicate the height): as the (1) height of the left line, (2) height of shading, (3) height of right line, (4) position of top horizontal line, (5) position (not content) of number at bar's 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:



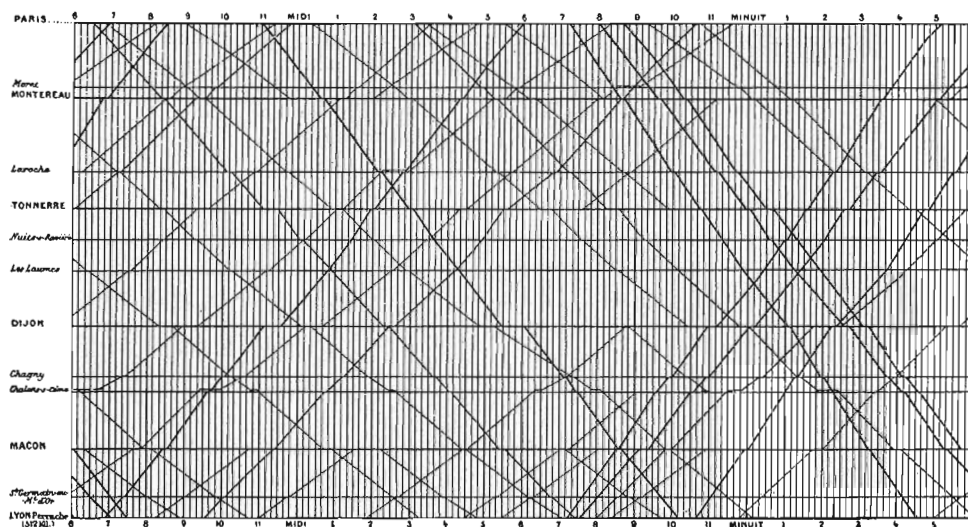
Half-faces carry the same information as full faces. Halves may be easier to sort (by matching the right half of an unsorted face to the left half of a sorted face) than full faces. Or else an asymmetrical full face can be used to report additional variables.¹

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

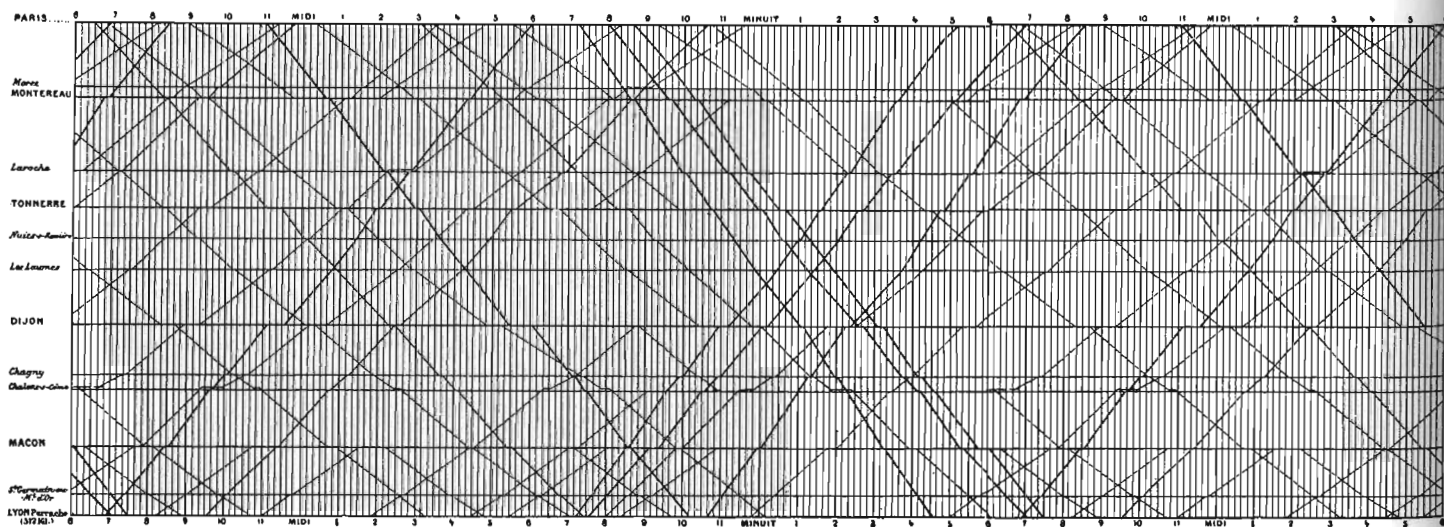
¹Bernhard Flury and Hans Riedwyl, “Graphical Representation of Multivariate Data by Means of Asymmetrical Faces,” *Journal of the American Statistical Association*, 76 (December 1981), 757–765.

²Leonard 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:

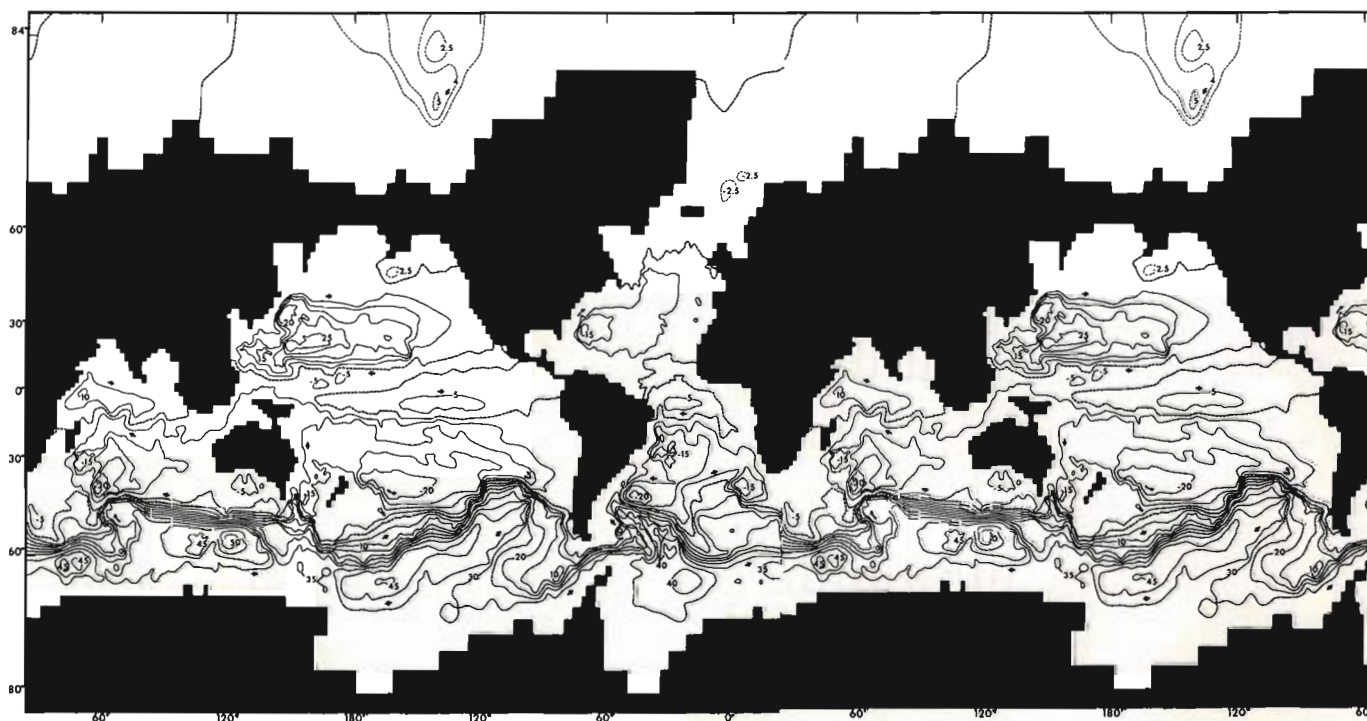
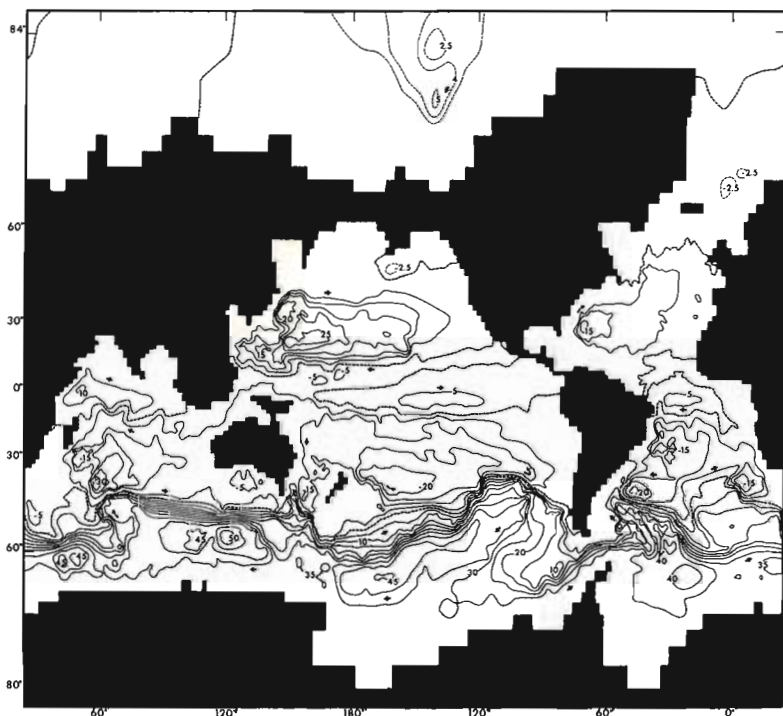


