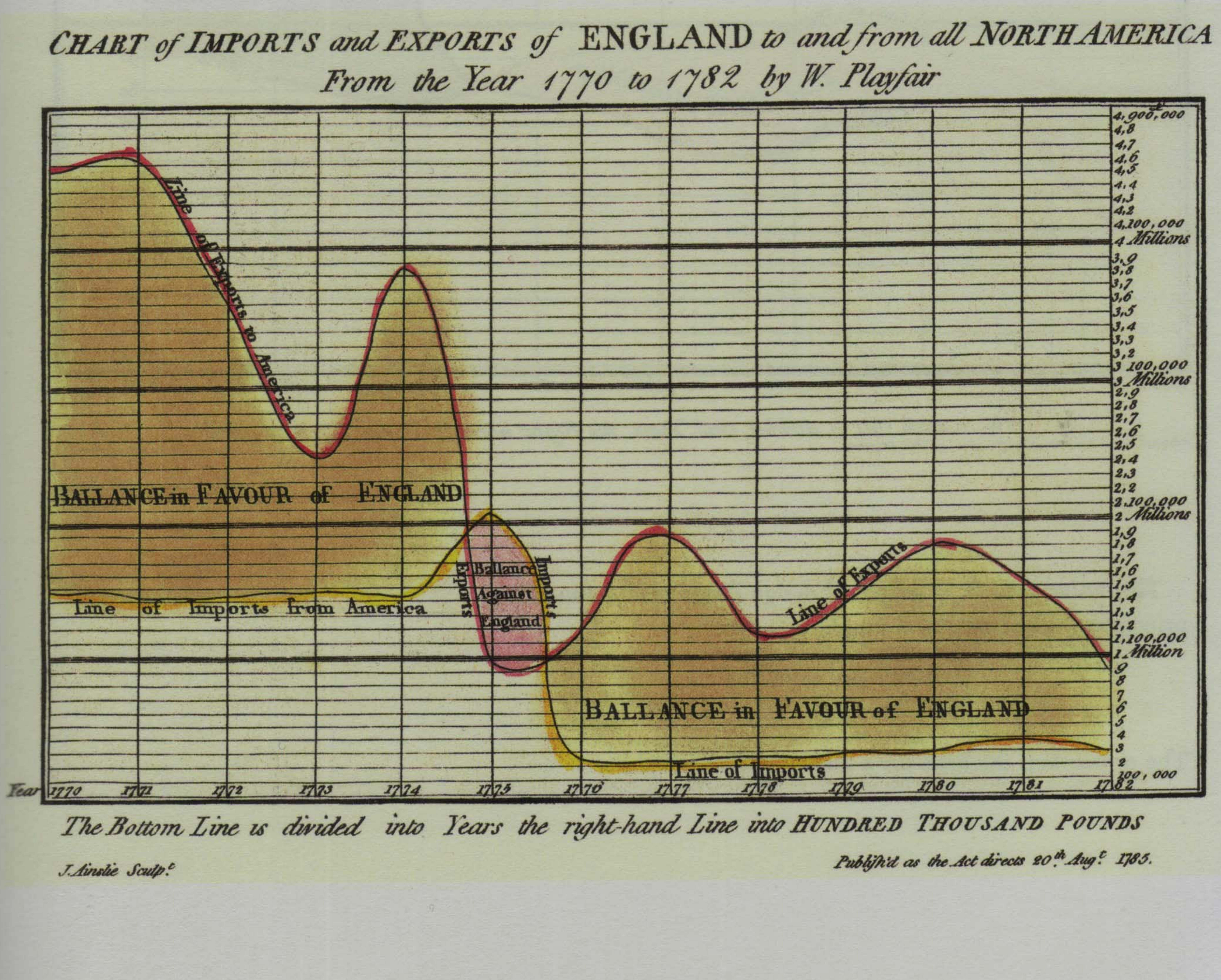
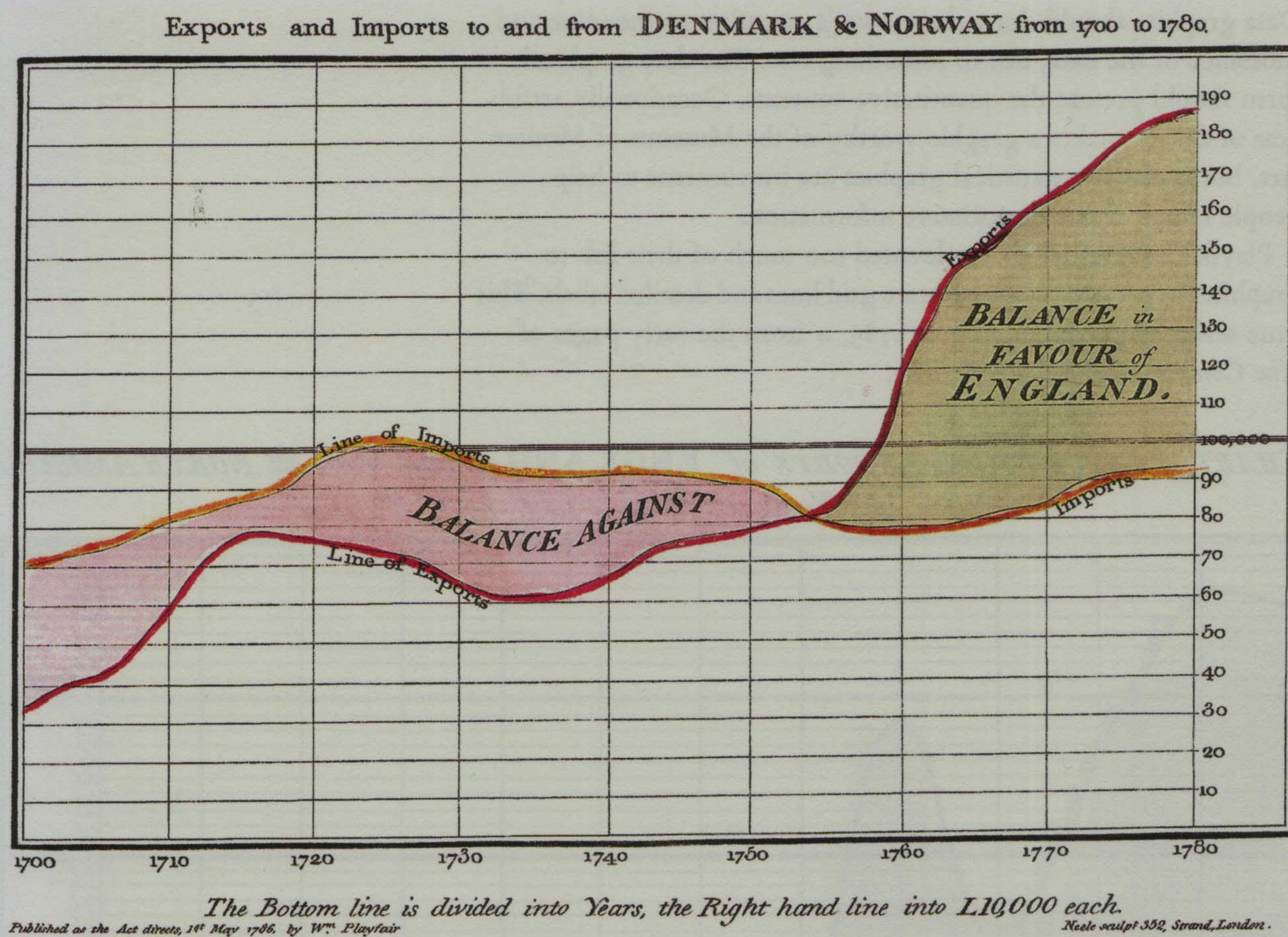
Data-Ink and Graphical Redesign

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*:



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

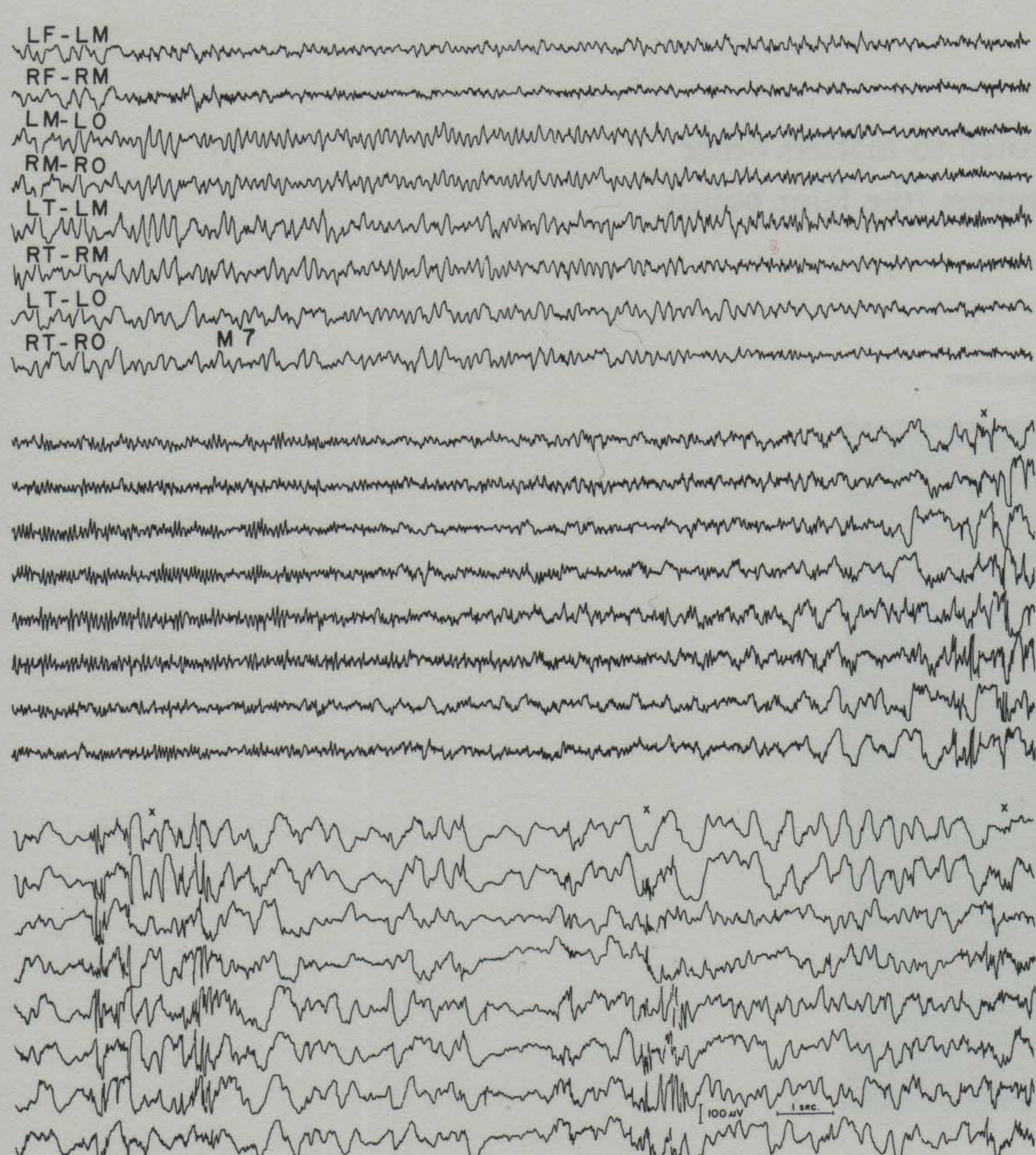
A large share of ink on a graphic should present data-information, the ink changing as the data change. *Data-ink* is the non-erasable core of a graphic, the non-redundant ink arranged in response to variation in the numbers represented. Then,

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

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

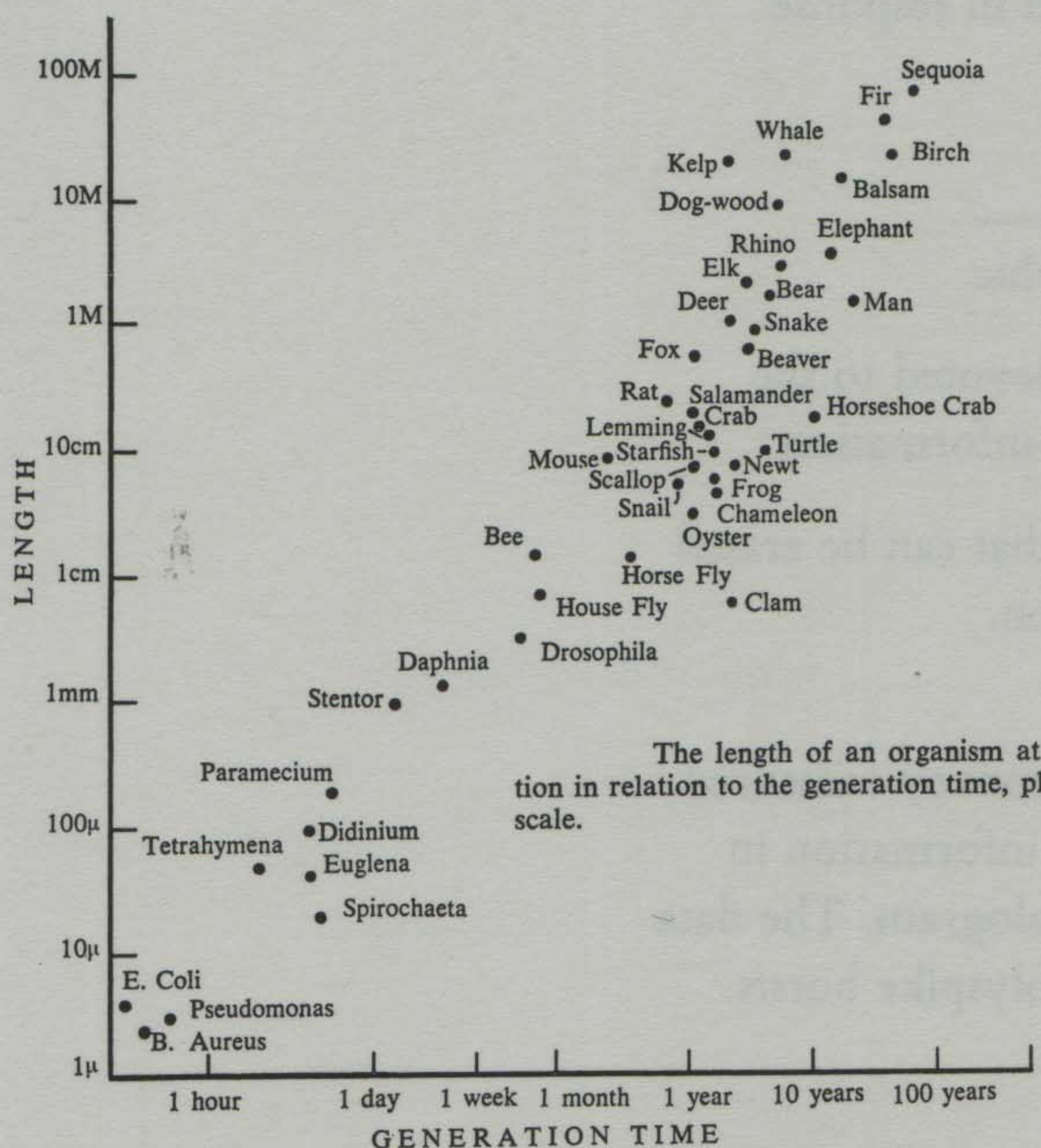
$$= 1.0 - \text{proportion of a graphic that can be erased without loss of data-information.}$$

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:



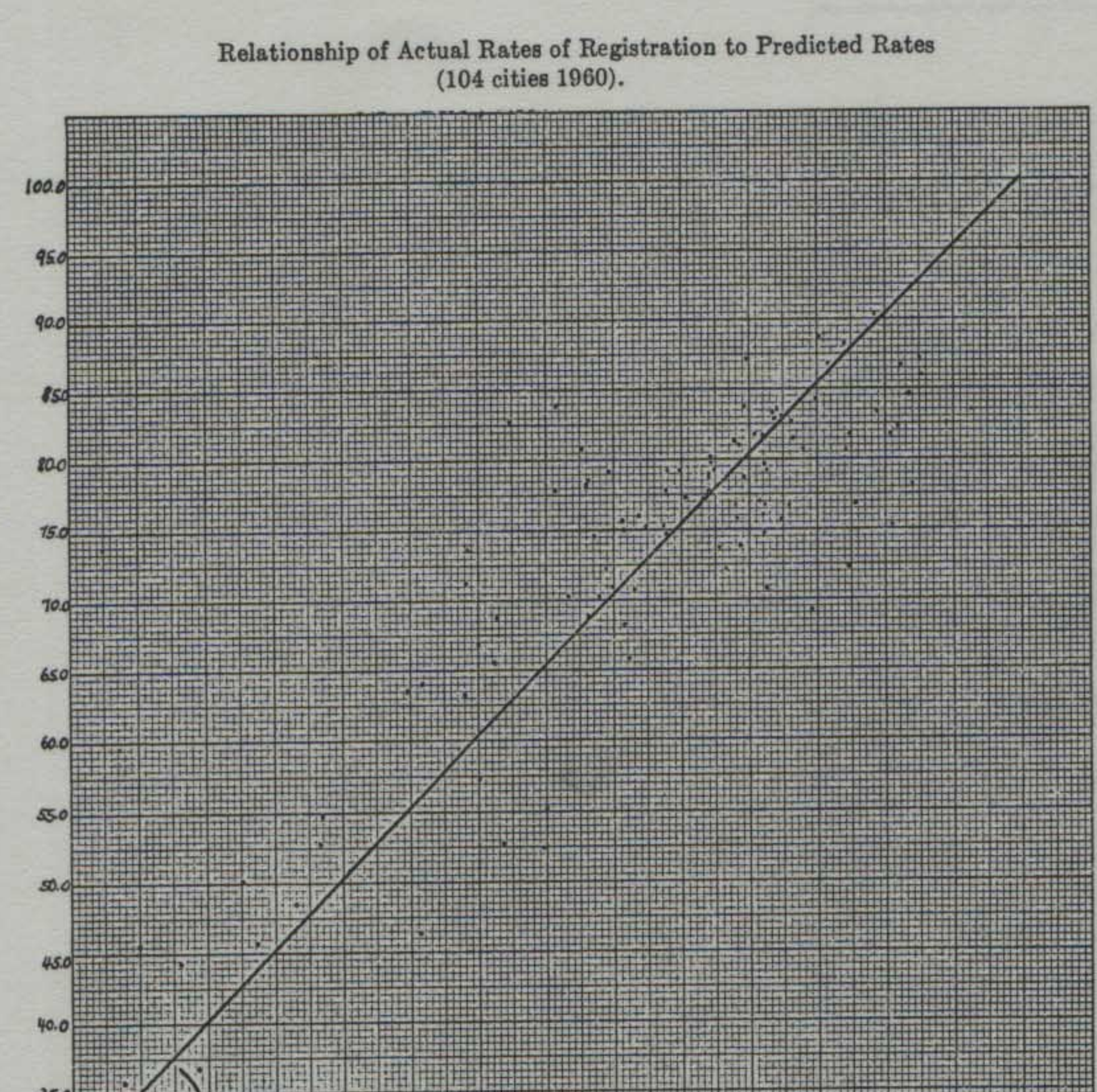
Kenneth A. Kooi, *Fundamentals of Electroencephalography* (New York, 1971), p. 110.

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):

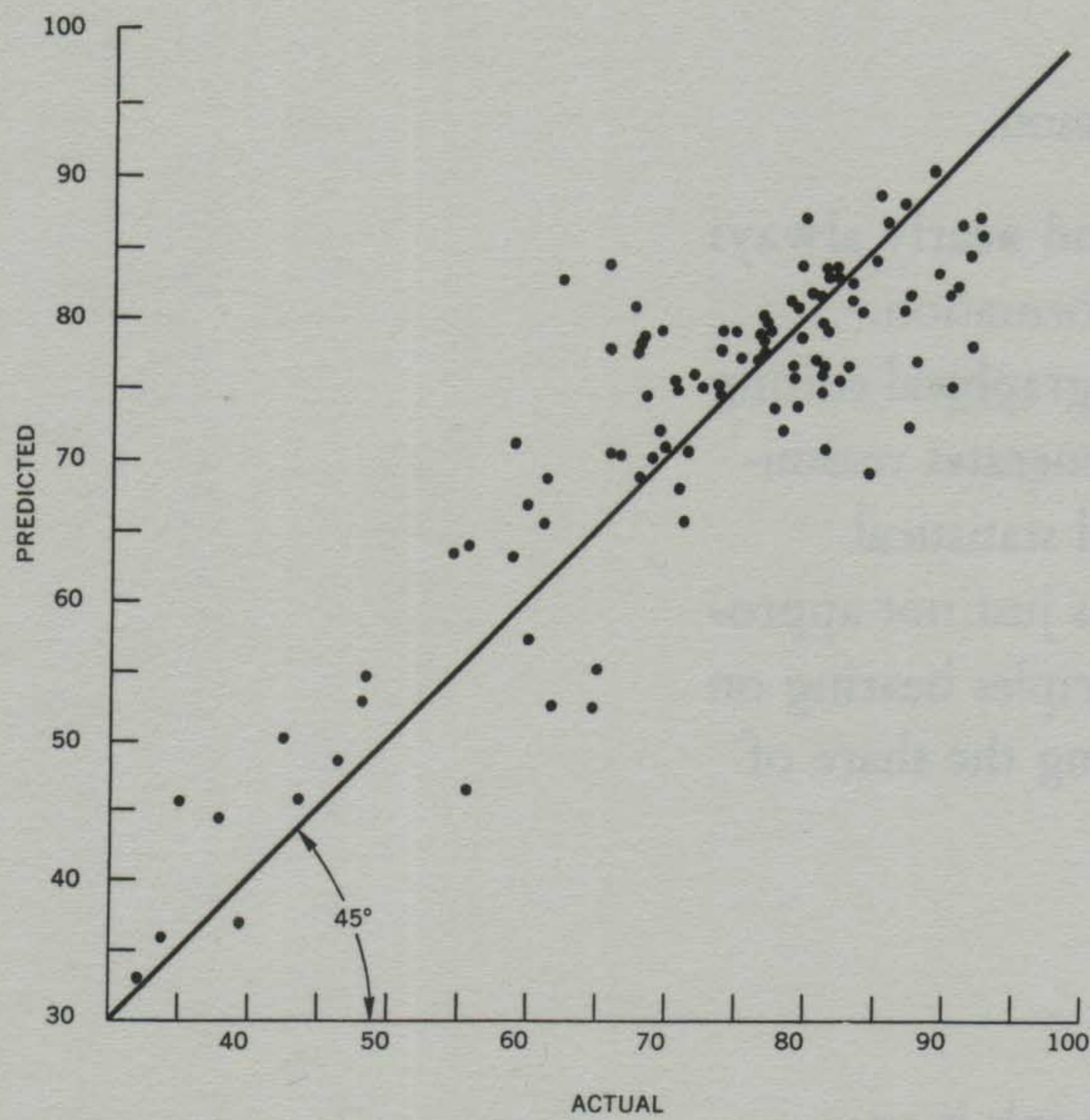


John Tyler Bonner, *Size and Cycle: An Essay on the Structure of Biology* (Princeton, 1965), p. 17.

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):



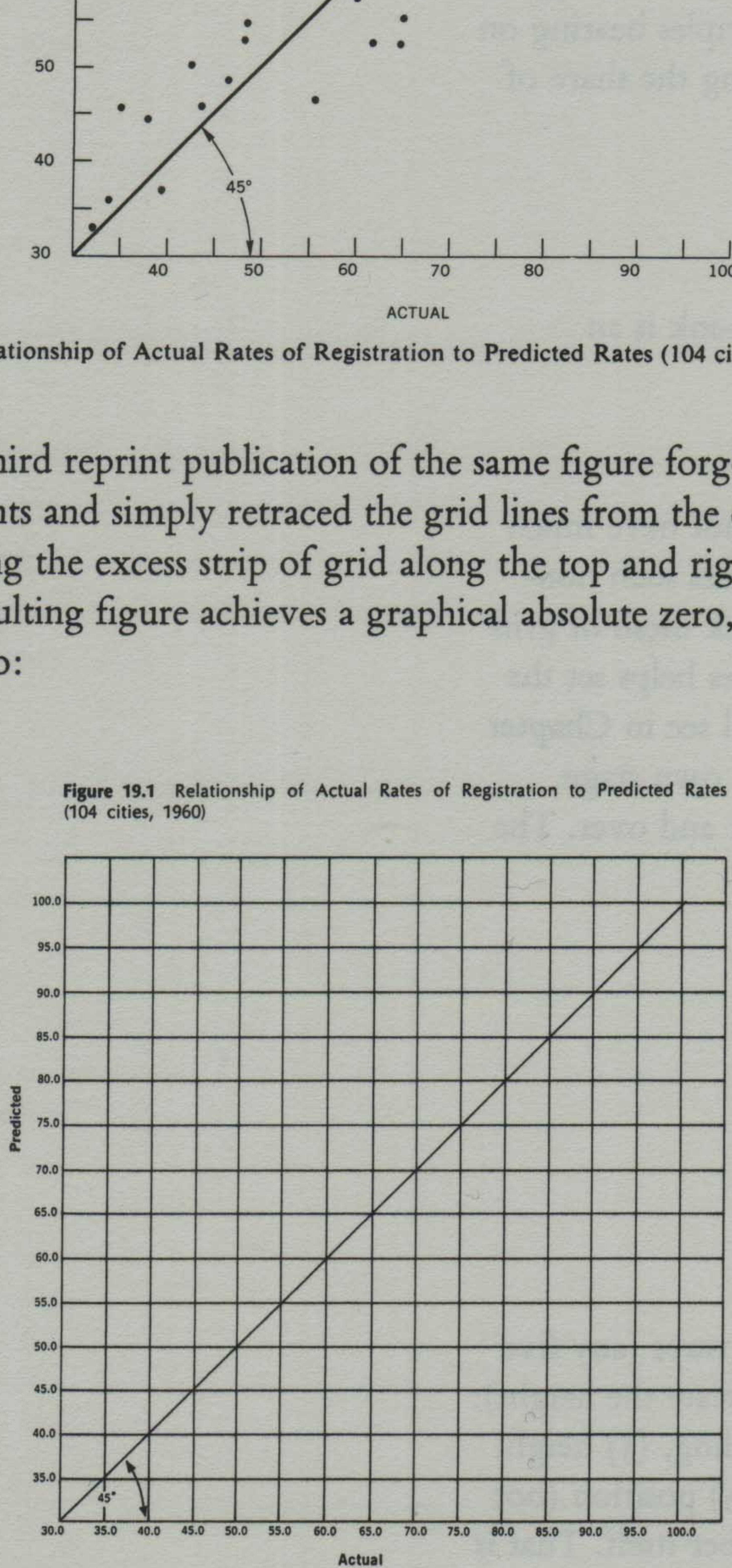
Another published version of the same data drove the share of data-ink up to about 0.7, an improvement:



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.

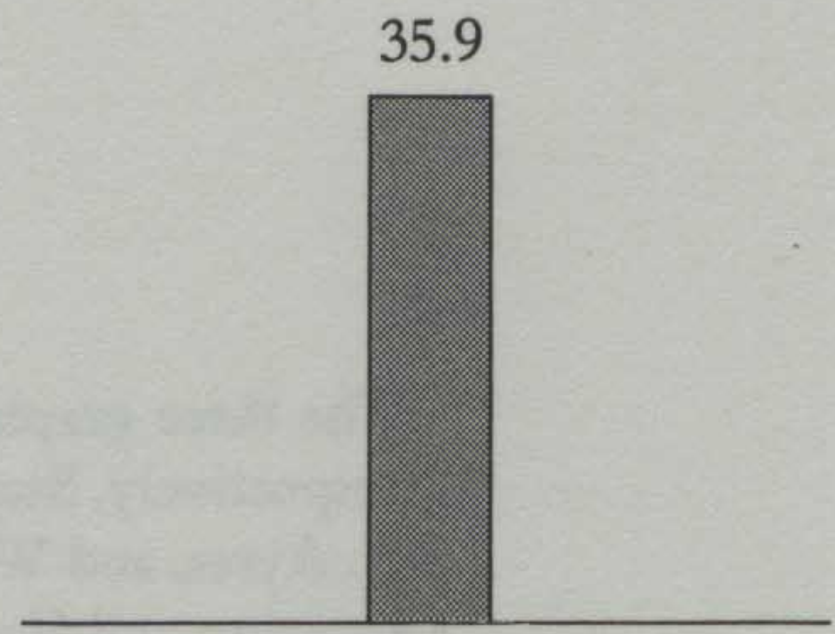
Two Erasing Principles

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

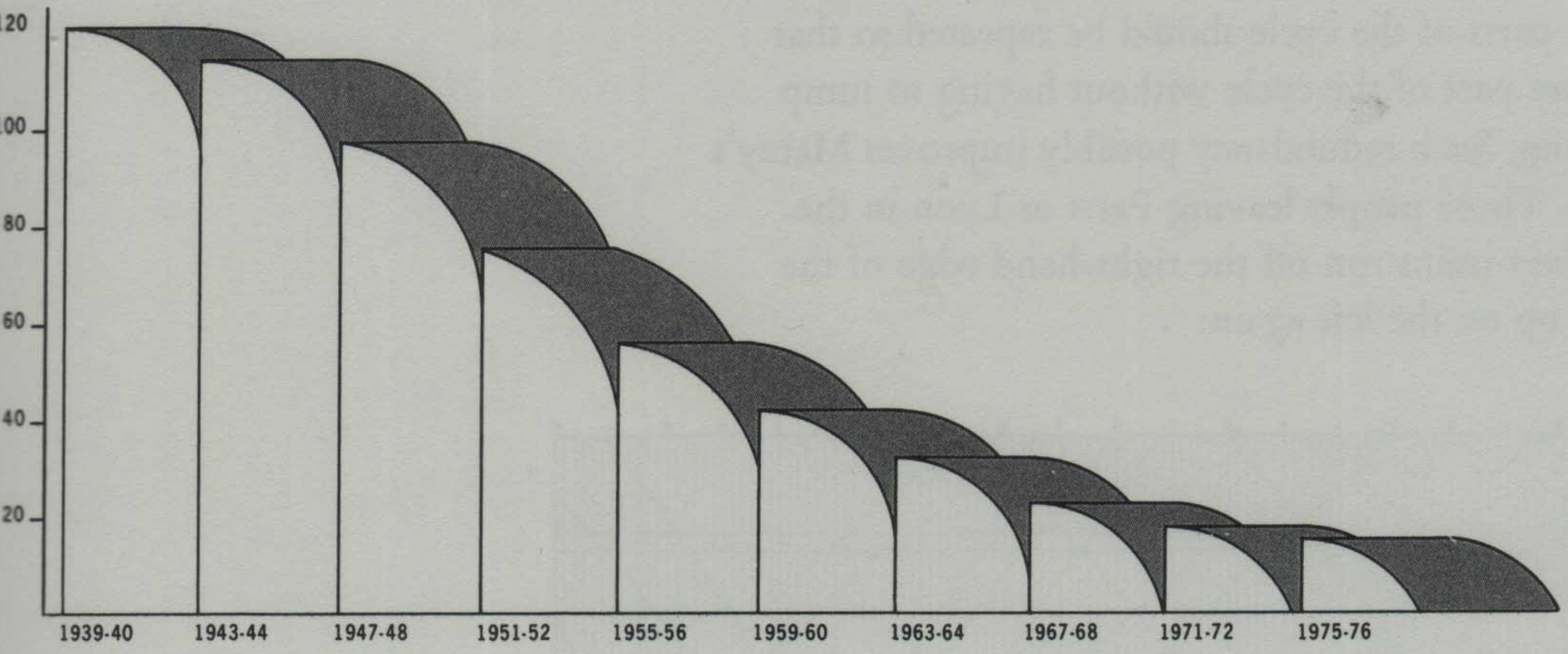
Erase non-data-ink, within reason.

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.

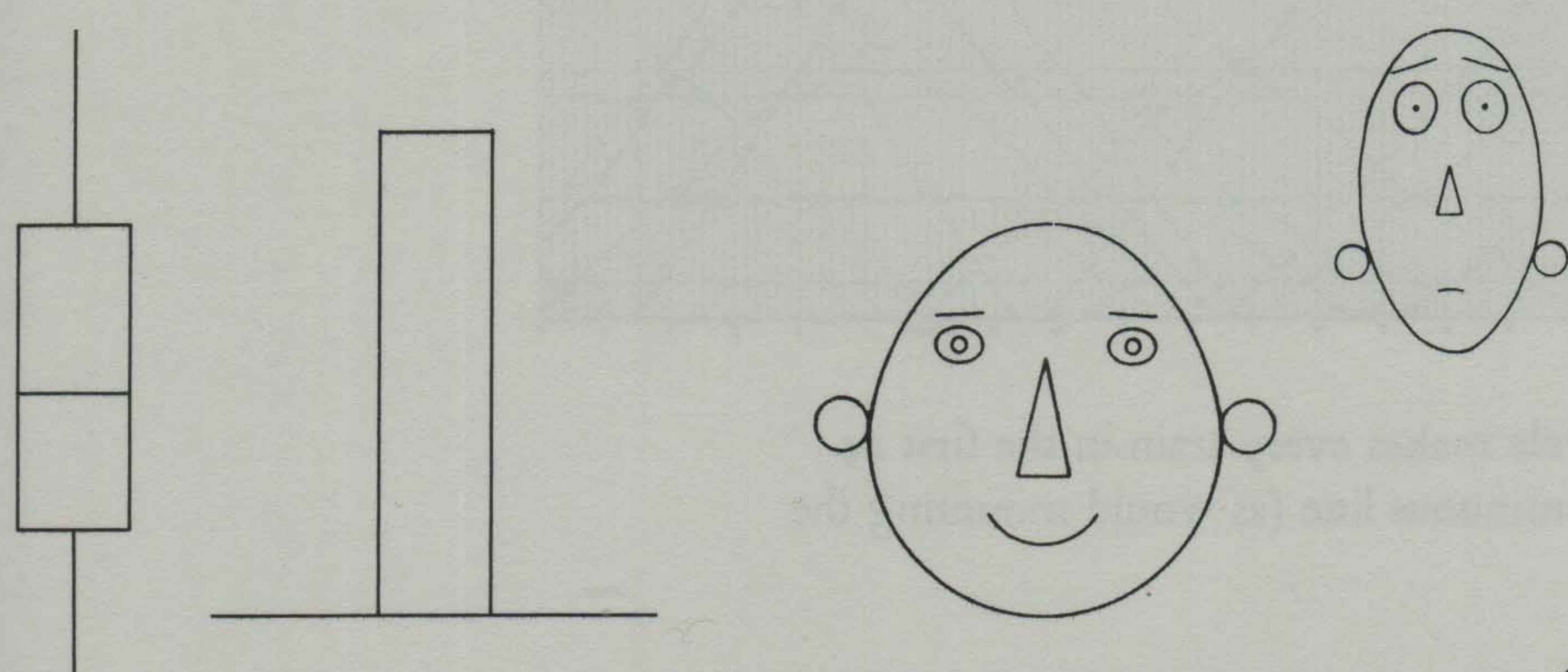
Redundant data-ink depicts the same number over and over. The labeled, shaded bar of the bar chart, for example,

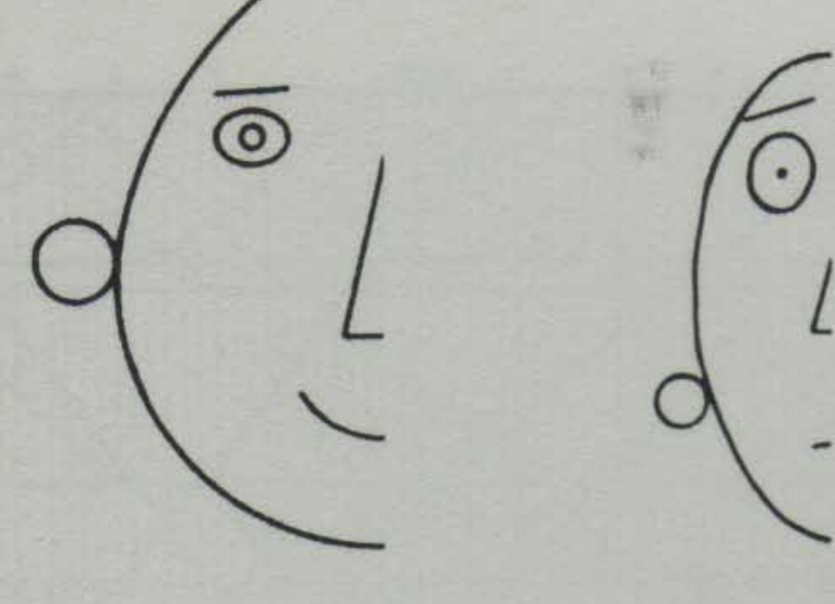


unambiguously locates the altitude in six separate ways (any five of the six can be erased and the sixth will still indicate the height): as the (1) height of the left line, (2) height of shading, (3) height of right line, (4) position of top horizontal line, (5) position (not content) of number at bar's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





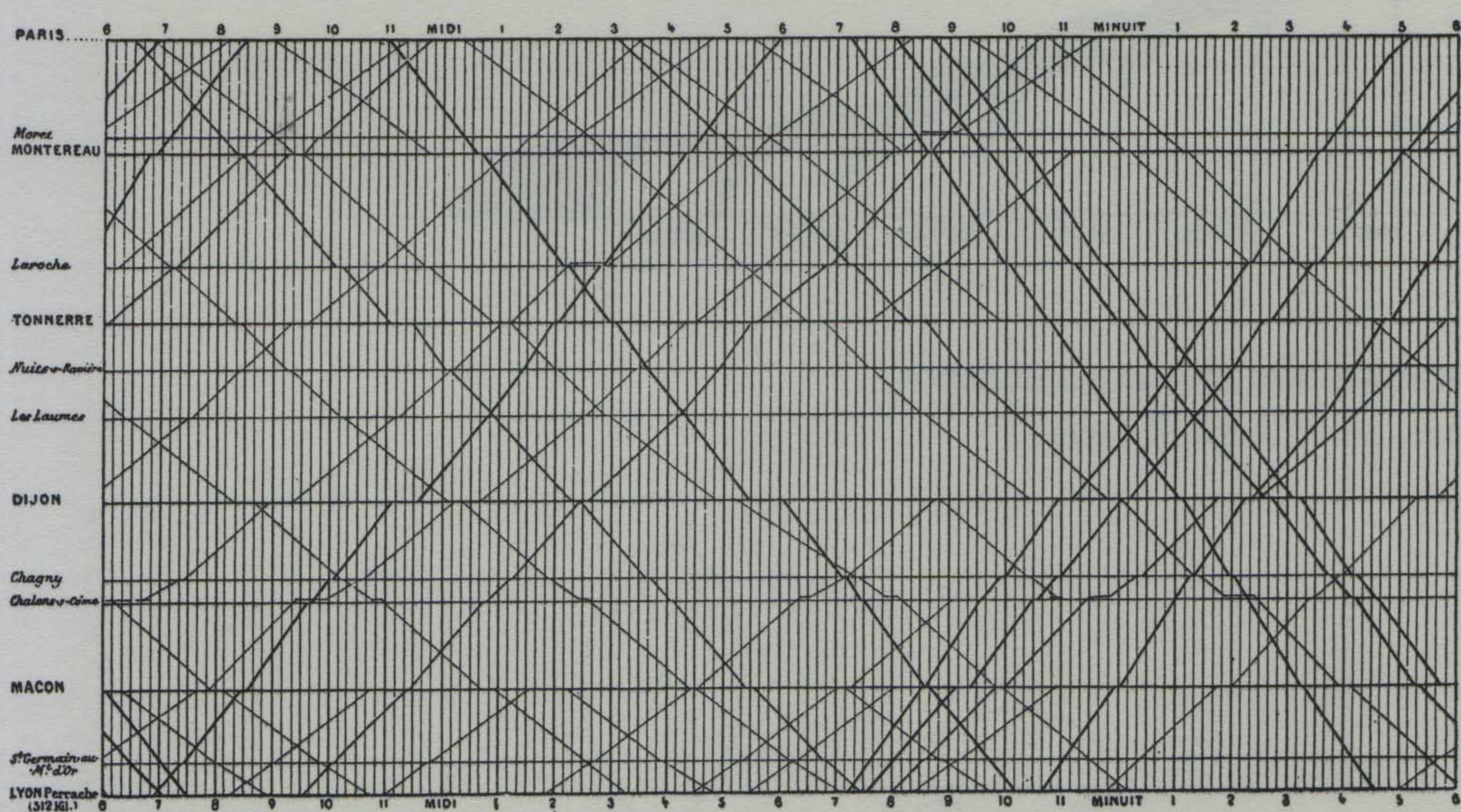
Half-faces carry the same information as full faces. Halves may be easier to sort (by matching the right half of an unsorted face to the left half of a sorted face) than full faces. Or else an asymmetrical full face can be used to report additional variables.[1]

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]

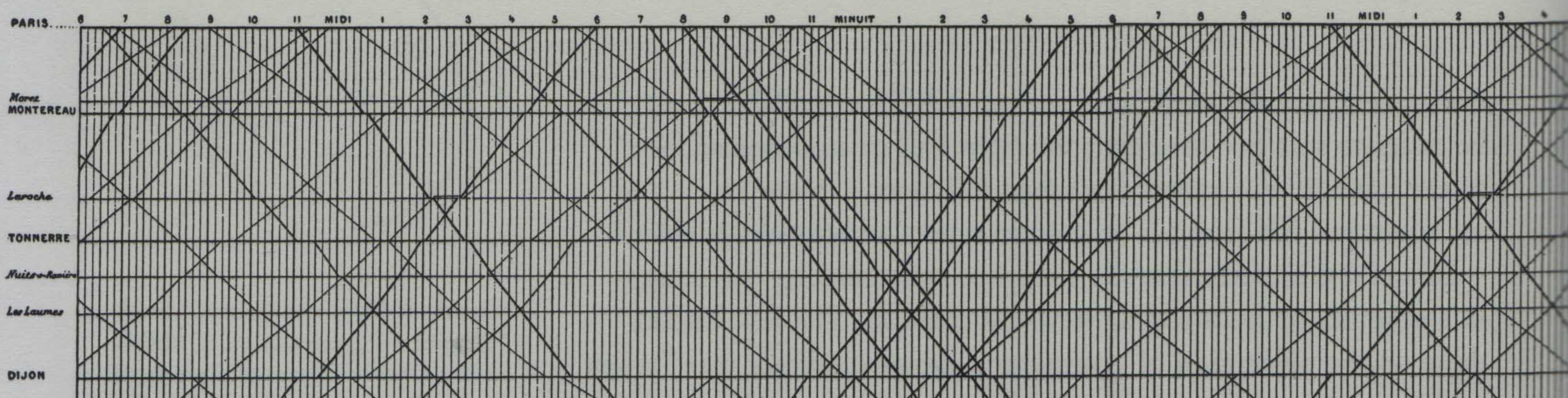
[1] Bernhard Flury and Hans Riedwyl, "Graphical Representation of Multivariate Data by Means of Asymmetrical Faces," *Journal of the American Statistical Association*, 76 (December 1981), 757–765.