Attaching an extra half cycle makes every train in the first 24 hours of the schedule a continuous line (as would mounting the original on a cylinder):



And, similarly, instead of once around the world in this display of surface ocean currents, one and two-thirds times around is better:

Kirk Bryan and Michael D. Cox, "The Circulation of the World Ocean: A Numerical Study. Part 1, A Homogeneous Model," *Journal of Physical Oceanography*, 2 (1972), 330.



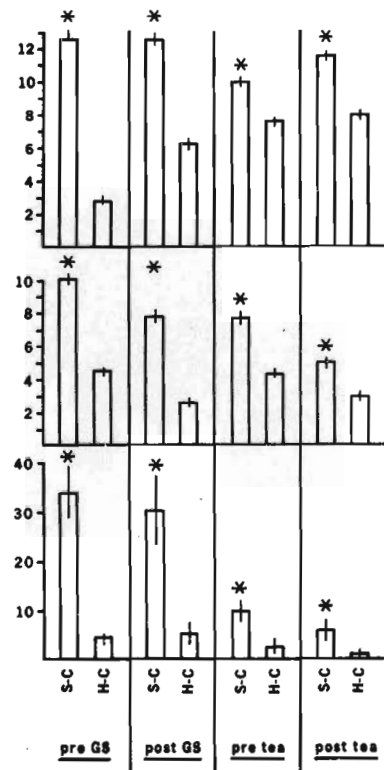
Most data representations, however, are of a single, uncomplicated number, and little graphical repetition is needed. Unless redundancy has a distinctly worthy purpose, the second erasing principle applies:

Erase redundant data-ink, within reason.

Application of the Principles in Editing and Redesign

Just as a good editor of prose ruthlessly prunes out unnecessary words, so a designer of statistical graphics should prune out ink that fails to present fresh data-information. Although nothing can replace a good graphical idea applied to an interesting set of numbers, editing and revision are as essential to sound graphical design work as they are to writing. T. S. Eliot emphasized the "capital importance of criticism in the work of creation itself. Probably, indeed, the larger part of the labour of an author in composing his work is critical labour; the labour of sifting, combining, constructing, expunging, correcting, testing: this frightful toil is as much critical as creative."³

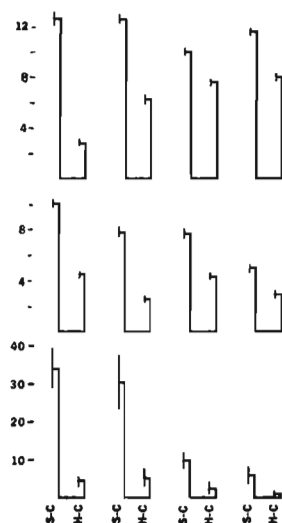
Consider this display, which compares each long bar with the adjacent short bar to show the viewer that, under the various experimental conditions, the long bar is longer:



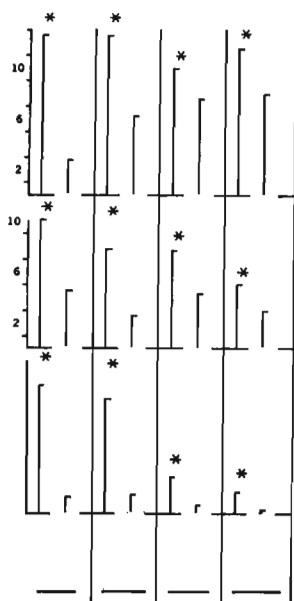
³T. S. Eliot, "The Function of Criticism," in *Selected Essays 1917-1932* (New York, 1932), p. 18.

James T. Kuznicki and N. Bruce McCutcheon, "Cross-Enhancement of the Sour Taste on Single Human Taste Papillae," *Journal of Experimental Psychology: General*, 108 (1979), 76.

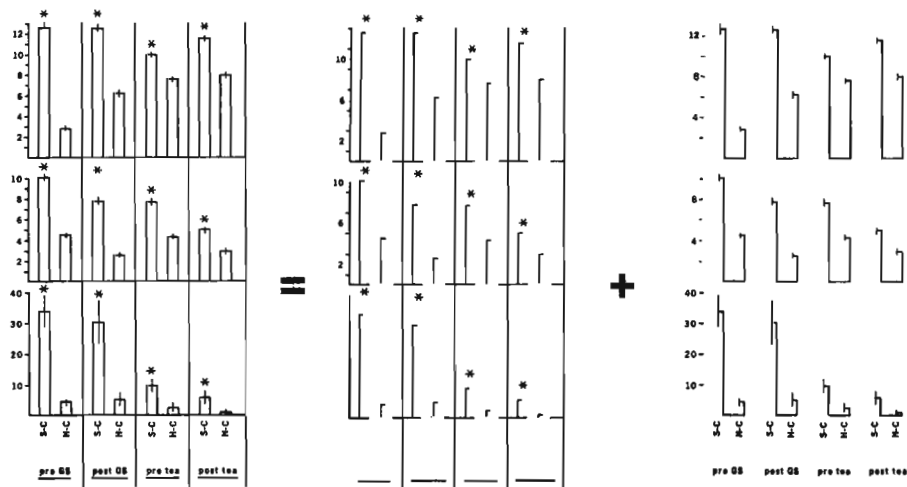
Vigorous pruning improves the graphic immensely, while still retaining all the data of the original. It is remarkable that erasing alone can work such a transformation:



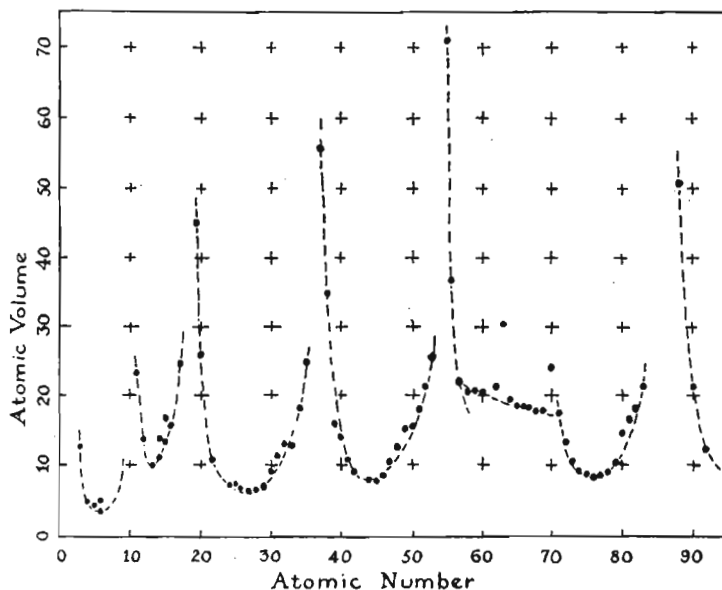
The horizontals indicate the paired comparisons and would change if the experimental design changed—so they count as information-carrying. All the asterisks are out since every paired comparison was statistically significant, a point that the caption can note. Here is the mix of non-data-ink and redundant data-ink that was erased, about 65 percent of the original:



The data graphical arithmetic looks like this—the original design equals the erased part plus the good part:

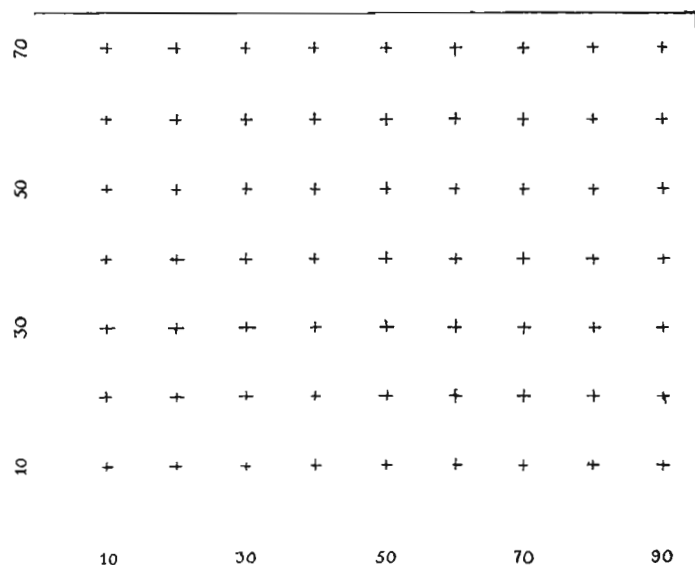


The next graphic, drawn by the distinguished science illustrator Roger Hayward, shows the periodicity of properties of chemical elements, exemplified by atomic volume as a function of atomic number. The data-ink ratio is less than 0.6, lowered because the 76 data points and the reference curves are obscured by the 63 dark grid marks arrayed over the data plane like a precision marching band of 63 mosquitoes:

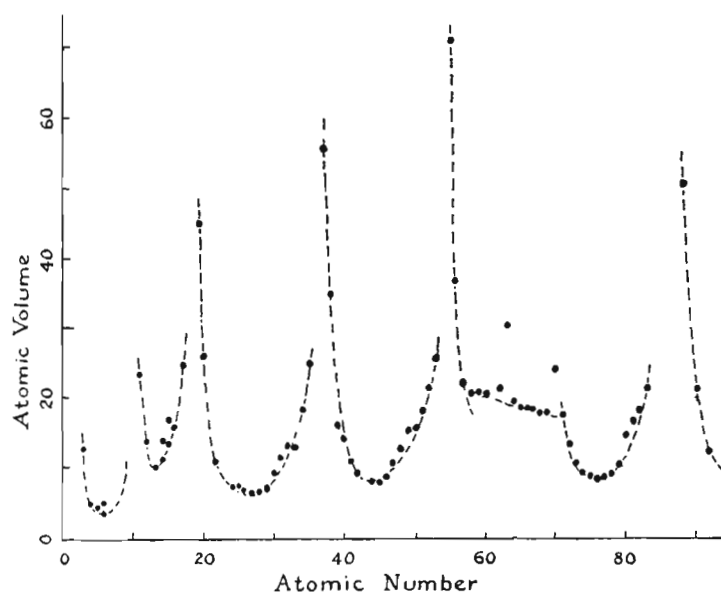


Linus Pauling, *General Chemistry* (San Francisco, 1947), p. 64.

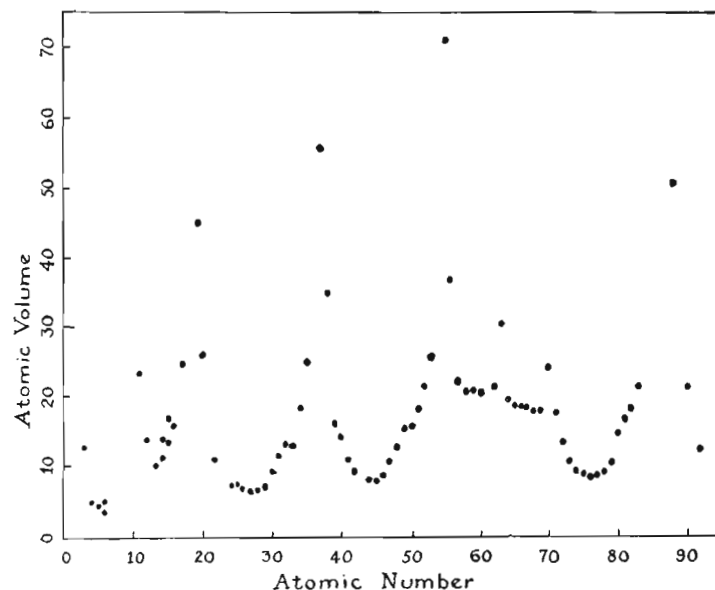
The grid ticks compete with the essential information of the graphic, the curves tracing out the periods and the empirical observations. The little grid marks and part of the frame can be safely erased, removed from the denominator of the data-ink ratio:



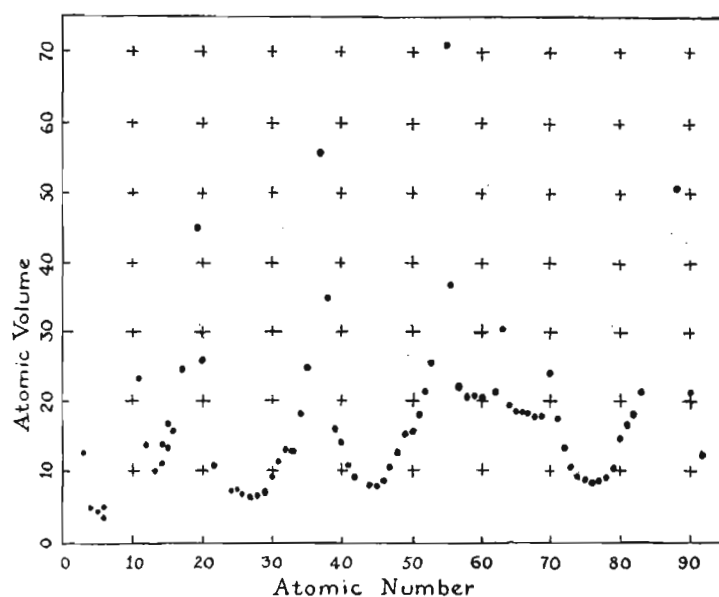
The uncluttered display brings out another aspect of the data: several of the elements do not fit the smooth theoretical curves all that well. The data-ink ratio has increased to about .9, with only the frame lines remaining as pure non-information:



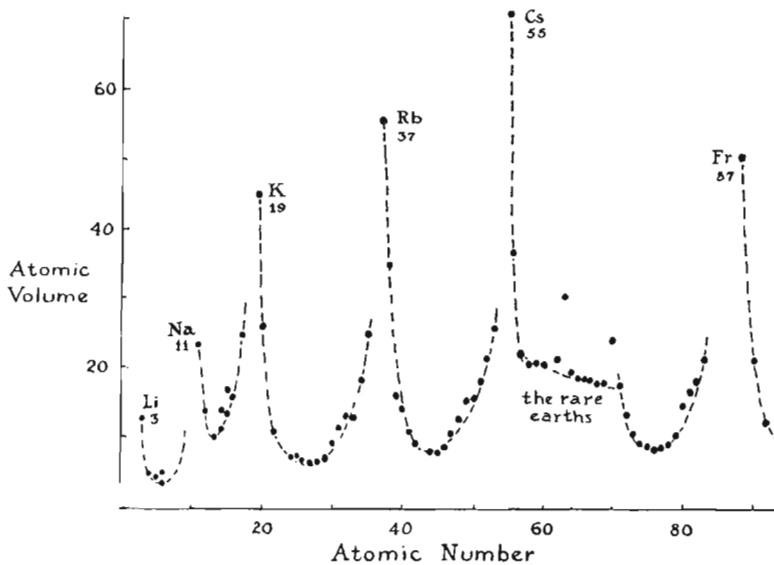
The reference curves prove essential for organizing the data to show the periodicity. The curves create a structure, giving an ordering, a hierarchy, to the flow of information from the page:



Restoring the grid fails to organize the data. The ticks are too powerful, and they also add a disconcerting visual vibration to the graphic. With the ticks, the reference curves become all the more necessary, since the eye needs some guidance through the maze of dots and crosses:



The space opened up by erasing can be effectively used. Labels for the initial elements of each period, an alkali, show the beginning of each cycle in the periodic table of elements—and in the graphic. The unusual rare-earths are indicated. In addition, the label and numbers on the vertical axis are turned to read from left to right rather than bottom to top, making the graphic slightly more accessible, a little more friendly:



Conclusion

Five principles in the theory of data graphics produce substantial changes in graphical design. The principles apply to many graphics and yield a series of design options through cycles of graphical revision and editing.

Above all else show the data.

Maximize the data-ink ratio.

Erase non-data-ink.

Erase redundant data-ink.

Revise and edit.

*With savage pictures fill their gaps
And o'er unhabitable downs
Place elephants for want of towns.*

Jonathan Swift's indictment of 17th-century cartographers

5 *Chartjunk: Vibrations, Grids, and Ducks*

The interior decoration of graphics generates a lot of ink that does not tell the viewer anything new. The purpose of decoration varies—to make the graphic appear more scientific and precise, to enliven the display, to give the designer an opportunity to exercise artistic skills. Regardless of its cause, it is all non-data-ink or redundant data-ink, and it is often chartjunk. Graphical decoration, which prospers in technical publications as well as in commercial and media graphics, comes cheaper than the hard work required to produce intriguing numbers and secure evidence.

Sometimes the decoration is thought to reflect the artist's fundamental design contribution, capturing the essential spirit of the data and so on. Thus principles of artistic integrity and creativity are invoked to defend—even to advance—the cause of chartjunk. There are better ways to portray spirits and essences than to get them all tangled up with statistical graphics.

Fortunately most chartjunk does not involve artistic considerations. It is simply conventional graphical paraphernalia routinely added to every display that passes by: over-busy grid lines and excess ticks, redundant representations of the simplest data, the debris of computer plotting, and many of the devices generating design variation.

Like weeds, many varieties of chartjunk flourish. Here three widespread types found in scientific and technical research work are catalogued—unintentional optical art, the dreaded grid, and the self-promoting graphical duck. A hundred chartjunky examples from commercial and media graphics have been forgone so as to demonstrate the relevance of the critique to the professional scientific production of data graphics.

Unintentional Optical Art

Contemporary optical art relies on moiré effects, in which the design interacts with the physiological tremor of the eye to produce the distracting appearance of vibration and movement.