[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:

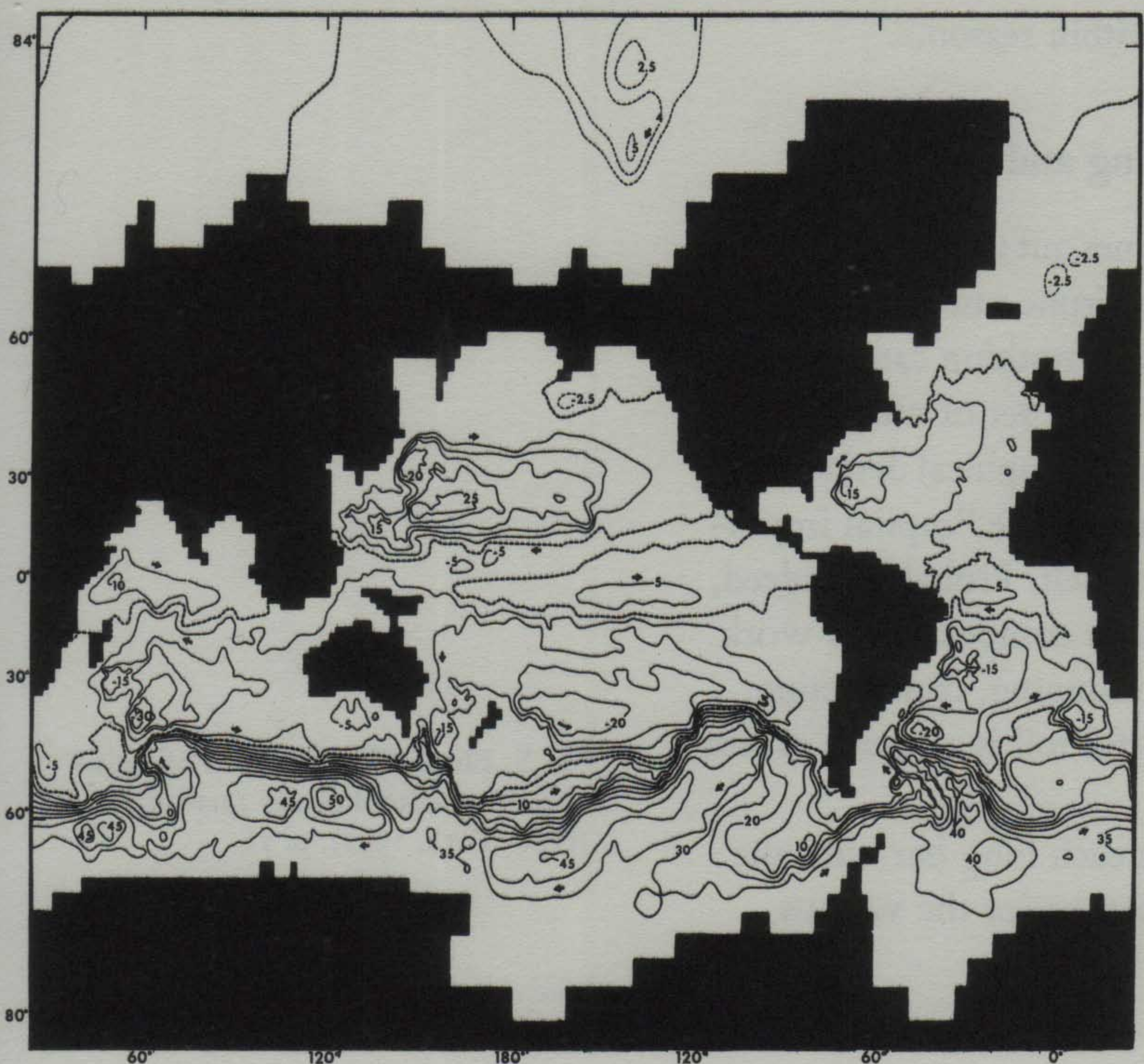


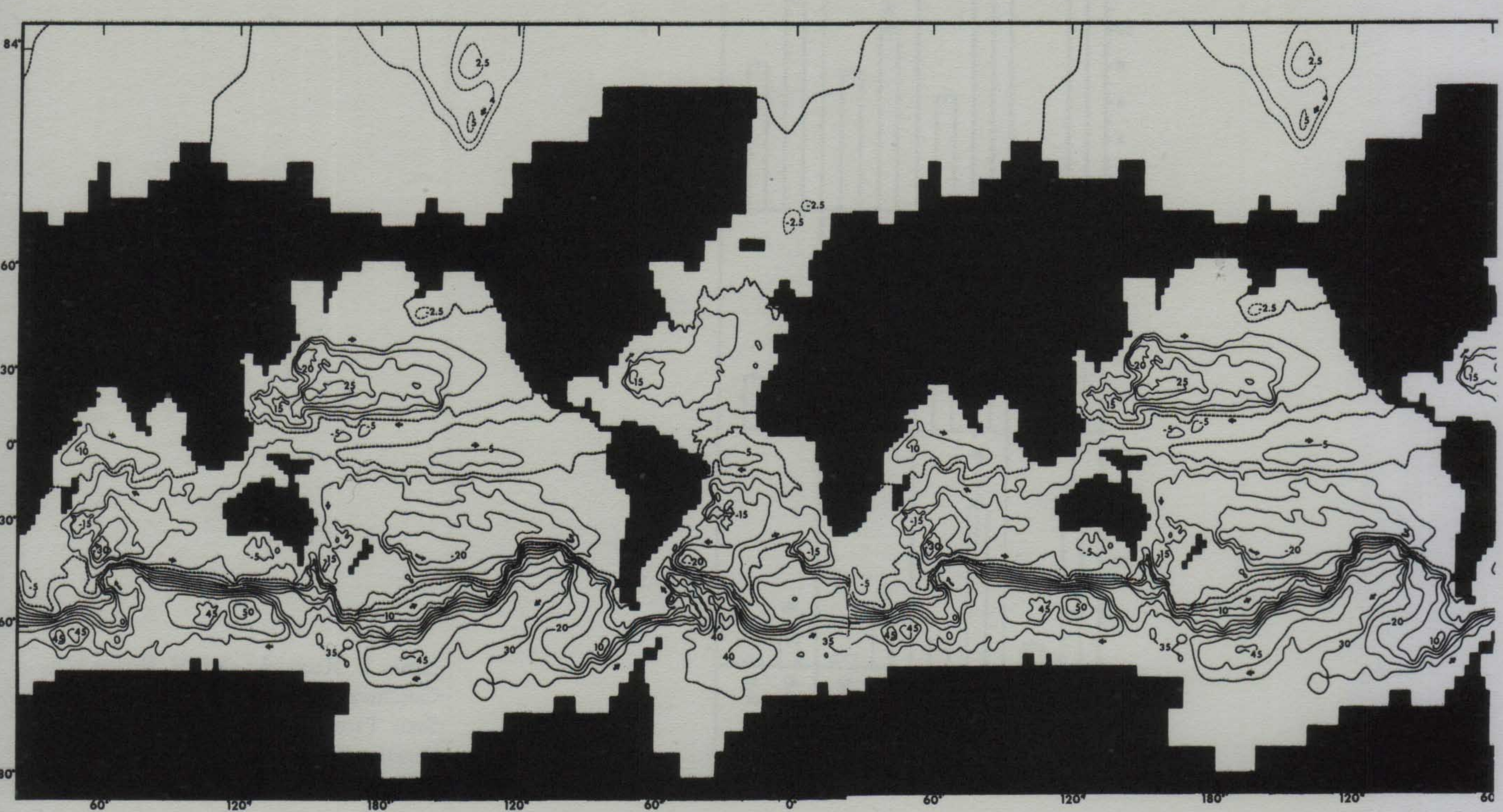
Attaching an extra half cycle makes every train in the first 24 hours of the schedule a continuous line (as would mounting the original on a cylinder):



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:

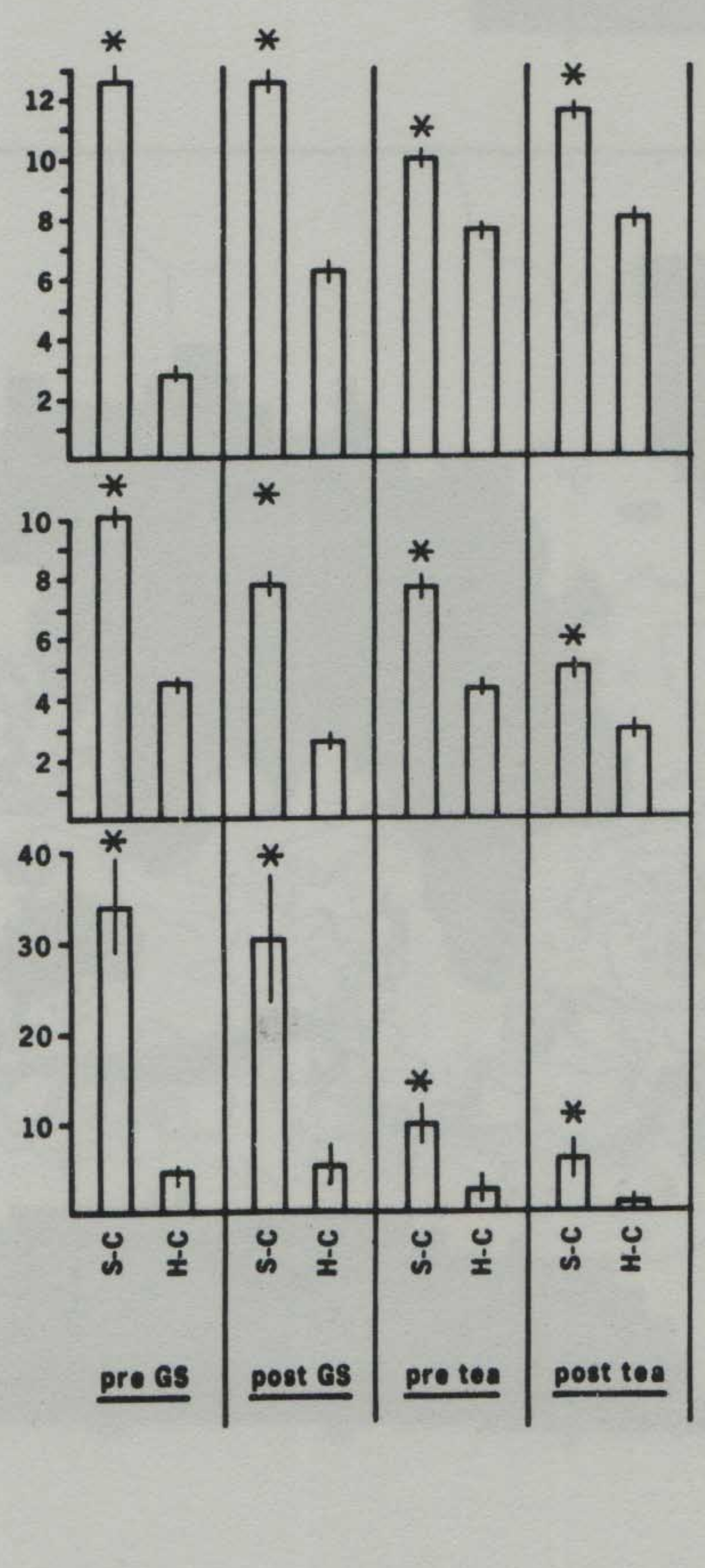
Erase redundant data-ink, within reason.

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]

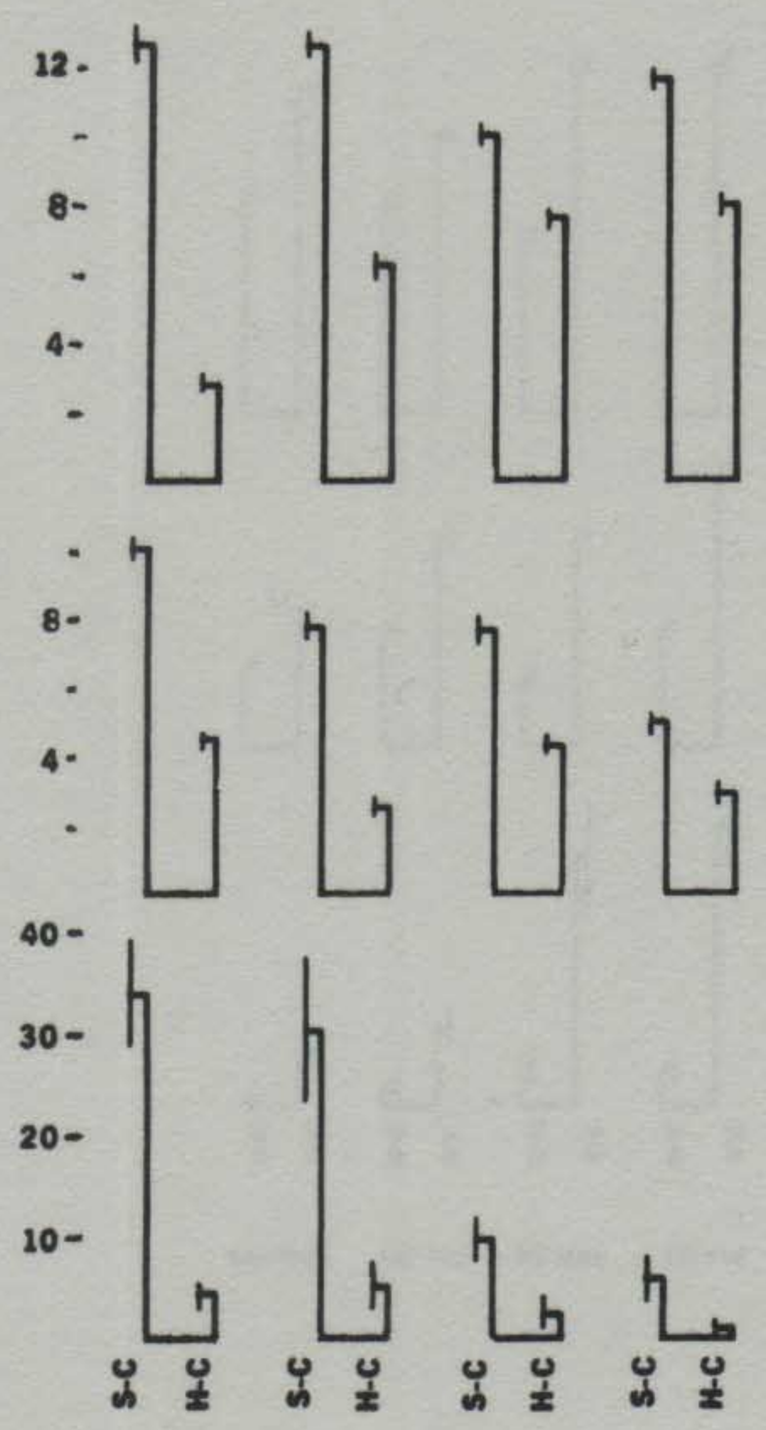
[3] T. S. Eliot, "The Function of Criticism," in *Selected Essays 1917–1932* (New York, 1932), p. 18.

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:

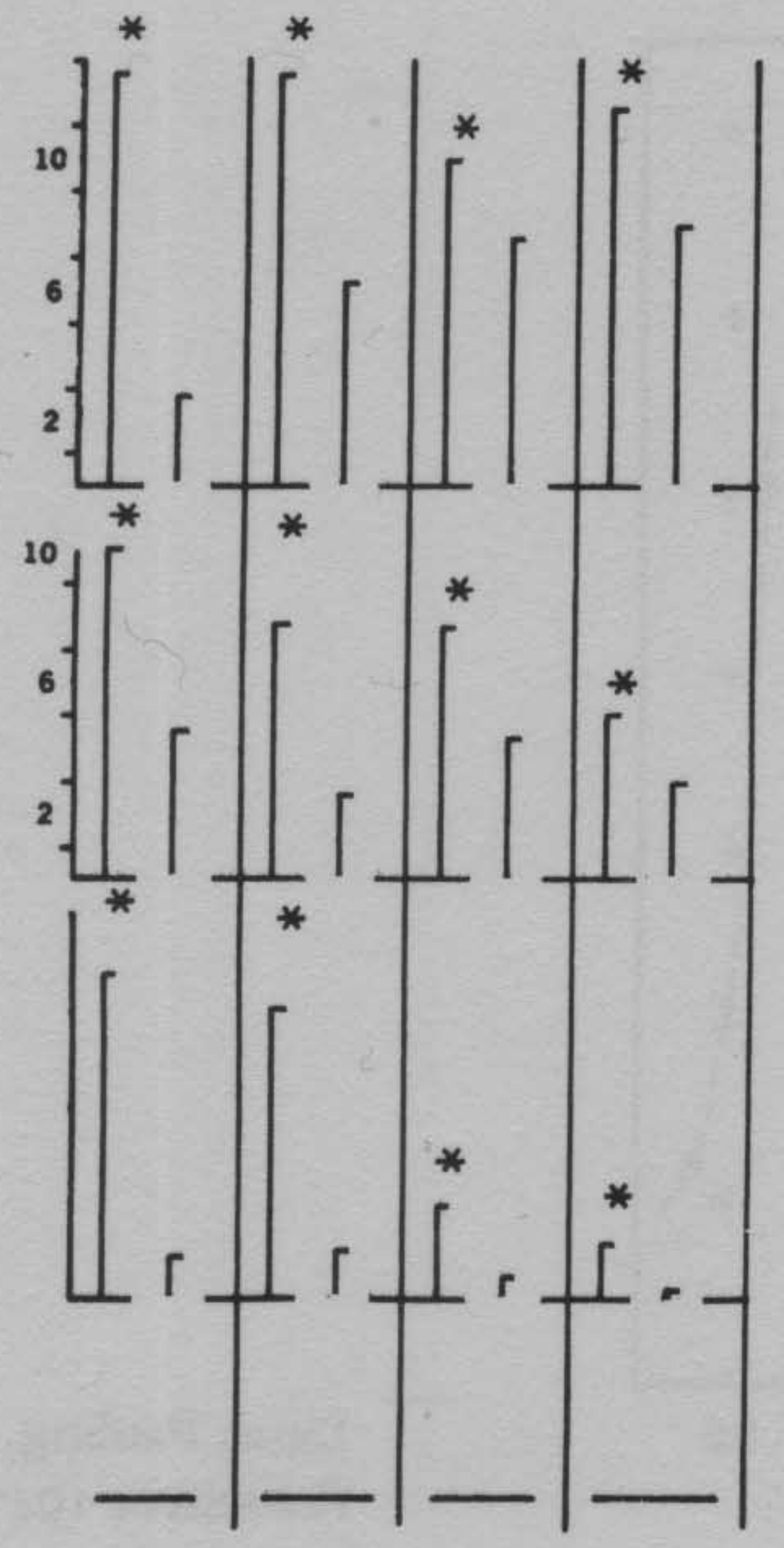


James T. Kuznicki and N. Bruce McCutcheon, "Cross-Enhancement of the Sour Taste on Single Human Taste Papillae," *Journal of Experimental Psychology: General*, 108 (1979), 76.