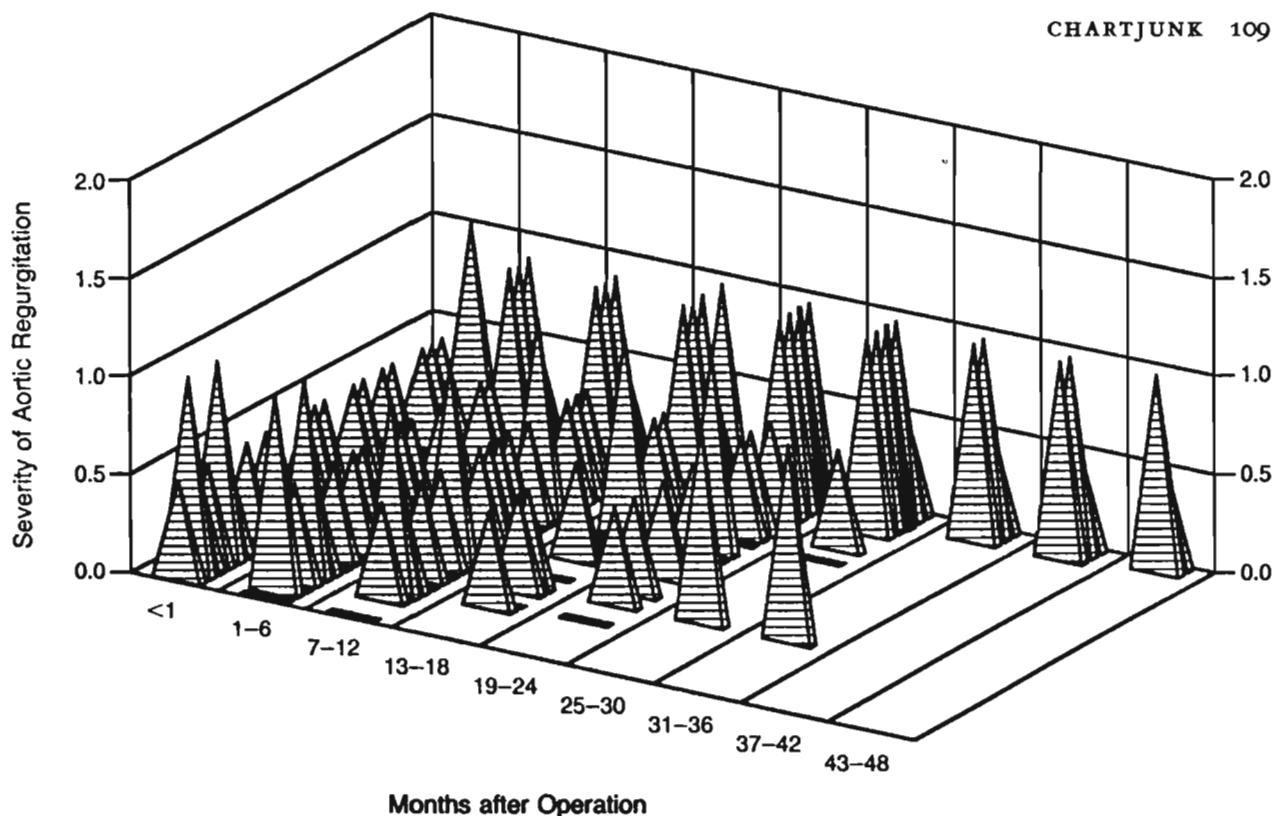
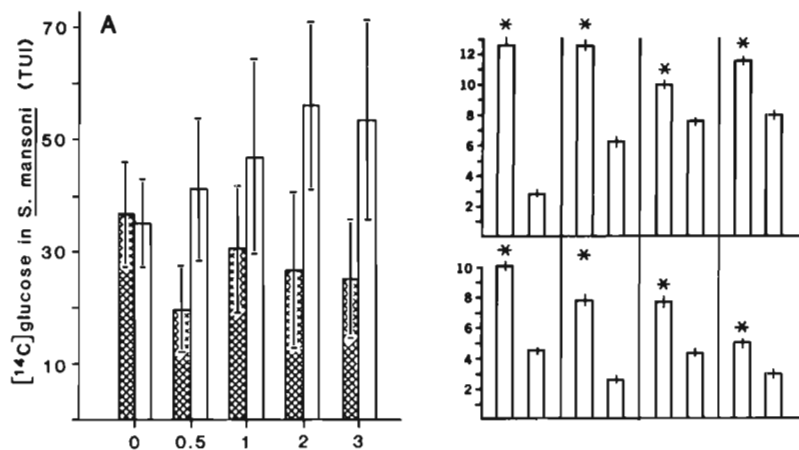


Figure 2. Serial Echocardiographic Assessments of the Severity of Regurgitation in the Pulmonary Autograft in 31 Patients. The numerical grades were assigned according to the severity of regurgitation, as follows: 0, none; 0.5, trivial; 1.0 to 1.5, mild; 2.0, moderate; and 3.0, severe.

On this page, what should have been simple tables are turned into bad graphics published in major scientific journals. Above a duck moiré with an unintentional Necker Illusion, as the two back planes optically flip to the front. Some pyramids conceal others; and one variable (stacked depth of the stupid pyramids) has no label or scale. Below, we learn very little about data, but do discover that moiré vibration may well be at a maximum for equally spaced bars:

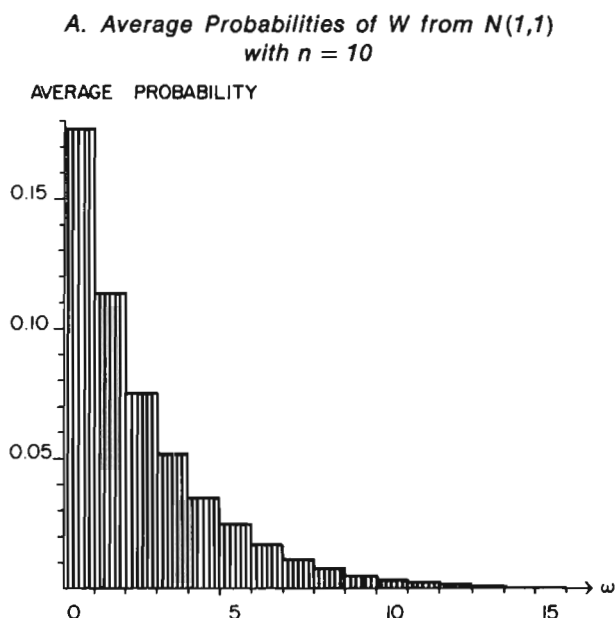
Nicholas T. Kouchoukos, *et al.*,
"Replacement of the Aortic Root with
a Pulmonary Autograft in Children and
Young Adults with Aortic-Valve Disease,"
The New England Journal of Medicine, 330
(January 6, 1994), p. 4.



James T. Kuznicki and N. Bruce Mc-
Cutcheon, "Cross-Enhancement of the
Sour Taste on Single Human Taste
Papillae," *Journal of Experimental Psy-
chology: General*, 108 (1979), 76.

Eain M. Cornford and Marie E. Huot,
"Glucose Transfer from Male to Female
Schistosomes," *Science*, 213 (September
11, 1981), 1270.

And, finally, from the style sheet once provided by the *Journal of the American Statistical Association*, a graphic described as “an example of a figure prepared in the proper form”:



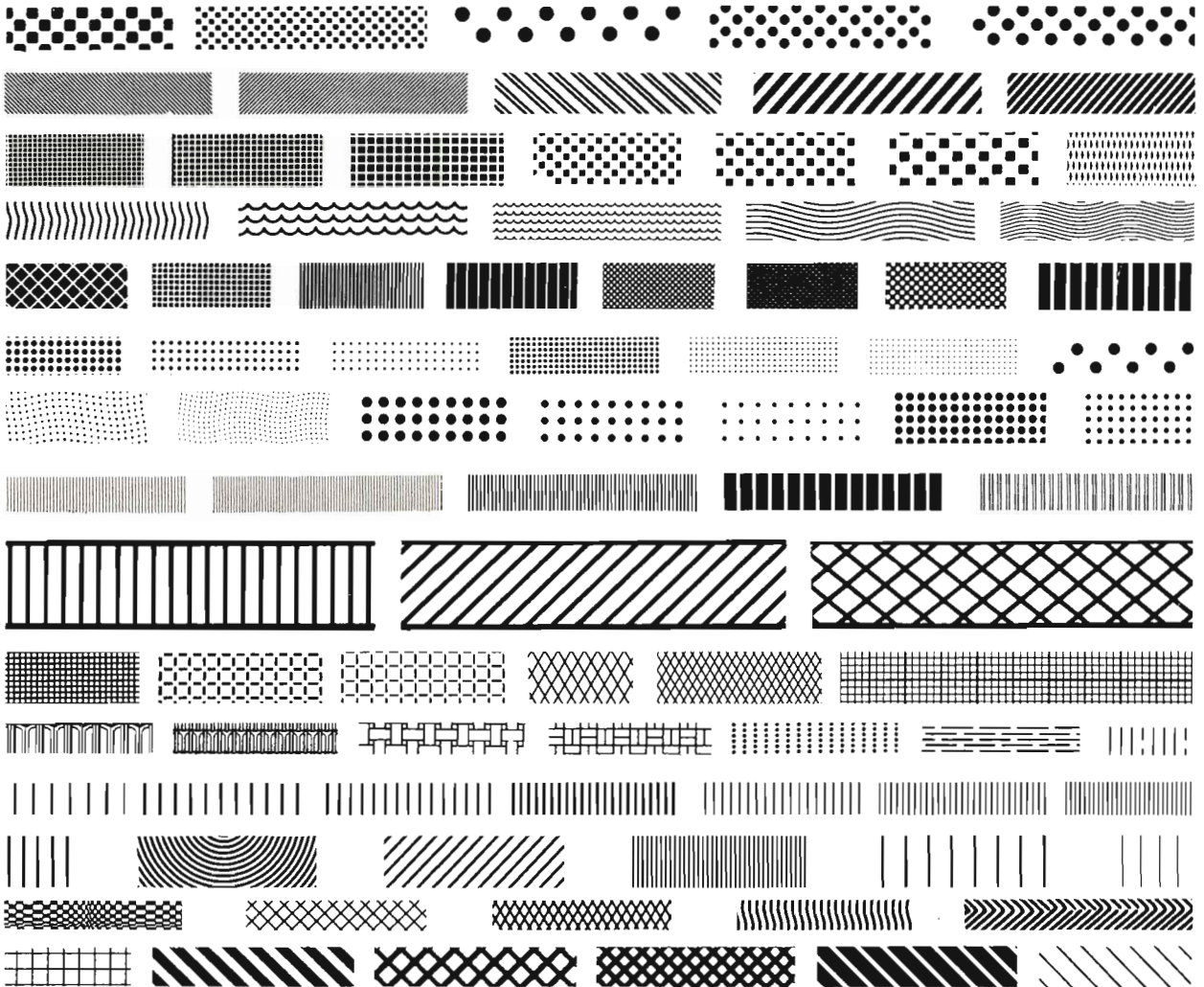
“JASA Style Sheet,” *Journal of the American Statistical Association*, 71 (March 1976), 260–261.