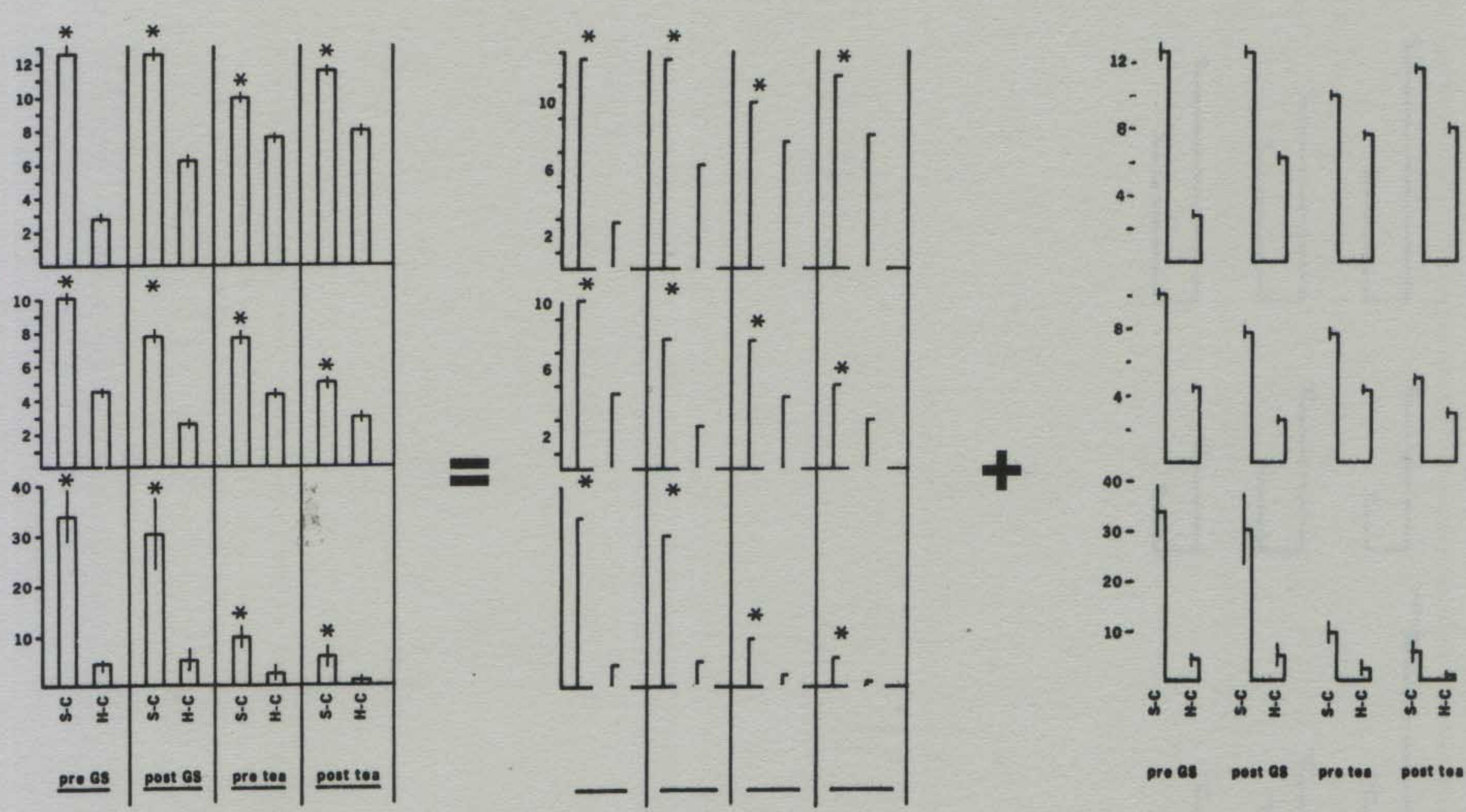
Vigorous pruning improves the graphic immensely, while still retaining all the data of the original. It is remarkable that erasing alone can work such a transformation:



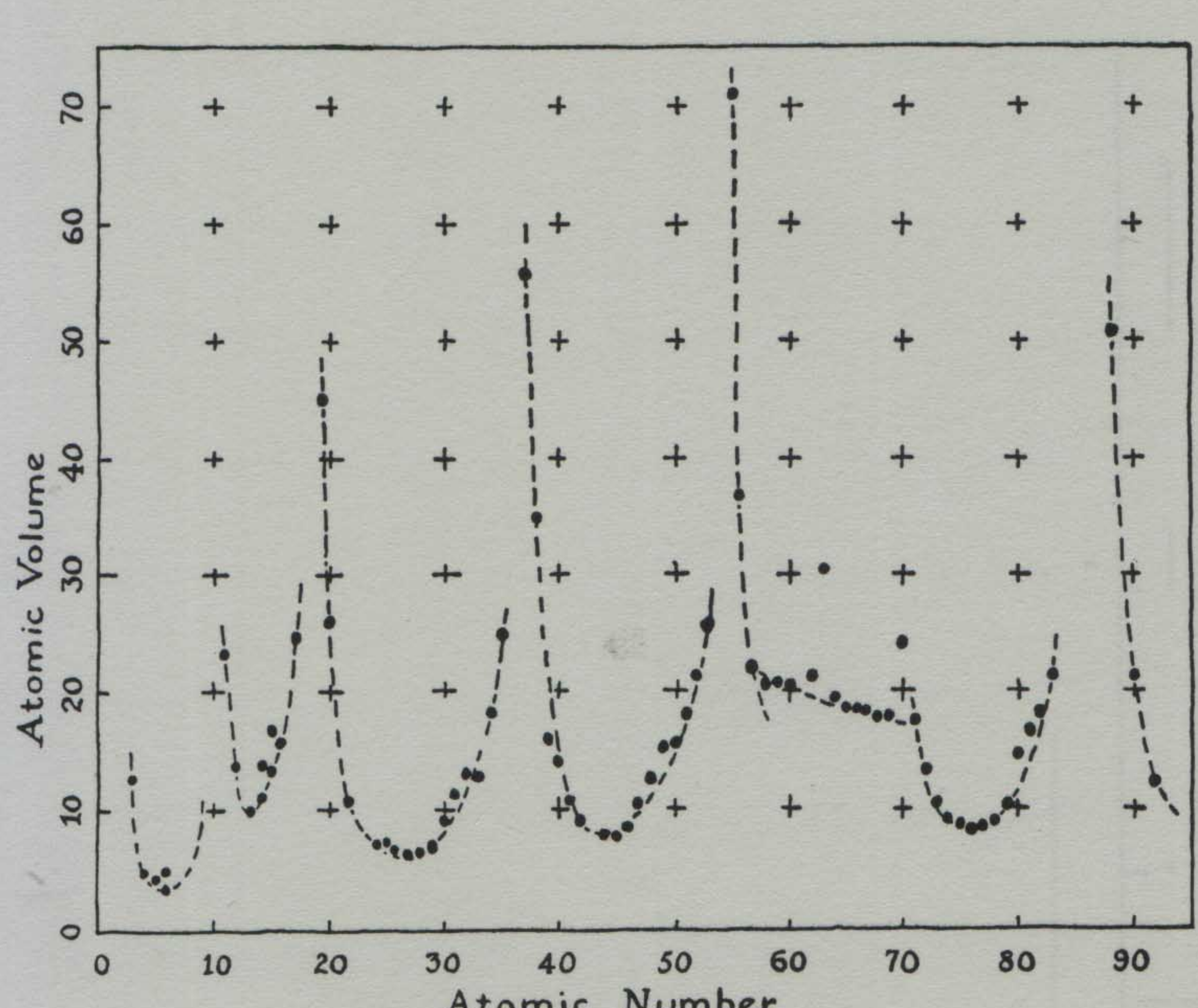
The horizontals indicate the paired comparisons and would change if the experimental design changed—so they count as information-carrying. All the asterisks are out since every paired comparison was statistically significant, a point that the caption can note. Here is the mix of non-data-ink and redundant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

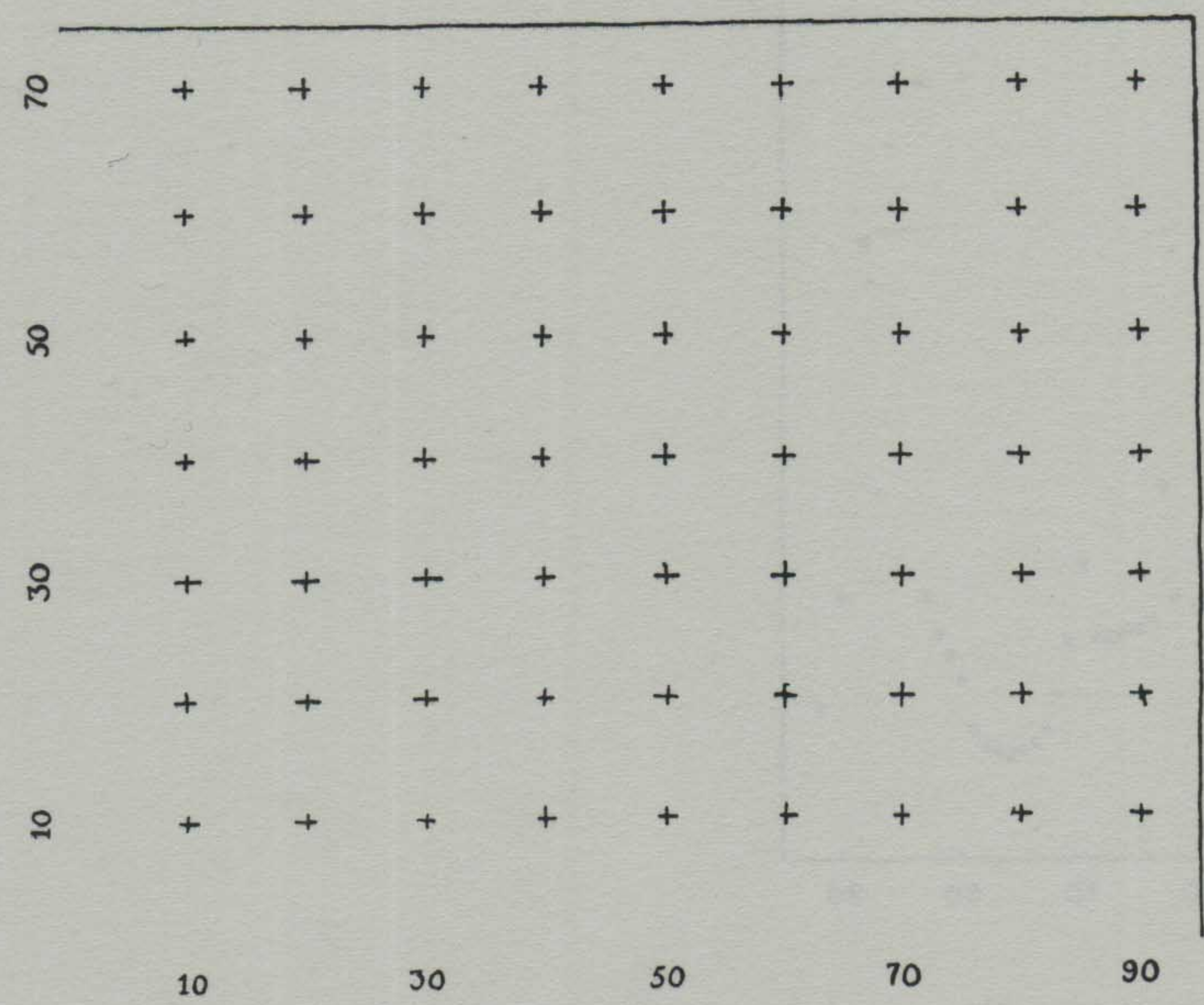


The next graphic, drawn by the distinguished science illustrator Roger Hayward, shows the periodicity of properties of chemical elements, exemplified by atomic volume as a function of atomic number. The data-ink ratio is less than 0.6, lowered because the 76 data points and the reference curves are obscured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

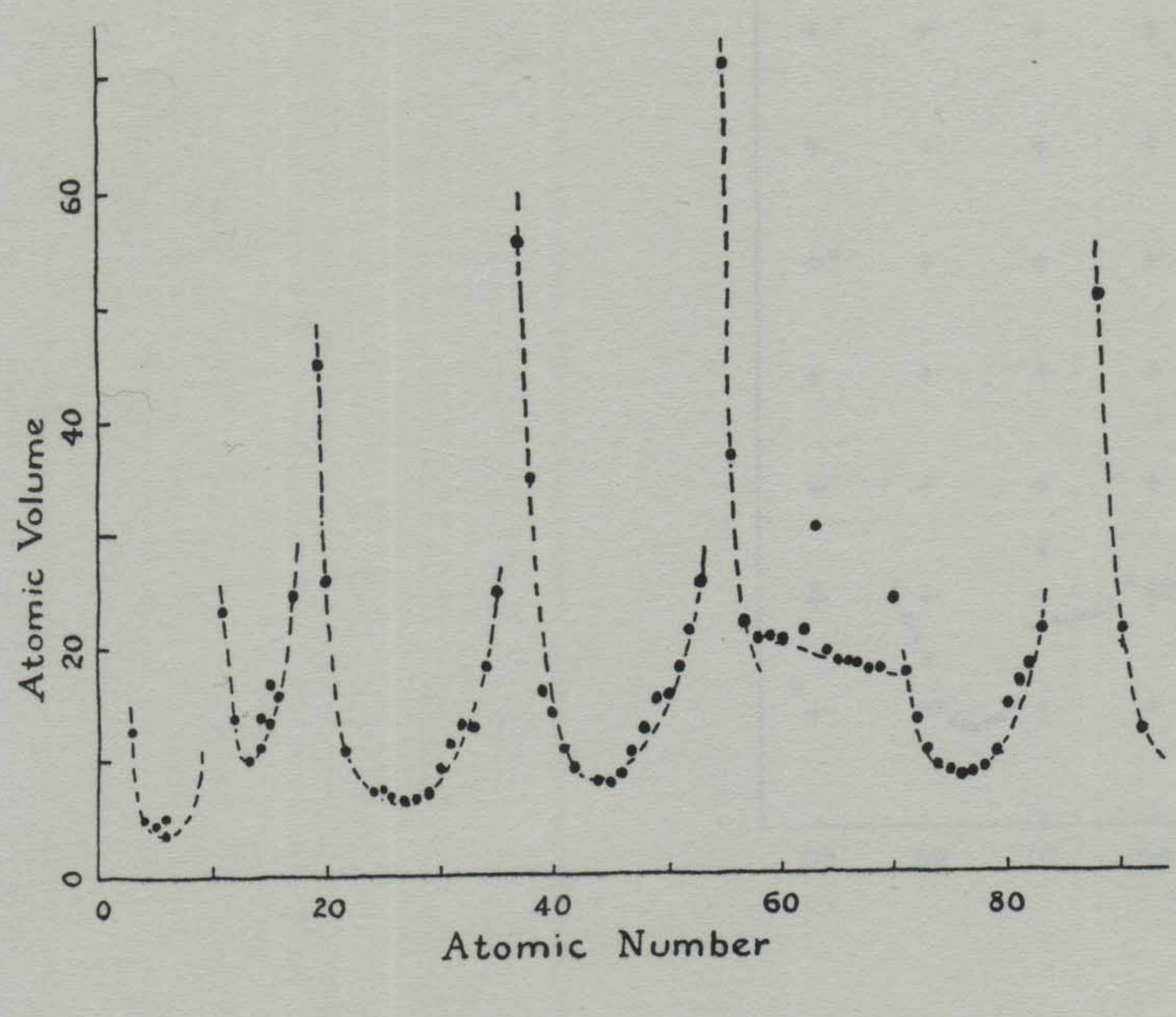


Linus Pauling, *General Chemistry* (San Francisco, 1947), p. 64.

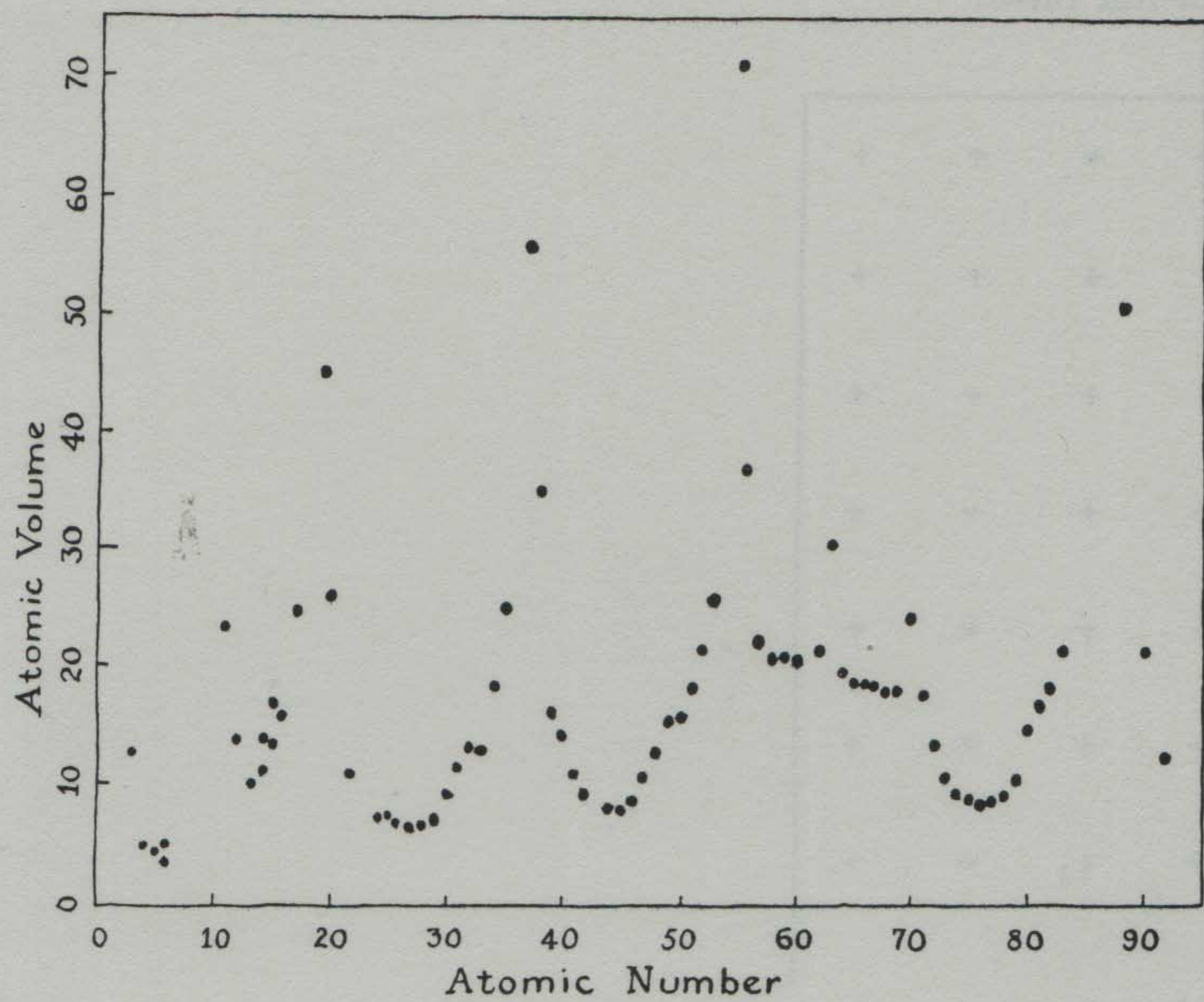
The grid ticks compete with the essential information of the graphic, the curves tracing out the periods and the empirical observations. The little grid marks and part of the frame can be safely erased, removed from the denominator of the data-ink ratio:



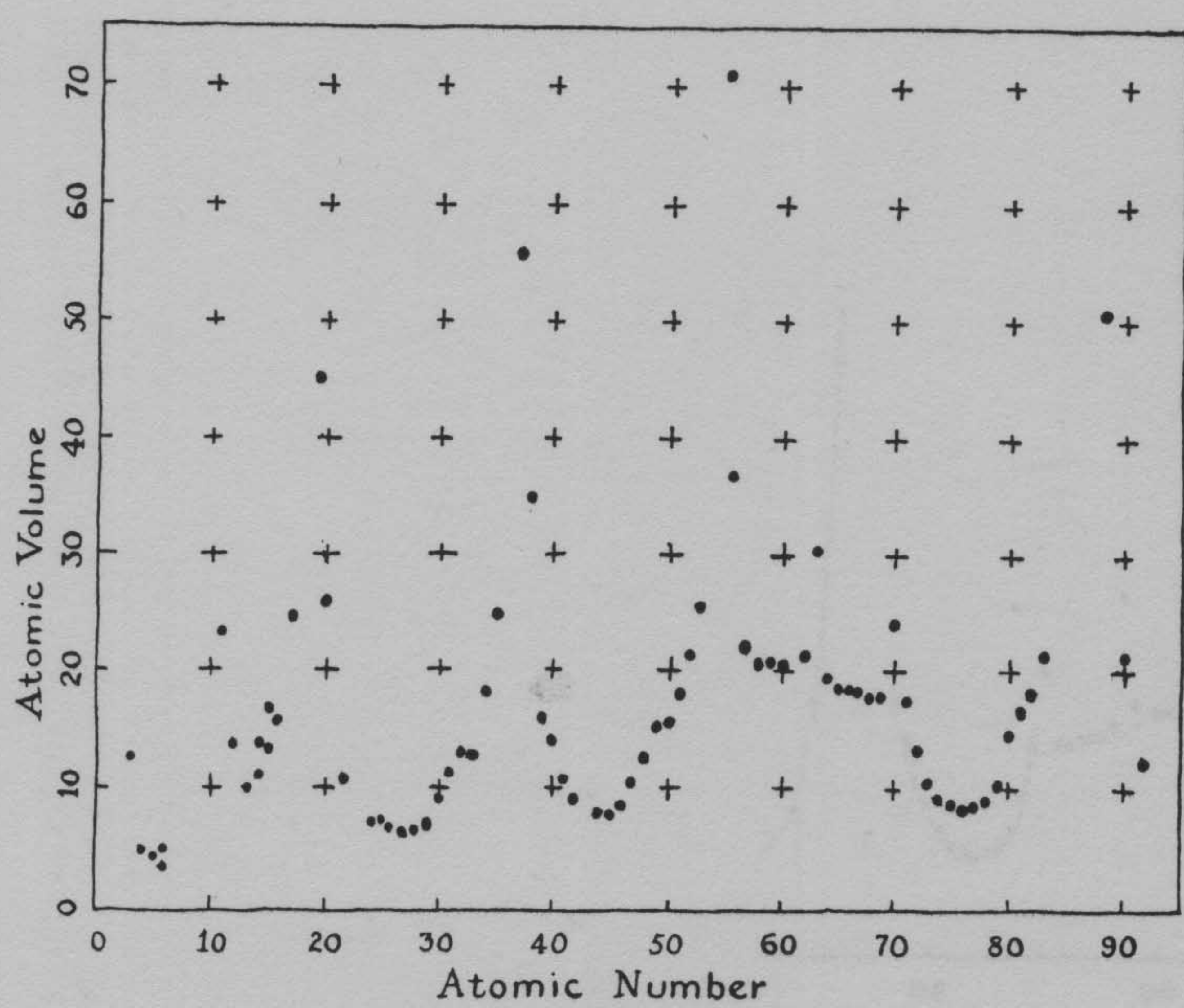
The uncluttered display brings out another aspect of the data: several of the elements do not fit the smooth theoretical curves all that well. The data-ink ratio has increased to about .9, with only the frame lines remaining as pure non-information:



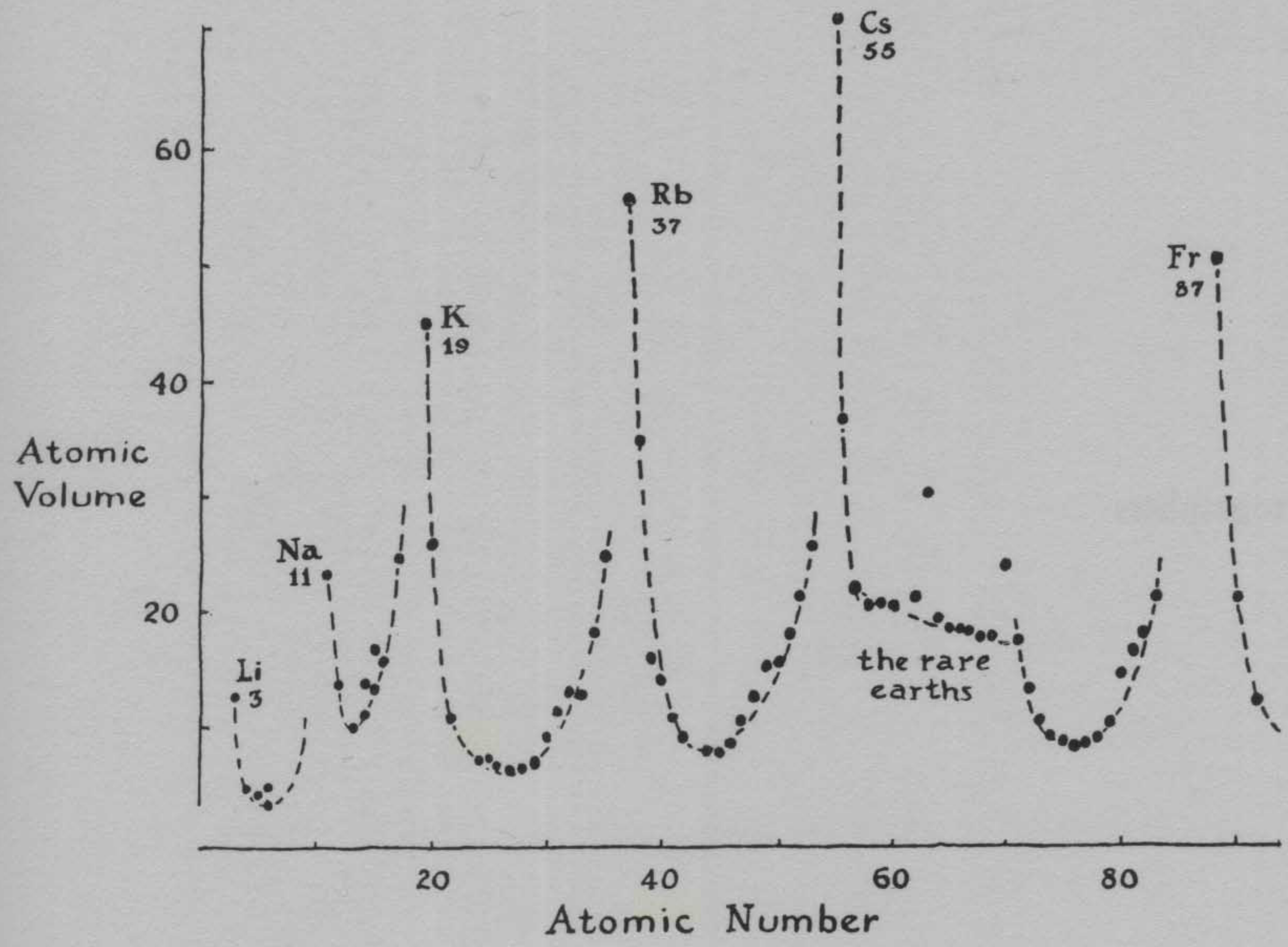
The reference curves prove essential for organizing the data to show the periodicity. The curves create a structure, giving an ordering, a hierarchy, to the flow of information from the page:



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.

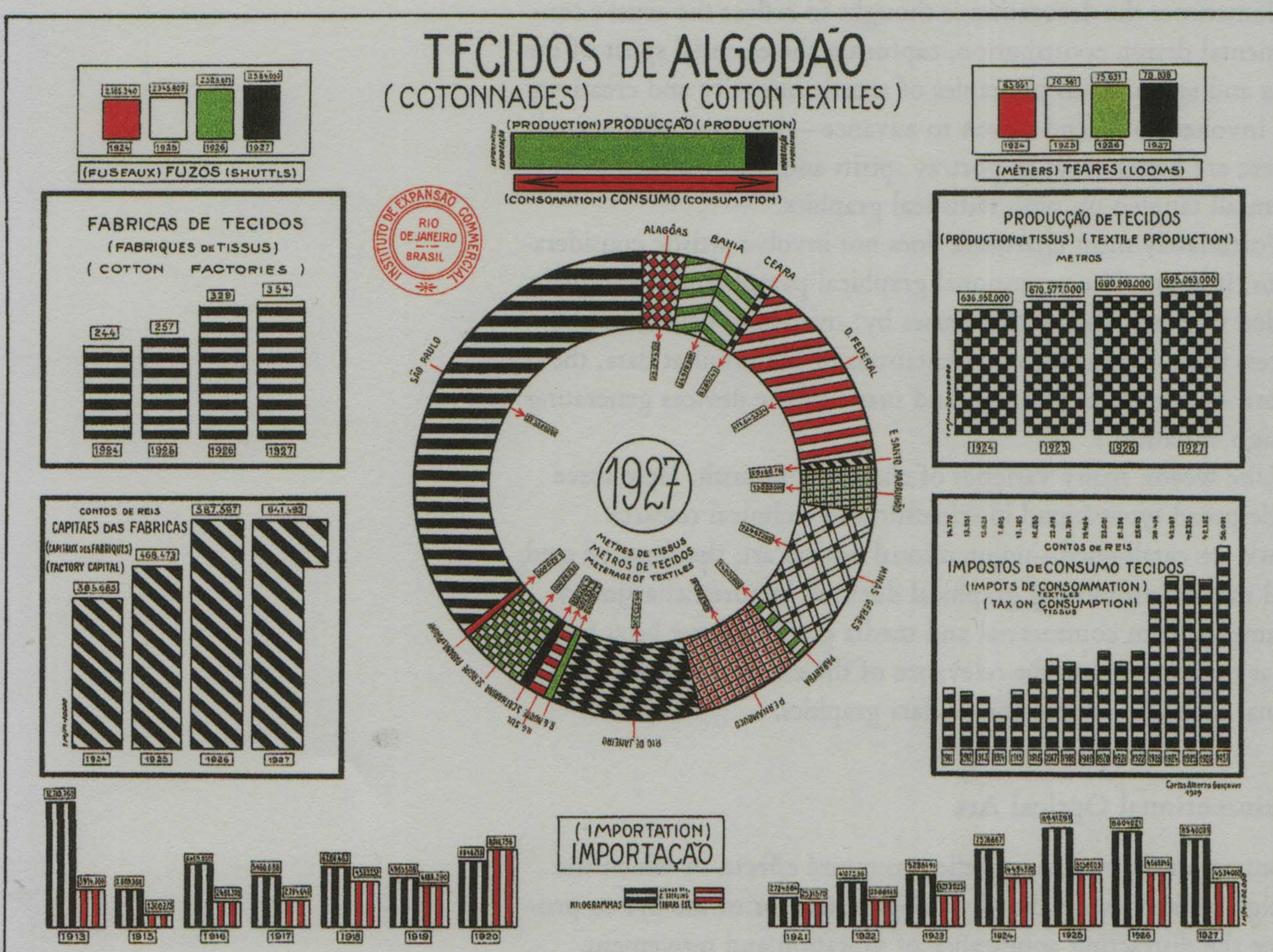
Unintentional Optical Art

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.

The effect extends beyond the ink of the design to the whole page. When exploited by the experts, such as Bridget Riley and Victor Vasarely, op art effects are undoubtedly eye-catching.

But statistical graphics are also often drawn up so as to shimmer. This moiré vibration, probably the most common form of graphical clutter, is inevitably bad art and bad data graphics. The noise clouds the flow of information as these examples from technical and scientific publications illustrate:

Instituto de Expansão Commercial, *Brasil: Graphicos Economicos–Estatisticas* (Rio de Janeiro, 1929), p. 15.



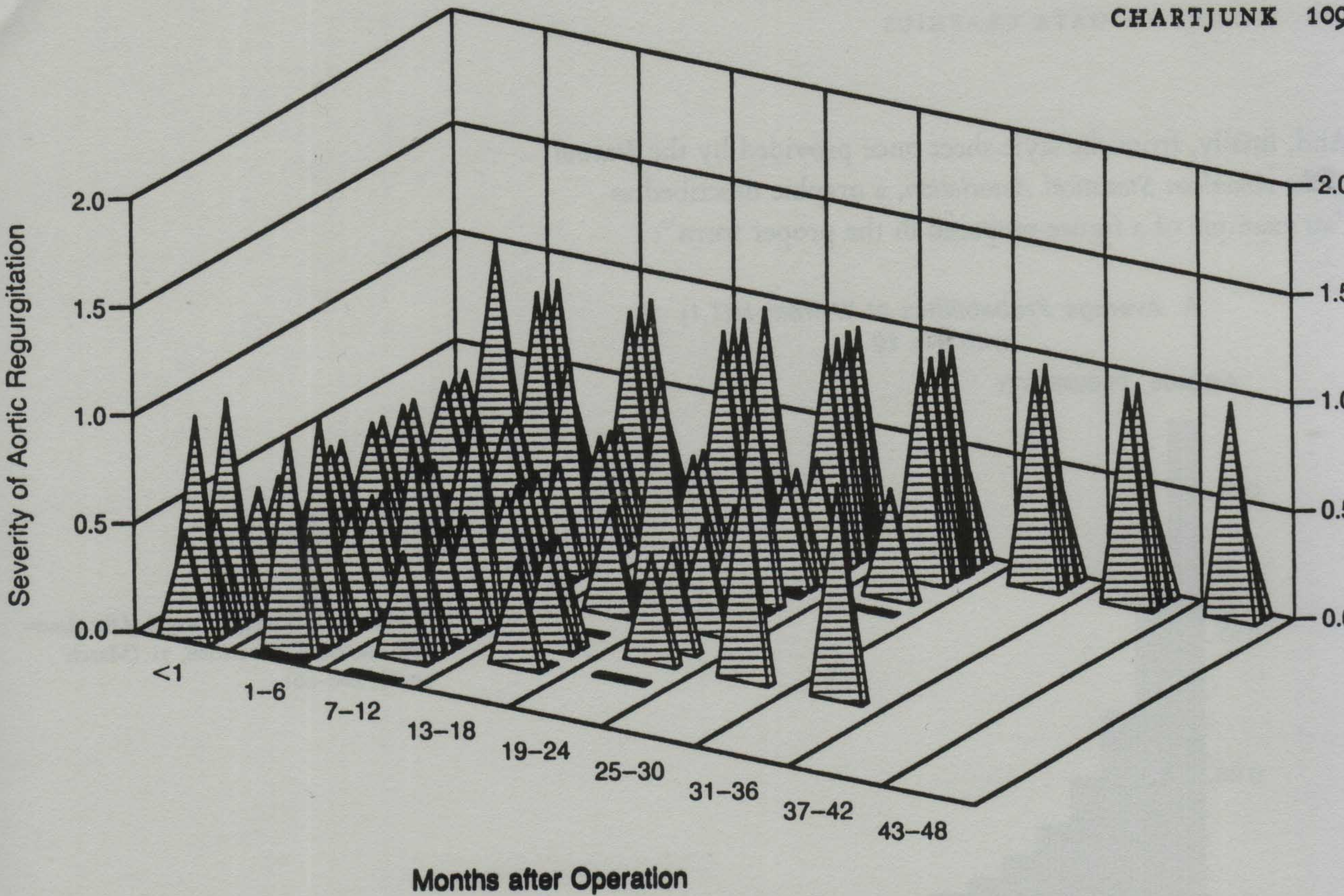
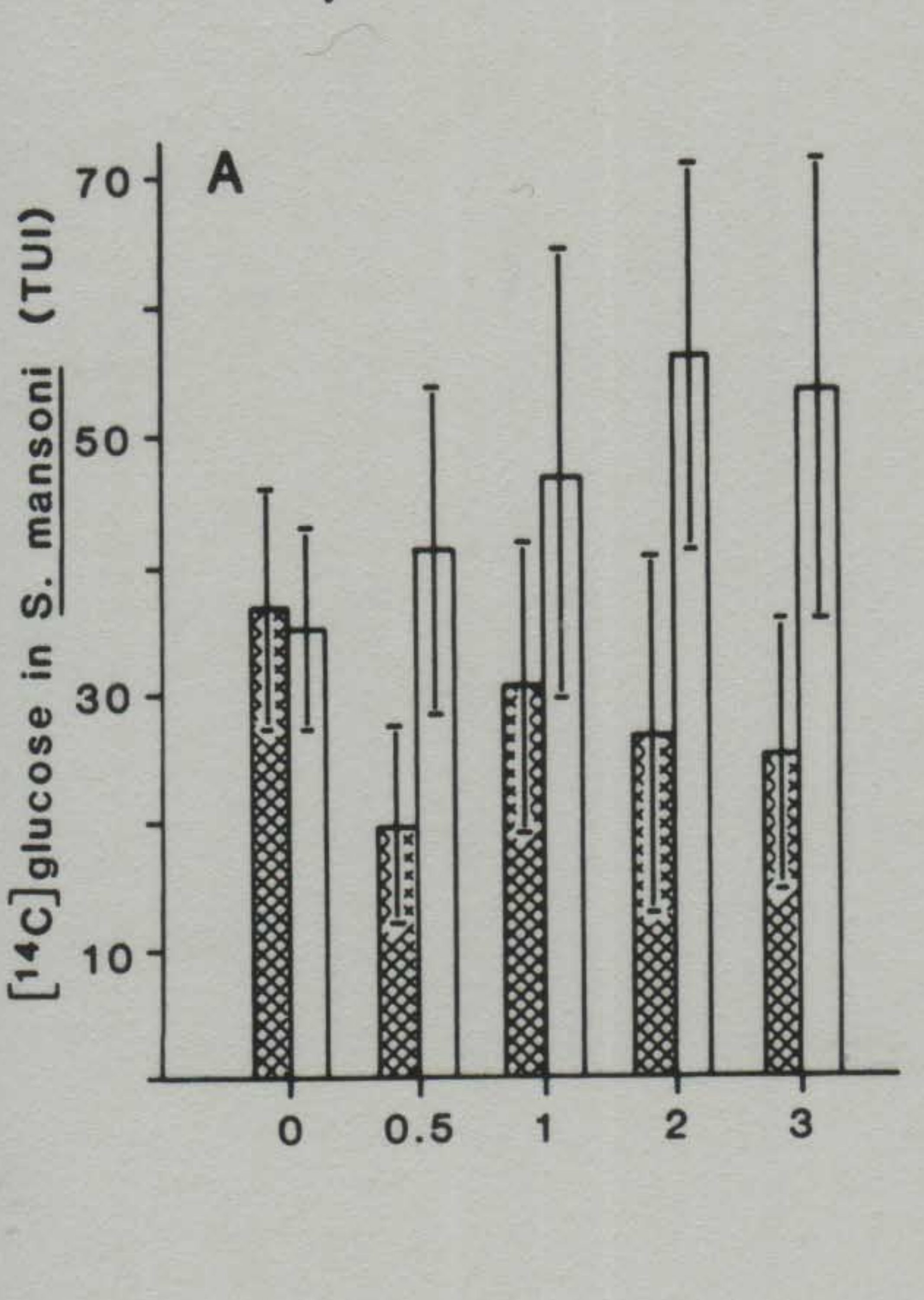
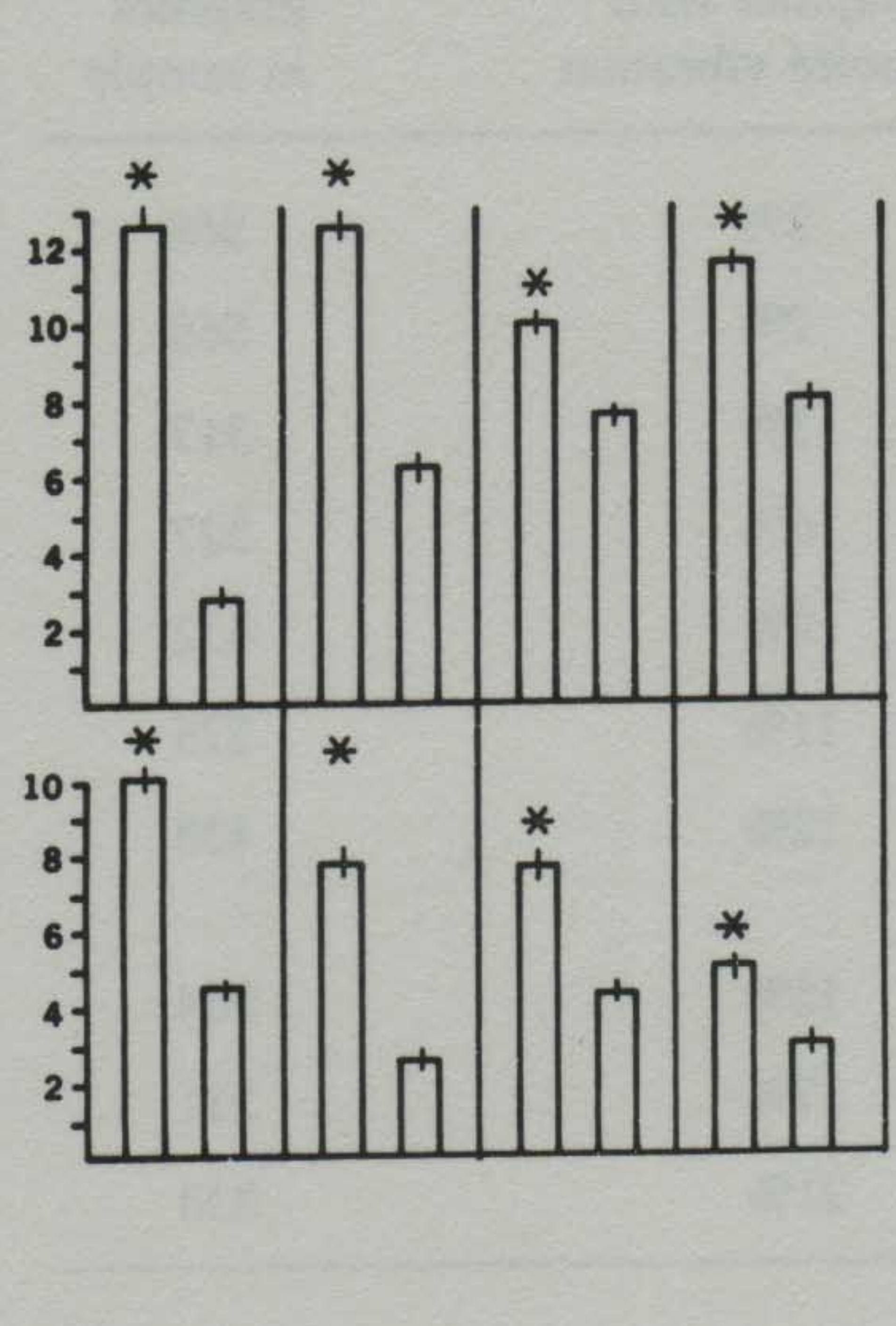


Figure 2. Serial Echocardiographic Assessments of the Severity of Regurgitation in the Pulmonary Autograft in 31 Patients. The numerical grades were assigned according to the severity of regurgitation, as follows: 0, none; 0.5, trivial; 1.0 to 1.5, mild; 2.0, moderate; and 3.0, severe.