The display required 131 line-strokes and 15 digits to communicate its simple information. The vibrating lines are poorly drawn, unevenly spaced, and misaligned with the vertical axis.

Vibrating chartjunk even frequents the graphics of major scientific journals:

The ten most frequently cited (footnoted) scientific journals: random sample of issues published 1980–1982	Percentage of graphics with moiré vibration	Number of graphics in sample
<i>Biochemistry</i>	2%	568
<i>Journal of Biological Chemistry</i>	2%	565
<i>Journal of the American Chemical Society</i>	3%	317
<i>Journal of Chemical Physics</i>	6%	327
<i>Biochimica et Biophysica Acta</i>	8%	432
<i>Nature</i>	11%	225
<i>Proceedings of the National Academy of Sciences, U.S.A.</i>	12%	438
<i>Lancet</i>	15%	364
<i>Science</i>	17%	311
<i>New England Journal of Medicine</i>	21%	338

Moiré effects have proliferated with computer graphics (in programs such as Excel). Such unfortunate patterns were once generated by means of thin plastic transfer sheets; now the computer produces instant chartjunk. Shown here are a few of the many vibrating possibilities. Cross-hatching should be replaced with tint screens of shades of gray. Specific areas on a graphic should be labeled with words rather than encoded with hatching.



This form of chartjunk is a twentieth-century innovation, and computer graphics are multiplying it more than ever. The handbooks and textbooks of statistical graphics, along with user's manuals for computer graphics programs, are filled up with vibrating graphics, presented as exemplars of design. Note the high

proportion of chartjunk graphics in the more recent publications. Computer graphics are particularly active:

Textbooks and handbooks of statistical graphics; and manuals for computer graphics programs (ordered by date of publication)	Percentage of graphics with moiré vibration	Total number of graphics
Willard C. Brinton, <i>Graphic Methods for Presenting Facts</i> (New York, 1914)	12%	255
R. Satet, <i>Les Graphiques</i> (Paris, 1932)	29%	28
Herbert Arkin and Raymond R. Colton, <i>Graphs: How to Make and Use Them</i> (New York, 1936)	17%	95
Mary Eleanor Spear, <i>Charting Statistics</i> (New York, 1952)	46%	134
Anna C. Rogers, <i>Graphic Charts Handbook</i> (Washington, D.C., 1961)	32%	201
F. J. Monkhouse and H. R. Wilkinson, <i>Maps and Diagrams</i> (London, third edition, 1971)	14%	322
Calvin F. Schmid and Stanton E. Schmid, <i>Handbook of Graphic Presentation</i> (New York, second edition, 1979)	22%	399
A. J. MacGregor, <i>Graphics Simplified</i> (Toronto, 1979)	34%	65
The user's manual for a widely distributed computer graphics package: <i>SAS/GRAPH User's Guide</i> (Cary, North Carolina, 1980)	68%	28
The manual for a very extensive computer graphics program: <i>Tell-A-Graf User's Manual</i> (San Diego, 1981)	53%	459

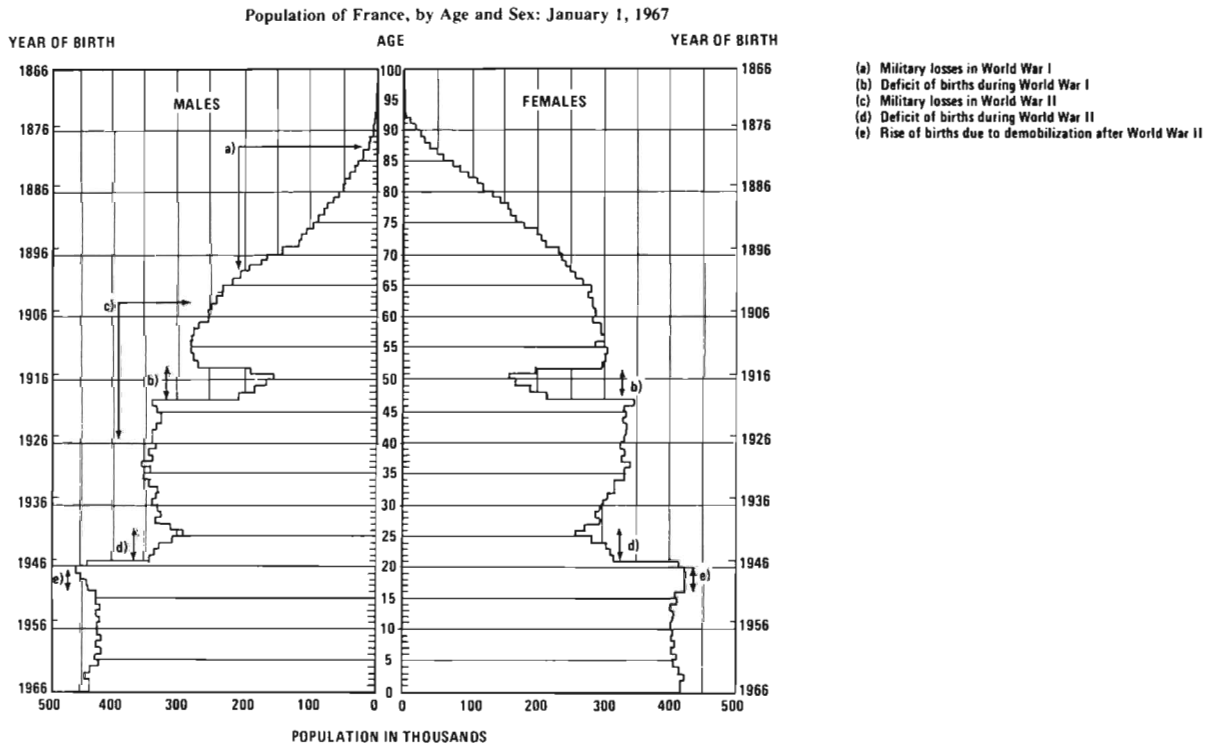
Can optical art effects ever produce a better graphic? Bertin exhorts: "It is the designer's duty to make the most of this variation; to obtain the resonance [of moiré vibration] without provoking an uncomfortable sensation: to flirt with ambiguity without succumbing to it."¹ But can statistical graphics successfully "flirt with ambiguity"? It is a clever idea, but no good examples are to be found. The key difficulty remains: moiré vibration is an *undisciplined* ambiguity, with an illusive, eye-straining quality that contaminates the entire graphic. It has no place in data graphical design.