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.

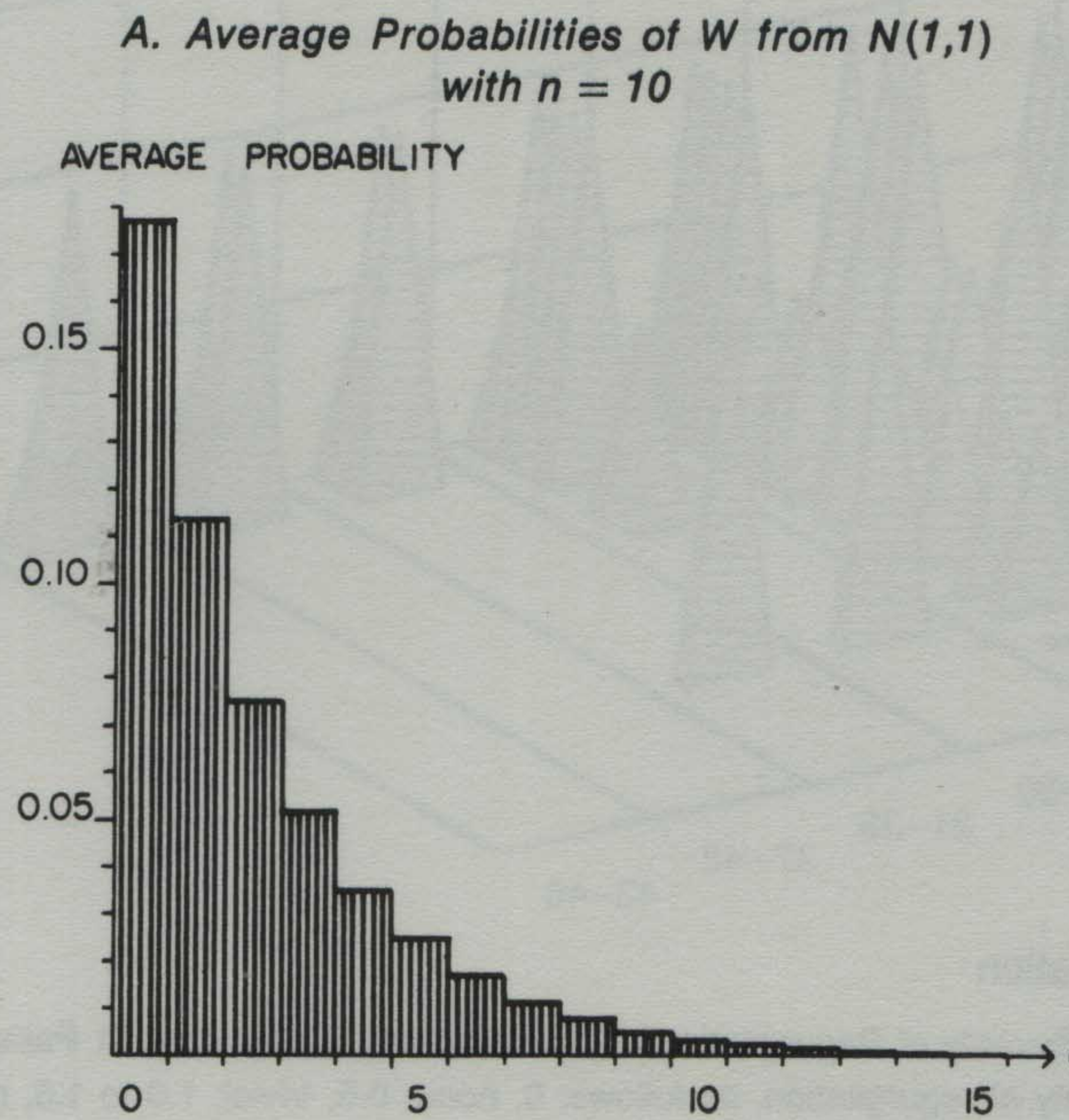




James T. Kuznicki and N. Bruce McCutcheon, "Cross-Enhancement of the Sour Taste on Single Human Taste Papillae," *Journal of Experimental Psychology: General*, 108 (1979), 76.

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":



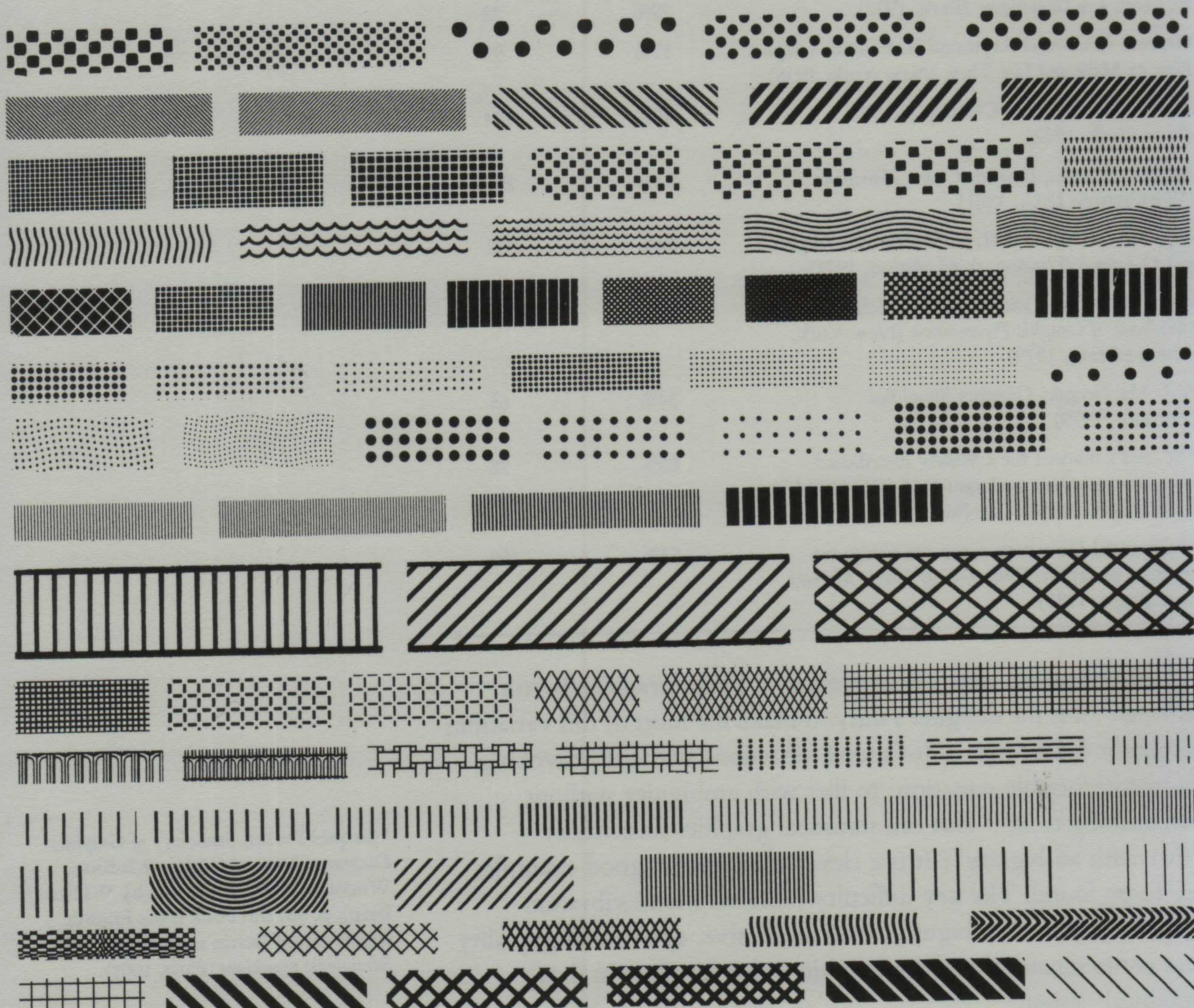
"JASA Style Sheet," *Journal of the American Statistical Association*, 71 (March 1976), 260–261.

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
Biochemistry	2%	568
Journal of Biological Chemistry	2%	565
Journal of the American Chemical Society	3%	317
Journal of Chemical Physics	6%	327
Biochimica et Biophysica Acta	8%	432
Nature	11%	225
Proceedings of the National Academy of Sciences, U.S.A.	12%	438
Lancet	15%	364
Science	17%	311
New England Journal of Medicine	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 chartjunky graphics in the more recent publications. Computer graphics are particularly active:

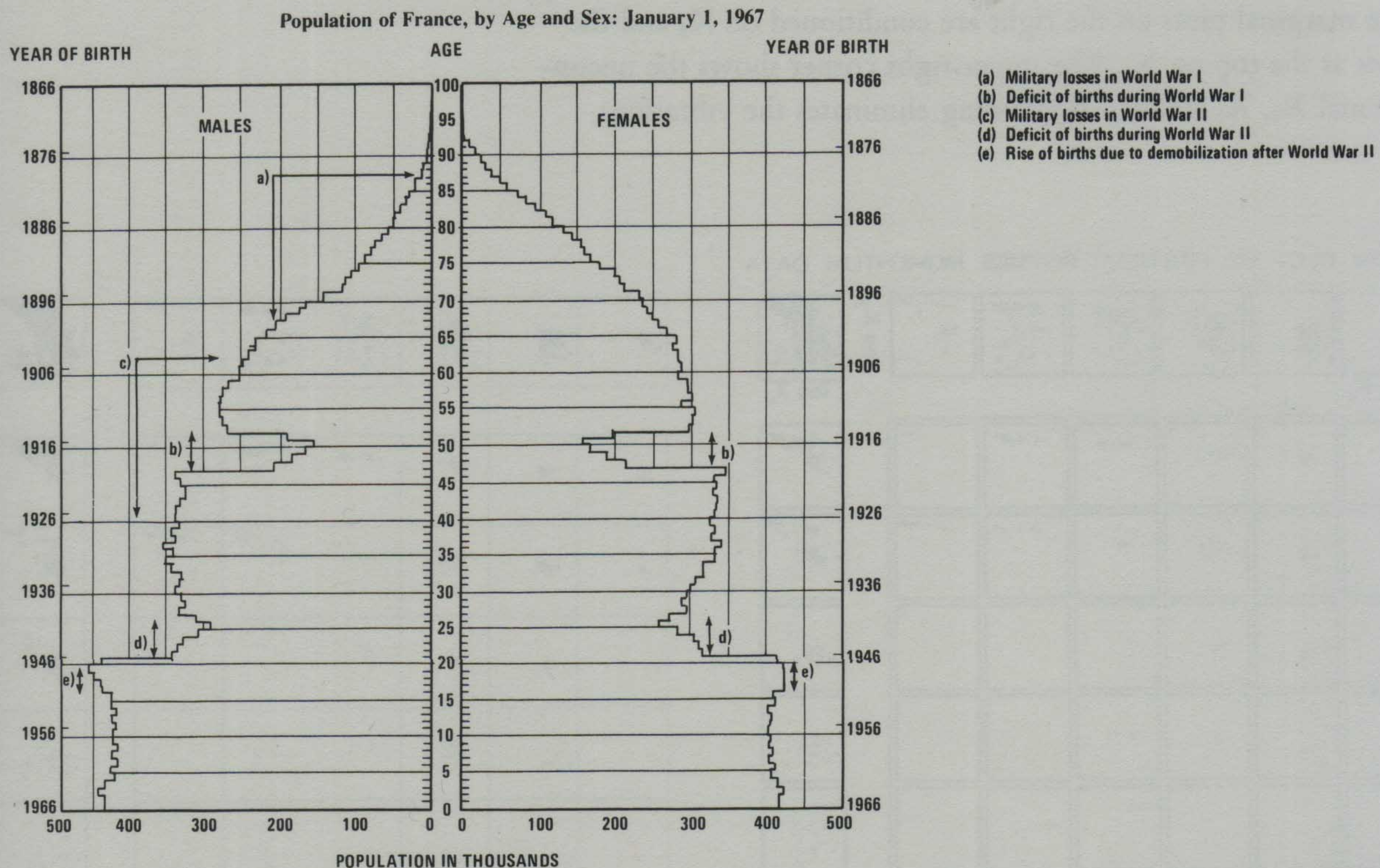
Textbooks and handbooks of statistical graphics; and manuals for computer graphics programs (ordered by date of publication)	Percentage of graphics with moiré vibration	Total number of graphics
Willard C. Brinton, *Graphic Methods for Presenting Facts* (New York, 1914)	12%	255
R. Satet, *Les Graphiques*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

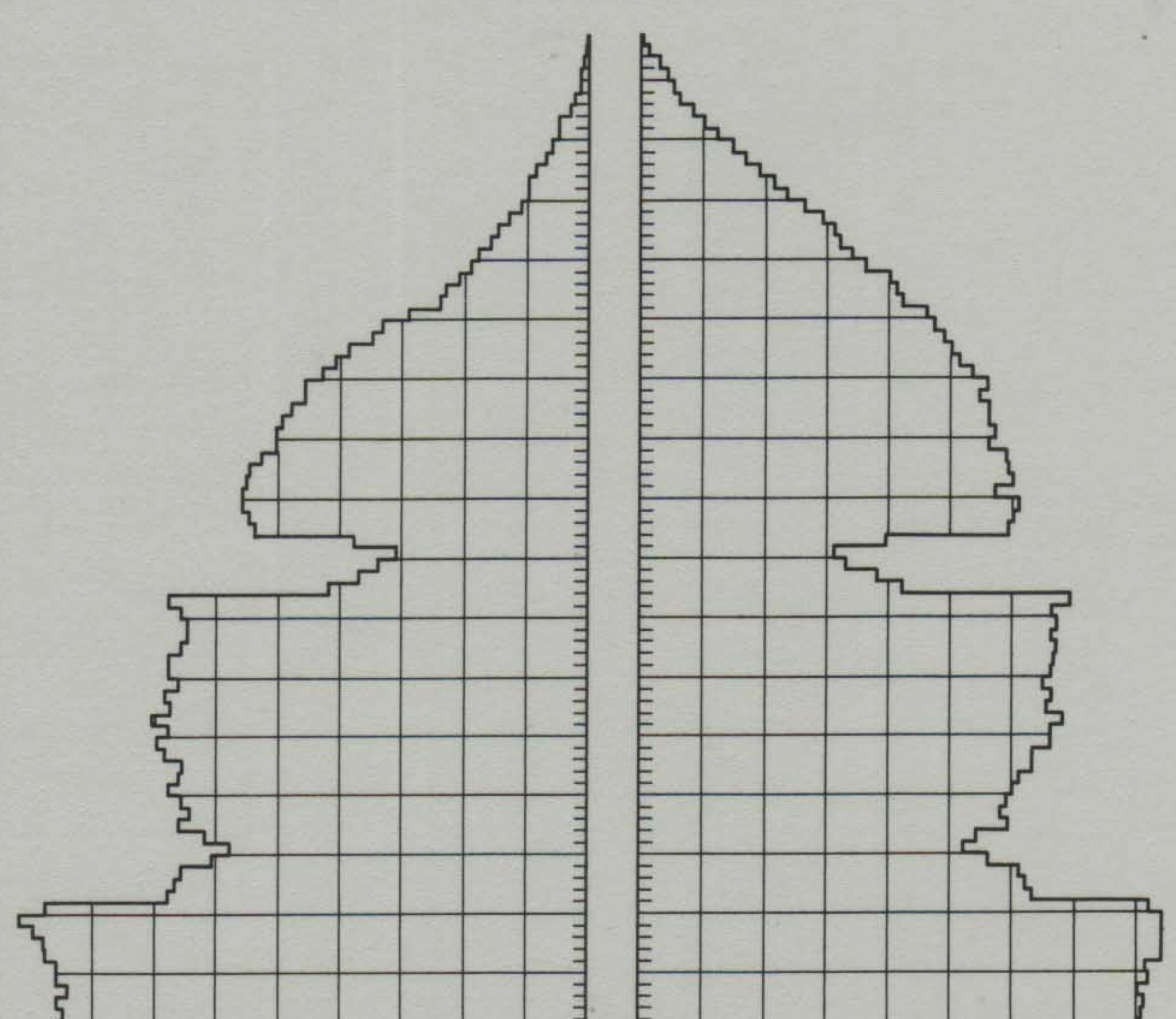
[1] Jacques Bertin, *Semiology of Graphics: Diagrams, Networks, Maps* (Madison, Wisconsin, 1983, translated by William J. Berg), p. 80; this book is the English translation of Bertin's important work, *Sémiologie graphique* (Paris, 1967).

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:



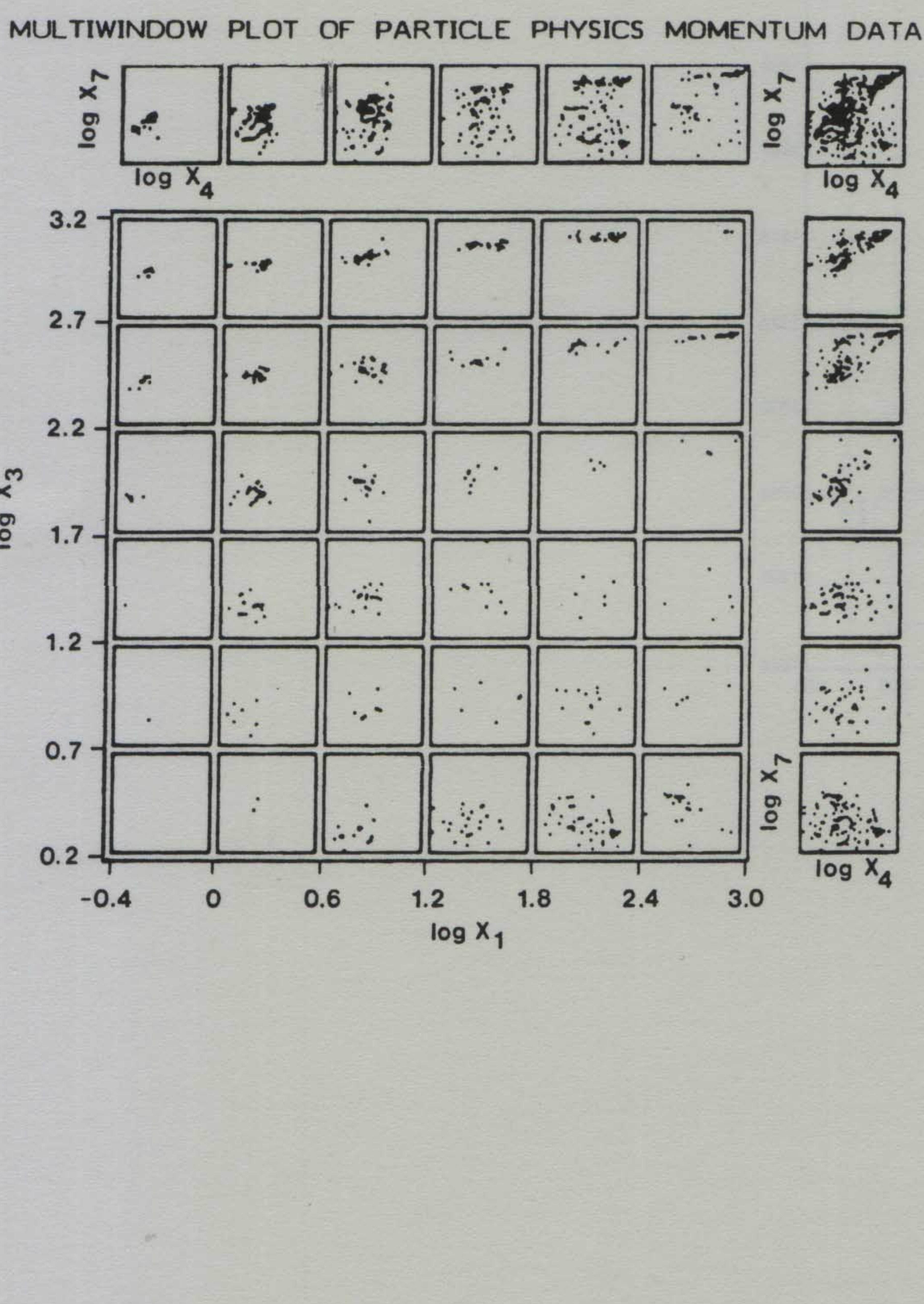
A revision quiets the grid and gives emphasis to the data:

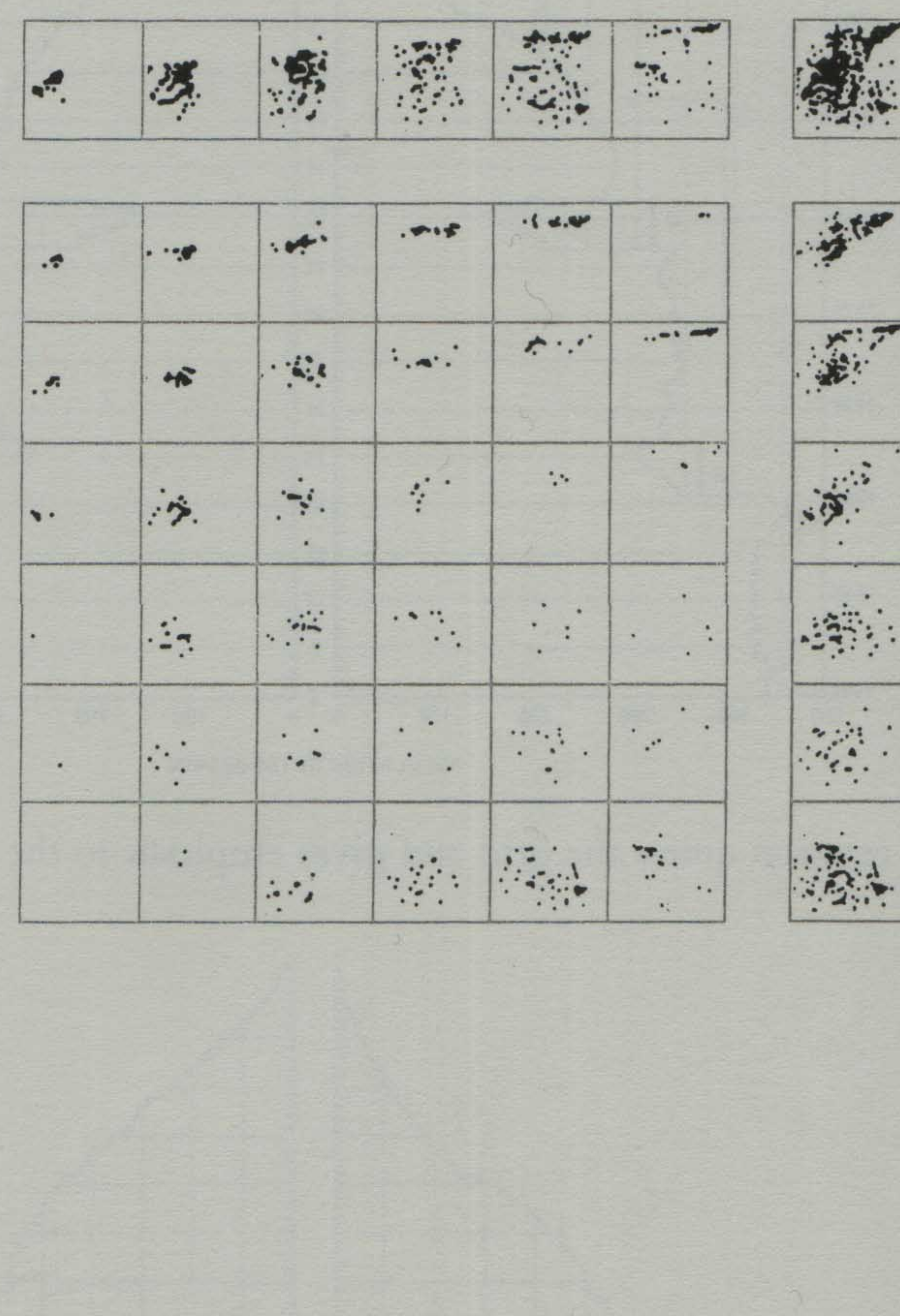


Based on data in Institut National de la Statistique et des Études Économiques, *Annuaire statistique de la France, 1968* (Paris, 1968), pp. 32–33; redrawn in Henry S. Shryock and Jacob S. Siegel, *The Methods and Materials of Demography* (Washington, D.C., 1973), vol. 1, 242.

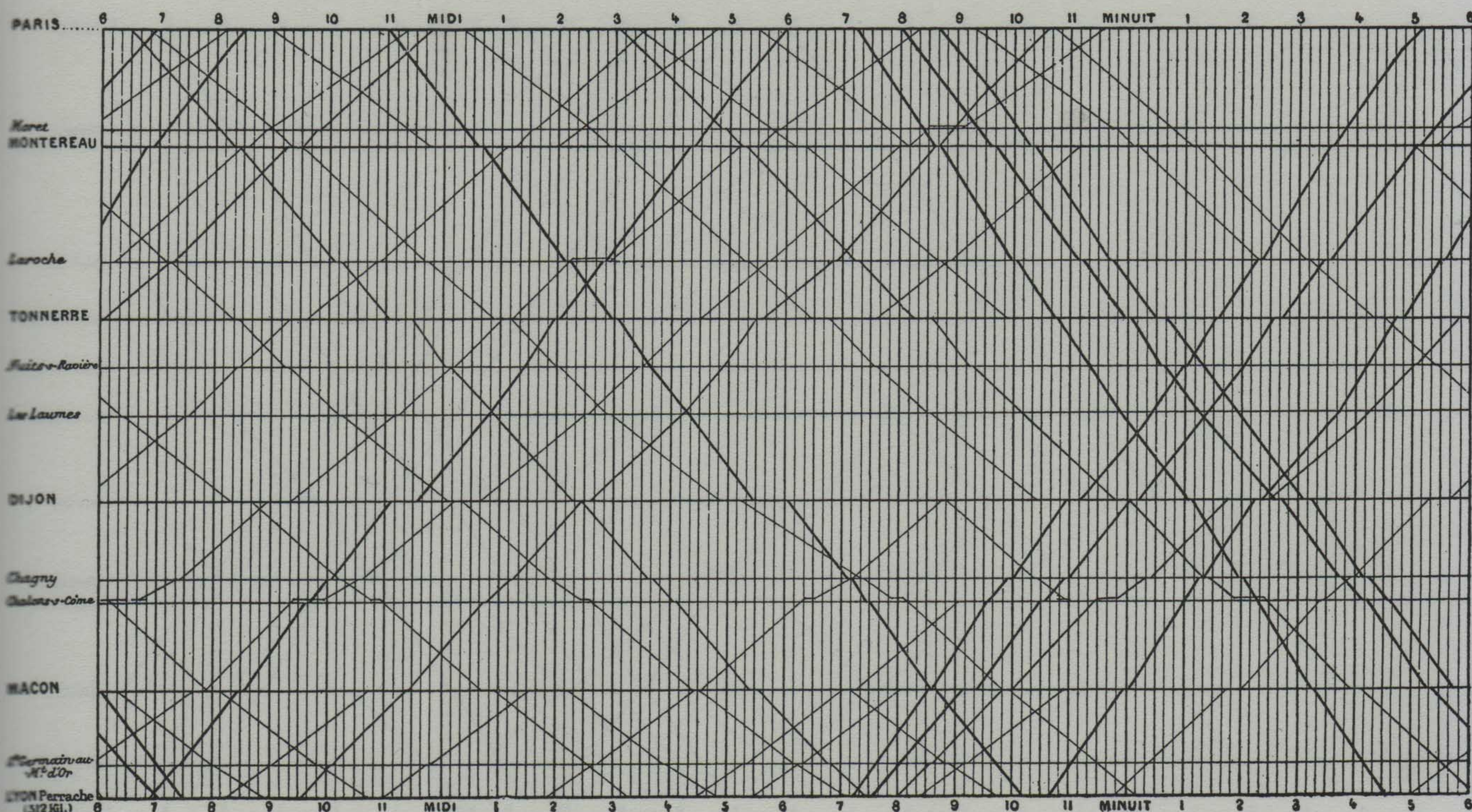
The space occupied by the doubled grid lines consumes 18 percent of the area of this otherwise most ingenious design, a "multi-window plot." Optical white dots appear at the intersections of the grid lines. (The plot shows the following: The large square contains X_4, X_7 scatterplots for the indicated levels of X_1 and X_3. The marginal plots on the right are conditioned on X_3 and the plots at the top on X_1. The upper right corner shows the unconditional X_4, X_7 scatter.) Redrawing eliminates the vibration:

Paul A. Tukey and John W. Tukey, "Data-Driven View Selection; Agglomeration and Sharpening," in Vic Barnett, ed., *Interpreting Multivariate Data* (Chichester, England, 1981), 231–232.

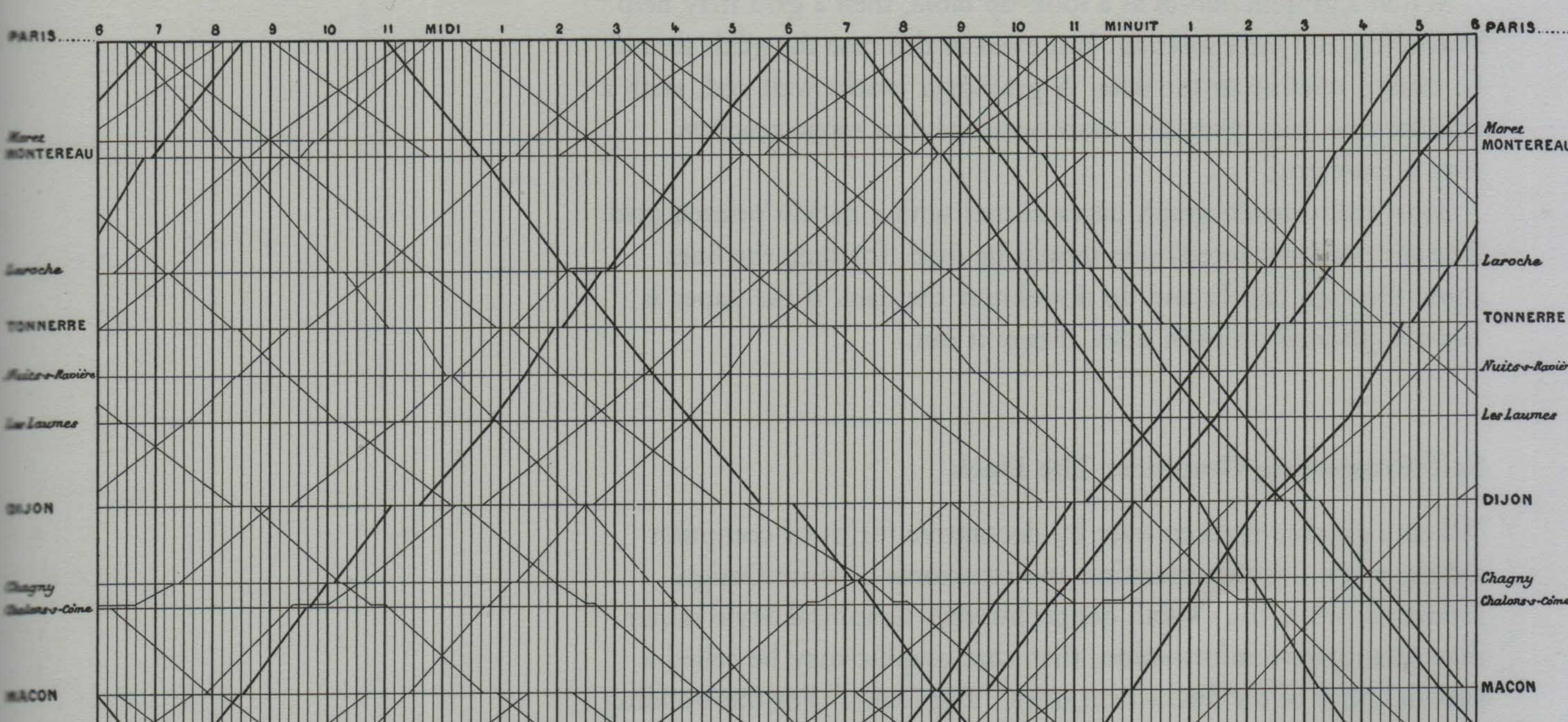




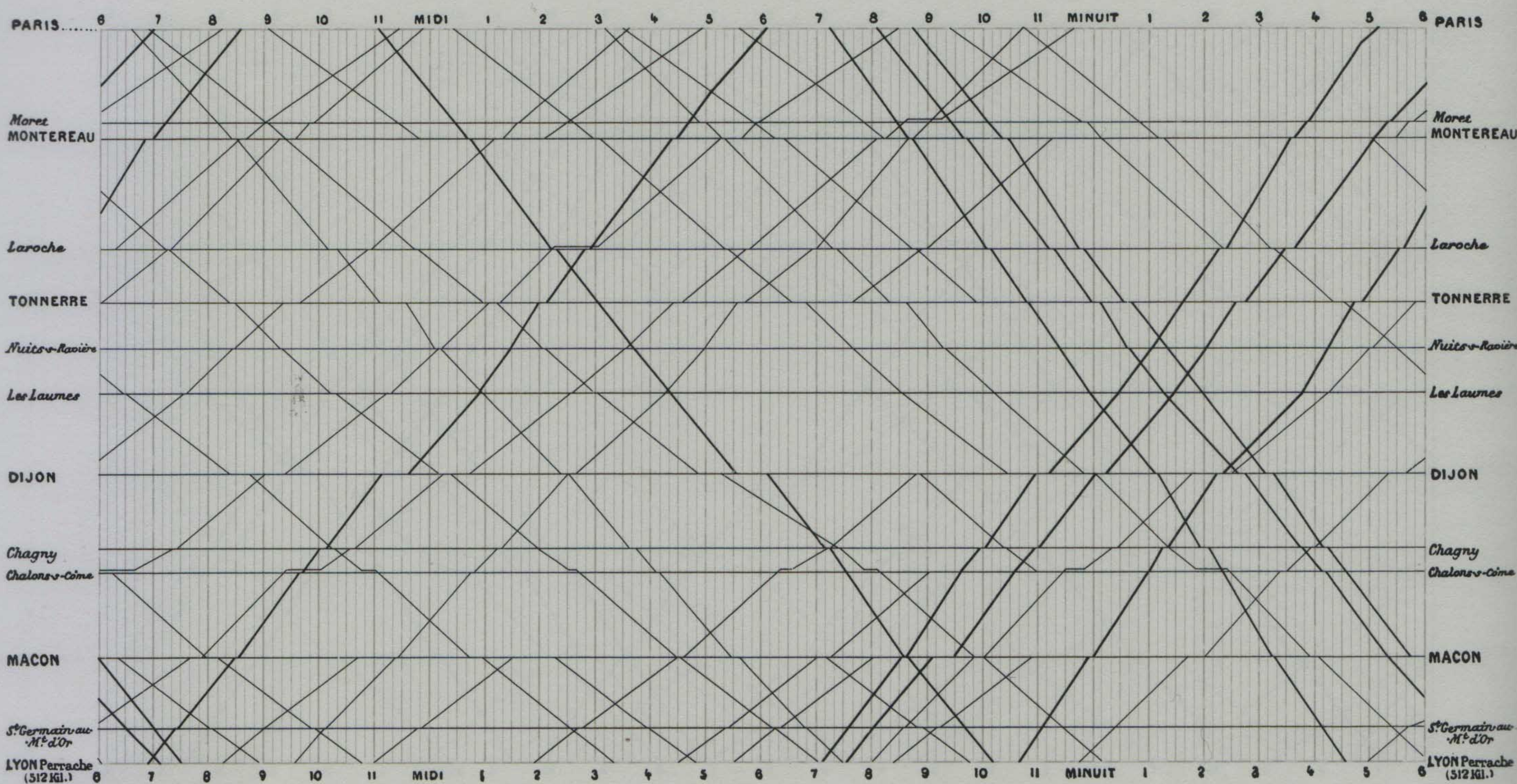
The grid in the classic Marey train schedule is very active:



Thinning the grid lines helps a little bit:



A better treatment, however, is a *gray grid*:



When a graphic serves as a look-up table, then a grid may help in reading and interpolating. But even in this case the grids should be muted relative to the data. A gray grid works well and, with a delicate line, may promote more accurate data reconstruction than a dark grid.

Most ready-made graph paper comes with a darkly printed grid. The reverse (unprinted) side should be used, for then the lines show through faintly and do not clutter the data. If the paper is heavily gridded on both sides, throw it out.

Self-Promoting Graphics: The Duck

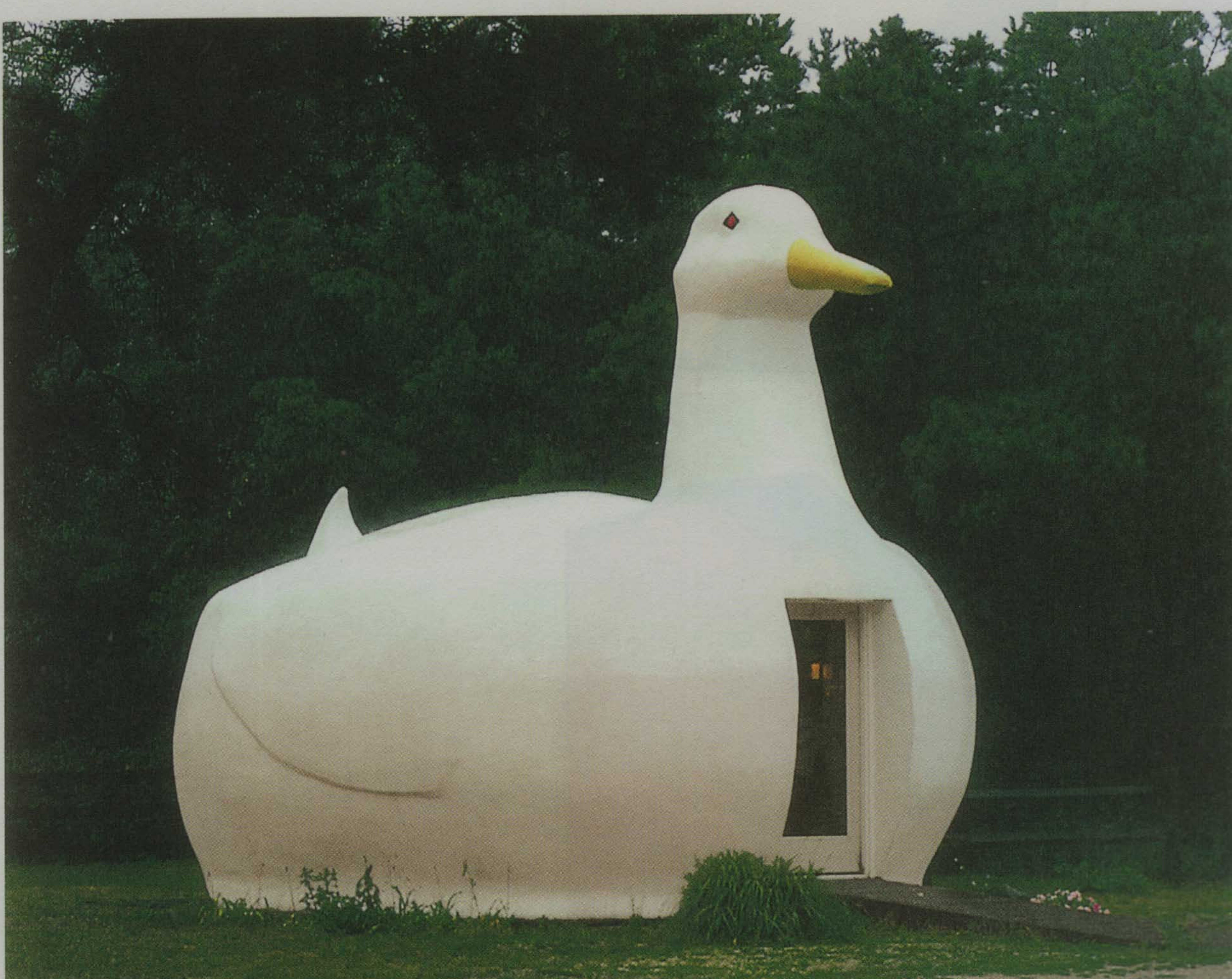
When a graphic is taken over by decorative forms or computer debris, when the data measures and structures become Design Elements, when the overall design purveys Graphical Style rather than quantitative information, then that graphic may be called a *duck* in honor of the duck-form store, "Big Duck." For this building the whole structure is itself decoration, just as in the duck data graphic. In *Learning from Las Vegas*, Robert Venturi, Denise Scott

Brown, and Steven Izenour write about the ducks of modern architecture—and their thoughts are relevant to the design of data graphics as well:

> When Modern architects righteously abandoned ornament on buildings, they unconsciously designed buildings that *were* ornament. In promoting Space and Articulation over symbolism and ornament, they distorted the whole building into a duck. They substituted for the innocent and inexpensive practice of applied decoration on a conventional shed the rather cynical and expensive distortion of program and structure to promote a duck. . . . It is now time to reevaluate the once-horrifying statement of John Ruskin that architecture is the decoration of construction, but we should append the warning of Pugin: It is all right to decorate construction but never construct decoration.[2]