¹ Jacques Bertin, *Semiology of Graphics: Diagrams, Networks, Maps* (Madison, Wisconsin, 1983, translated by William J. Berg), p. 80; this book is the English translation of Bertin's important work, *Sémiologie graphique* (Paris, 1967).

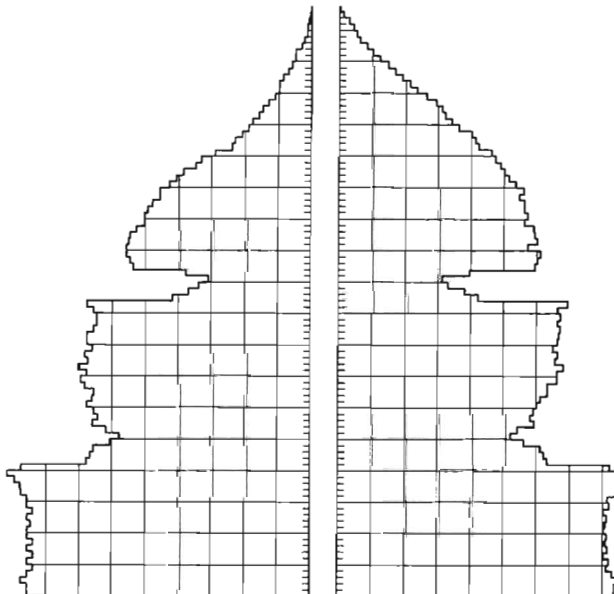
The Grid

One of the more sedate graphical elements, the grid should usually be muted or completely suppressed so that its presence is only implicit—lest it compete with the data. Grids are mostly for the initial plotting of data at home or office rather than for putting

into print. Dark grid lines are chartjunk. They carry no information, clutter up the graphic, and generate graphic activity unrelated to data information. This grid camouflages the profile of the data in the age-sex pyramid of the population of France in 1967:



A revision quiets the grid and gives emphasis to the data:



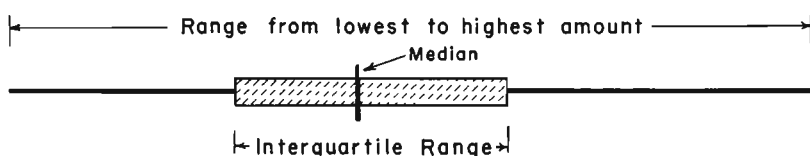
Based on data in Institut National de la Statistique et des Études Économiques, *Annuaire statistique de la France, 1968* (Paris, 1968), pp. 32–33; redrawn in Henry S. Shryock and Jacob S. Siegel, *The Methods and Materials of Demography* (Washington, D.C., 1973), vol. 1, 242.

6 *Data-Ink Maximization and Graphical Design*

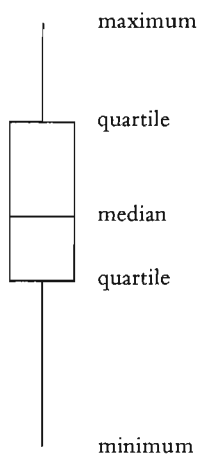
So far the principles of maximizing data-ink and erasing have helped to generate a series of choices in the process of graphical revision. This is an important result, but can the ideas reach beyond the details and particularities of editing? Is it possible to do what a theory of graphics is supposed to do, that is, to derive new graphical forms? In this chapter the principles are applied to many graphical designs, basic and advanced, including box plots, bar charts, histograms, and scatterplots. New designs result.

Redesign of the Box Plot

Mary Eleanor Spear's "range bar"



and John Tukey's "box plot"



Mary Eleanor Spear, *Charting Statistics* (New York, 1952), p. 166; and John W. Tukey, *Exploratory Data Analysis* (Reading, Massachusetts, 1977).

can be mostly erased without loss of information:



The revised design, a *quartile plot*, shows the same five numbers. It is easy to draw by hand or computer and, most importantly, can replace the conventional scatterplot frame. The straightedge need only be placed on the paper once to draw the quartile plot, compared to six separate placings for the box plot. An alternative is



but this design will not work effectively to frame a scatterplot. Nor does it look very good.

Perhaps special emphasis should be given to the middle half of the distribution, however, as in the box plot. This can be done by changing line weights



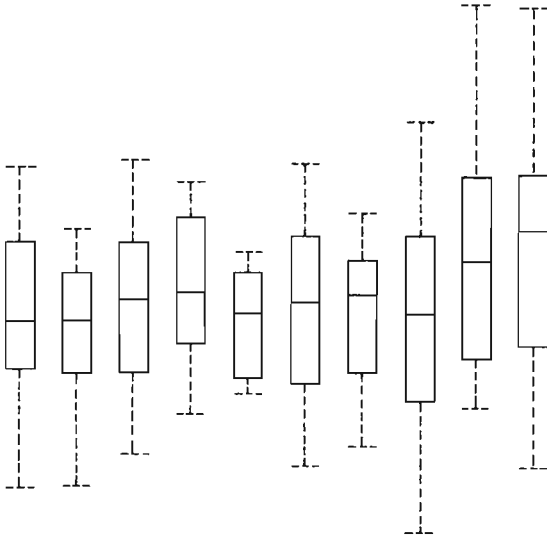
or, even better, by offsetting the middle half:



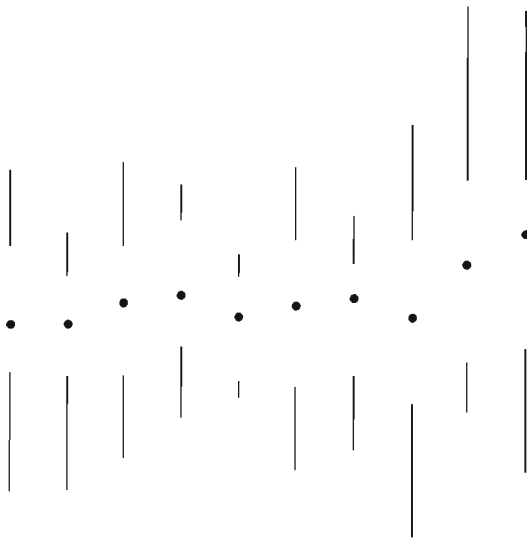
This latter design is the preferred form of the quartile plot. It uses the ink effectively and looks good.

In these revisions of the box plot, the principle of maximizing data-ink has suggested a variety of designs, but the choice of the best overall arrangement naturally also rests on statistical and aesthetic criteria—in other words, the procedure is one of *reasonable* data-ink maximizing.

The same logic applies to many similar designs, such as this “parallel schematic plot.” The original required 80 separate placements of the straightedge, 50 horizontals and 30 verticals:



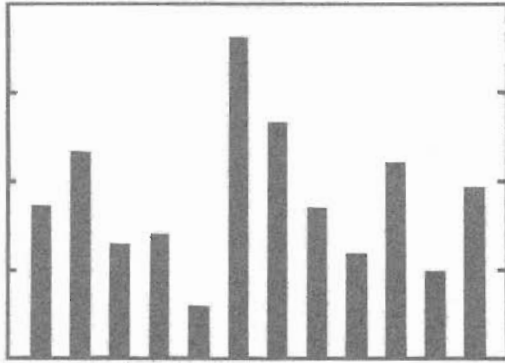
An erased version requires only 10 verticals to show the same information:



The large reduction in the amount of drawing is relevant for the use of such designs in informal, exploratory data analysis, where the research worker's time should be devoted to matters other than drawing lines.

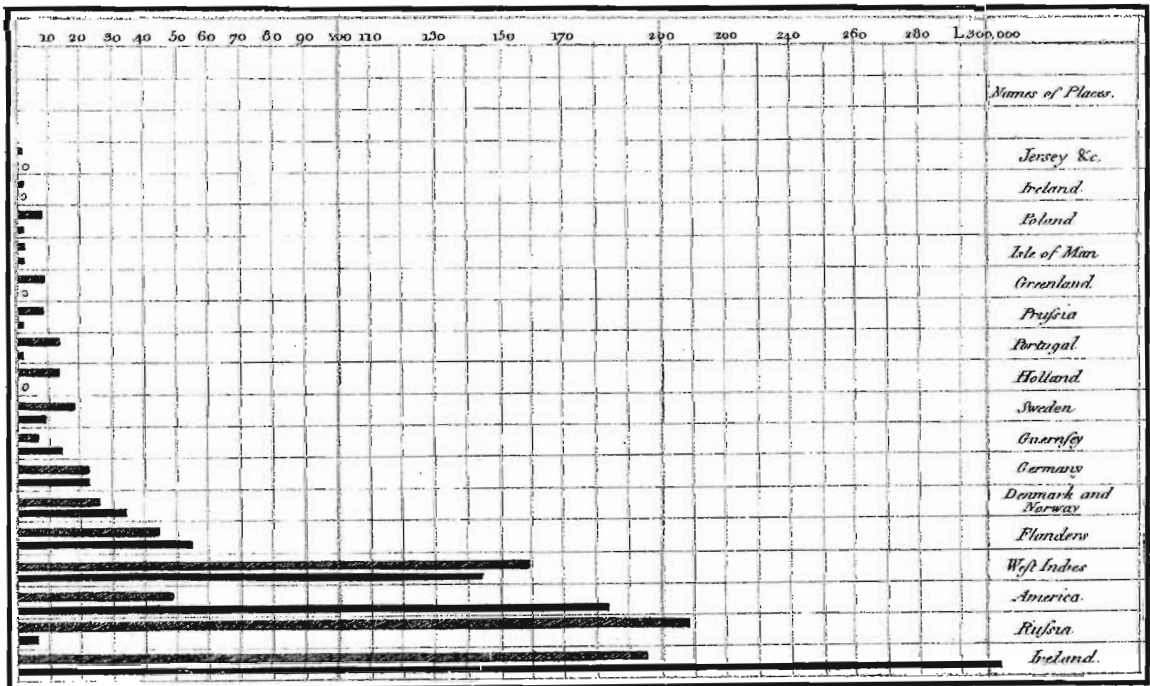
Redesign of the Bar Chart/Histogram

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:

Exports and Imports of SCOTLAND to and from different parts for one Year from Christmas 1780 to Christmas 1781

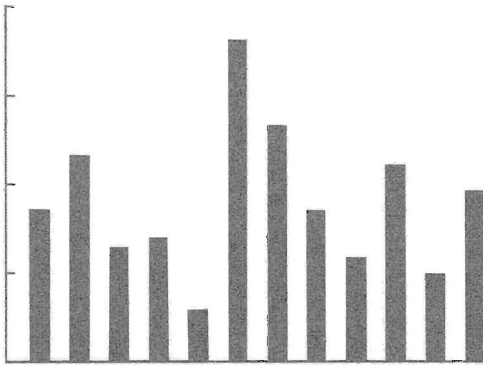


The Upright divisions are Ten Thousand Pounds each. The Black Lines are Exports the Ribbed lines Imports

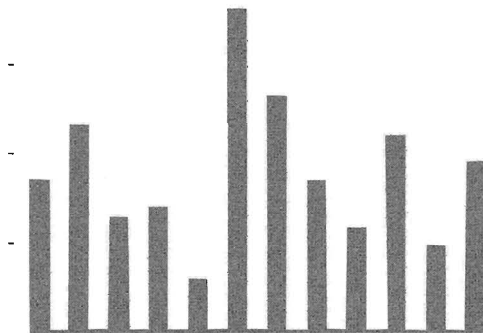
Published in the Art Magazine June 7th 1845 by W^m Playfair

Note: orig. 352 Strand, London.

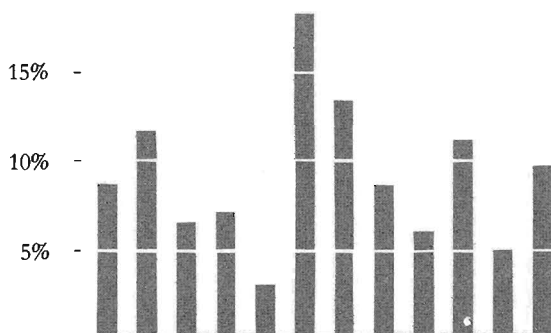
The box can be erased:



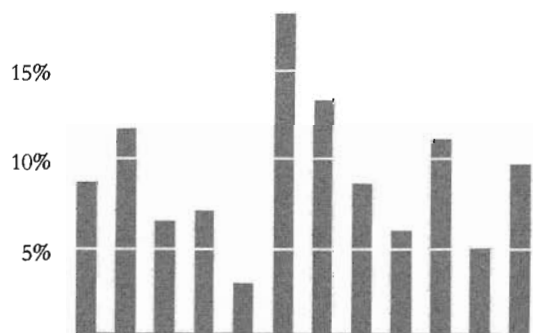
And the vertical axis, except for the ticks:



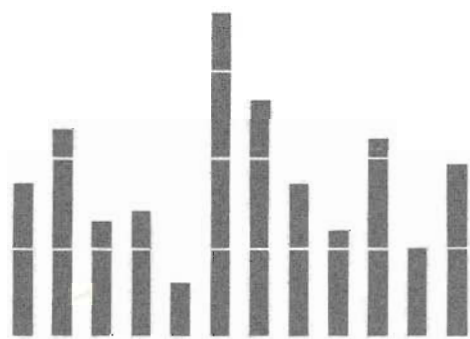
Even part of the data measures can be erased, making a *white grid*, which shows the coordinate lines more precisely than ticks alone:



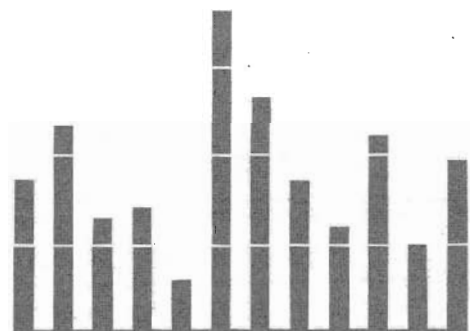
The white grid eliminates the tick marks, since the numerical labels on the vertical are tied directly to the white lines:



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:



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