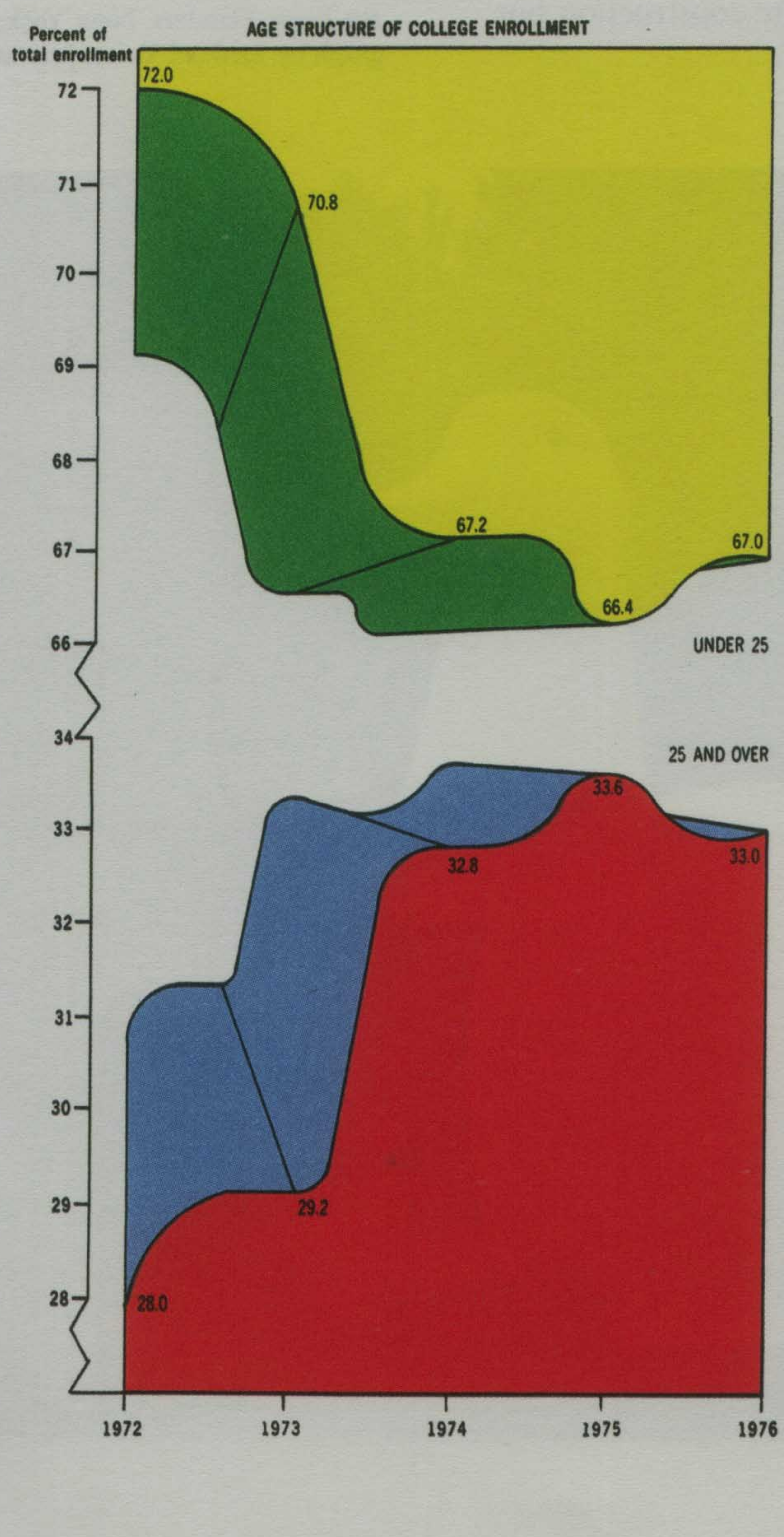
[2] Robert Venturi, Denise Scott Brown, and Steven Izenour, *Learning from Las Vegas* (Cambridge, revised edition, 1977), p. 163. The initial statement of the duck concept is found on pp. 87–103.

Big Duck, Flanders, New York; photograph by Edward Tufte, July 2000.



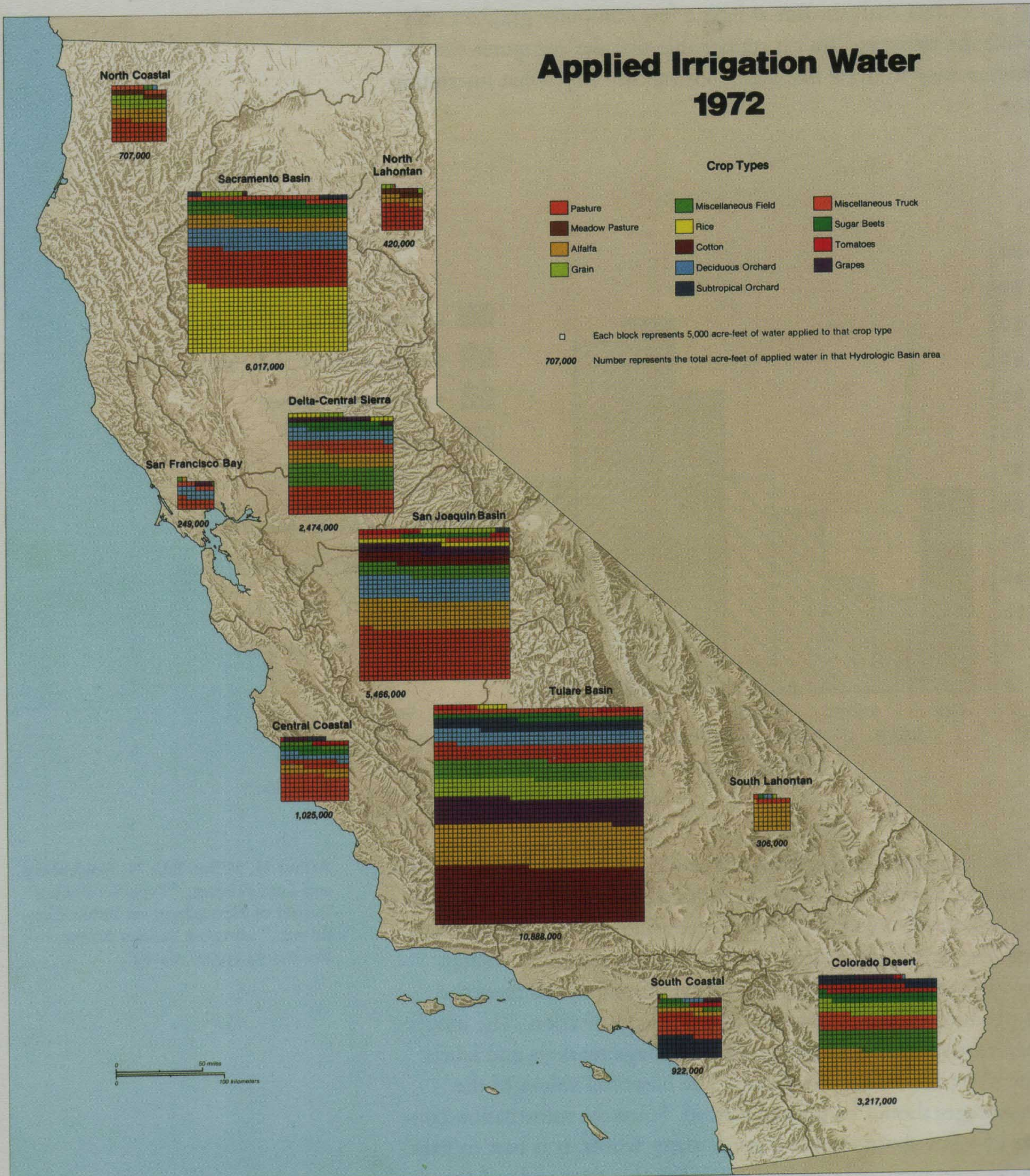
The addition of a fake perspective to the data structure clutters many graphics. This variety of chartjunk, now at high fashion in the world of Boutique Data Graphics, abounds in corporate annual reports, the phony statistical studies presented in advertisements, the mass media, and the more muddled sorts of social science research.

A series of weird three-dimensional displays appearing in the magazine *American Education* in the 1970s delighted connoisseurs of the graphically preposterous. Here five colors report, almost by happenstance, only five pieces of data (since the division within each year adds to 100 percent). This may well be the worst graphic ever to find its way into print:

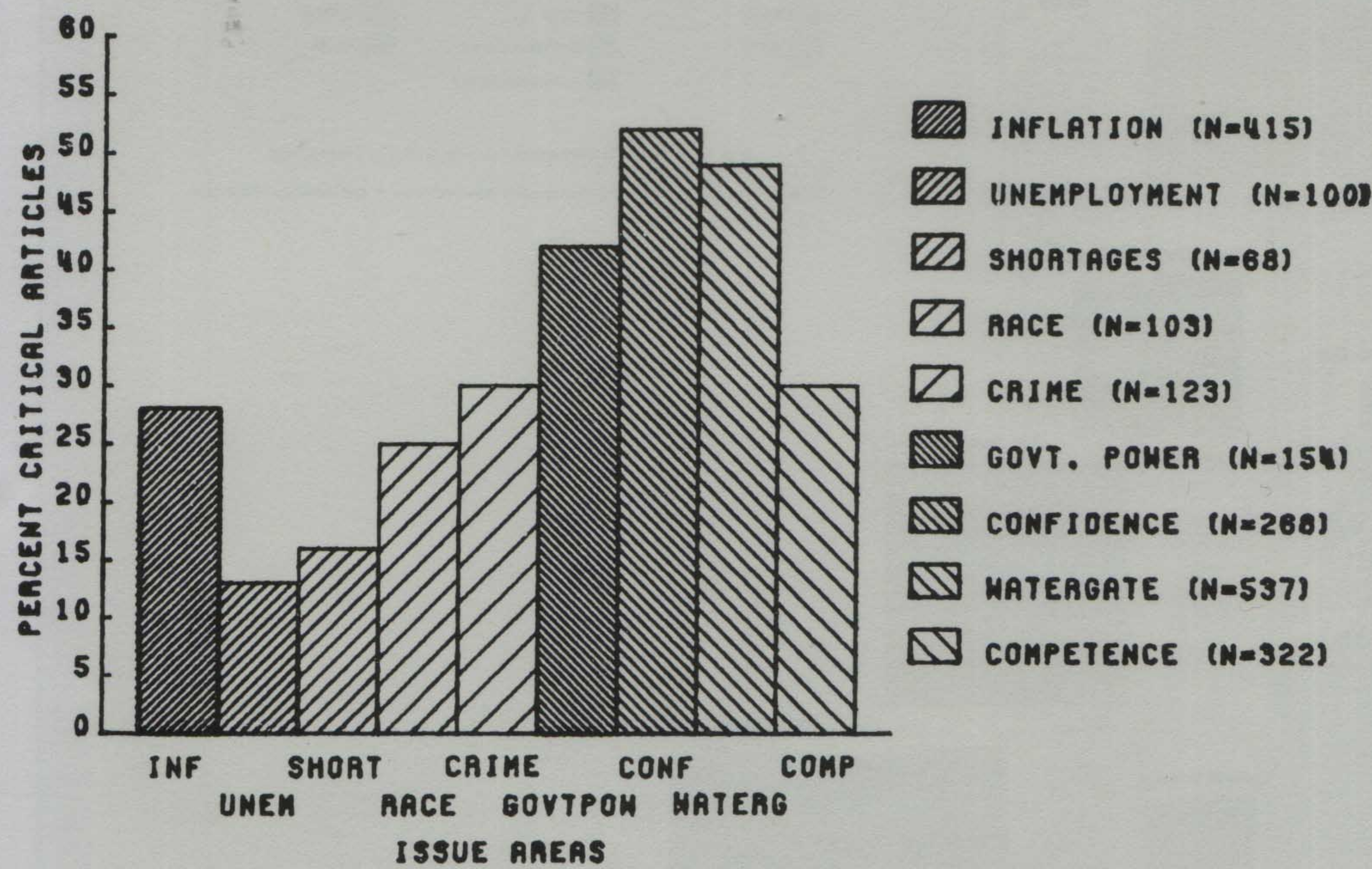


There are some superbly produced ducks:

William L. Kahrl, et al., *The California Water Atlas* (Sacramento, 1978, 1979), p. 55.



Occasionally designers seem to seek credit merely for possessing a new technology, rather than using it to make better designs. Computers and their affiliated apparatus can do powerful things graphically, in part by turning out the hundreds of plots necessary for good data analysis. But at least a few computer graphics only evoke the response "Isn't it remarkable that the computer can be programmed to draw like that?" instead of "My, what interesting data."



The symptoms of the We-Used-A-Computer-To-Build-A-Duck Syndrome appear in this display from a professional journal: the thin substance; the clotted, crinkly lettering all in upper-case sans serif; the pointlessly ordered cross-hatching; the labels written in computer abbreviations; the optical vibration—all these the by-products of the technology of graphic fabrication. The overly busy vertical scaling shows more percentage markers and labels than there are actual data points. The observed values of the percentages should be printed instead. Since the information consists of a few numbers and a good many words, it is best to pass up the computerized graphics capability this time and tell the story with a table:

Arthur H. Miller, Edie N. Goldenberg, and Lutz Erbring, "Type-Set Politics: Impact of Newspapers on Public Confidence," *American Political Science Review*, 73 (1979), 67–84.

Content and tone of front-page articles in 94 U.S. newspapers, October and November, 1974	Number of articles	Percent of articles with negative criticism of specific person or policy
Watergate: defendants and prosecutors, Ford's pardon of Nixon	537	49%
Inflation, high cost of living	415	28%
Government competence: costs, quality, salaries of public employees	322	30%
Confidence in government: power of special interests, trust in political leaders, dishonesty in politics	266	52%
Government power: regulation of business, secrecy, control of CIA and FBI	154	42%
Crime	123	30%
Race	103	25%
Unemployment	100	13%
Shortages: energy, food	68	16%

Conclusion

Chartjunk does not achieve the goals of its propagators. The overwhelming fact of data graphics is that they stand or fall on their content, gracefully displayed. Graphics do not become attractive and interesting through the addition of ornamental hatching and false perspective to a few bars. Chartjunk can turn bores into disasters, but it can never rescue a thin data set. The best designs (for example, Minard on Napoleon in Russia, Marey's graphical train schedule, the cancer maps, the *Times* weather history of New York City, the chronicle of the annual adventures of the Japanese beetle, the new view of the galaxies) are *intriguing and curiosity-provoking*, drawing the viewer into the wonder of the data, sometimes by narrative power, sometimes by immense detail, and sometimes by elegant presentation of simple but interesting data. But no information, no sense of discovery, no wonder, no substance is generated by chartjunk.

Forgo chartjunk, including

moiré vibration,

the grid, and the duck.

Painting is special, separate, a matter of meditation and contemplation, for me, no physical action or social sport. As much consciousness as possible. Clarity, completeness, quintessence, quiet. No noise, no schmutz, no schmerz, no fauve schwärmerei. Perfection, passiveness, consonance, consummateness. No palpitations, no gesticulation, no grotesquerie. Spirituality, serenity, absoluteness, coherence. No automatism, no accident, no anxiety, no catharsis, no chance. Detachment, disinterestedness, thoughtfulness, transcendence. No humbugging, no button-holing, no exploitation, no mixing things up.

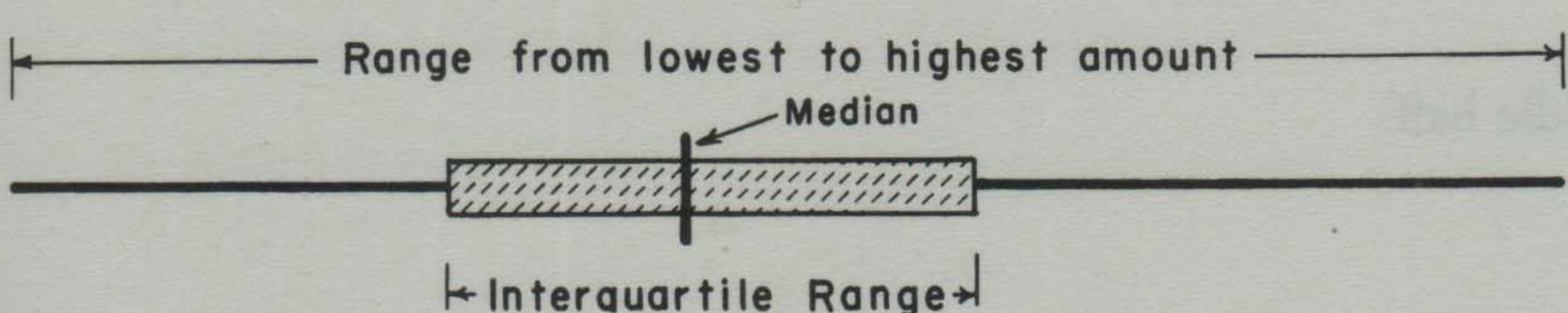
Ad Reinhardt, statement for the catalogue of the exhibition, "The New Decade: 35 American Painters and Sculptors," Whitney Museum of American Art, New York, 1955.

6 *Data-Ink Maximization and Graphical Design*

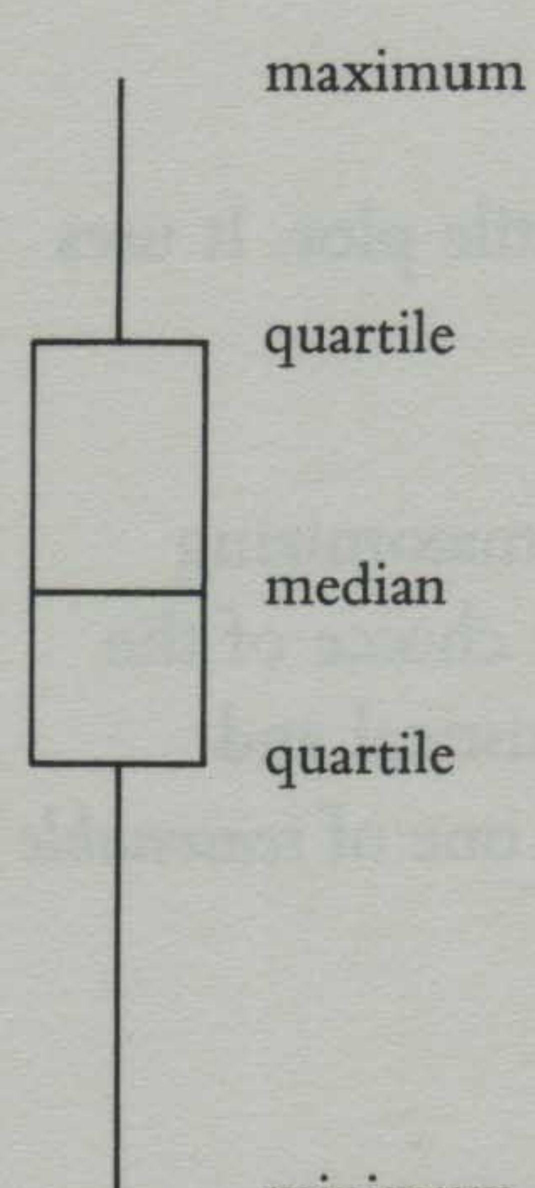
So far the principles of maximizing data-ink and erasing have helped to generate a series of choices in the process of graphical revision. This is an important result, but can the ideas reach beyond the details and particularities of editing? Is it possible to do what a theory of graphics is supposed 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"



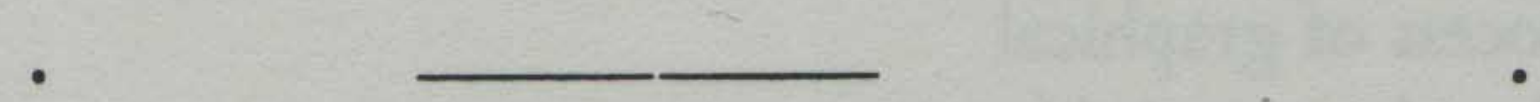
and John Tukey's "box plot"



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:

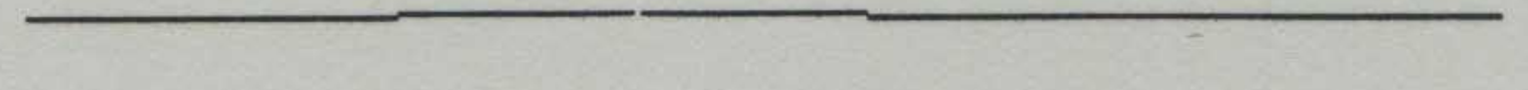
The revised design, a *quartile plot*, shows the same five numbers. It is easy to draw by hand or computer and, most importantly, can replace the conventional scatterplot frame. The straightedge need only be placed on the paper once to draw the quartile plot, compared to six separate placings for the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

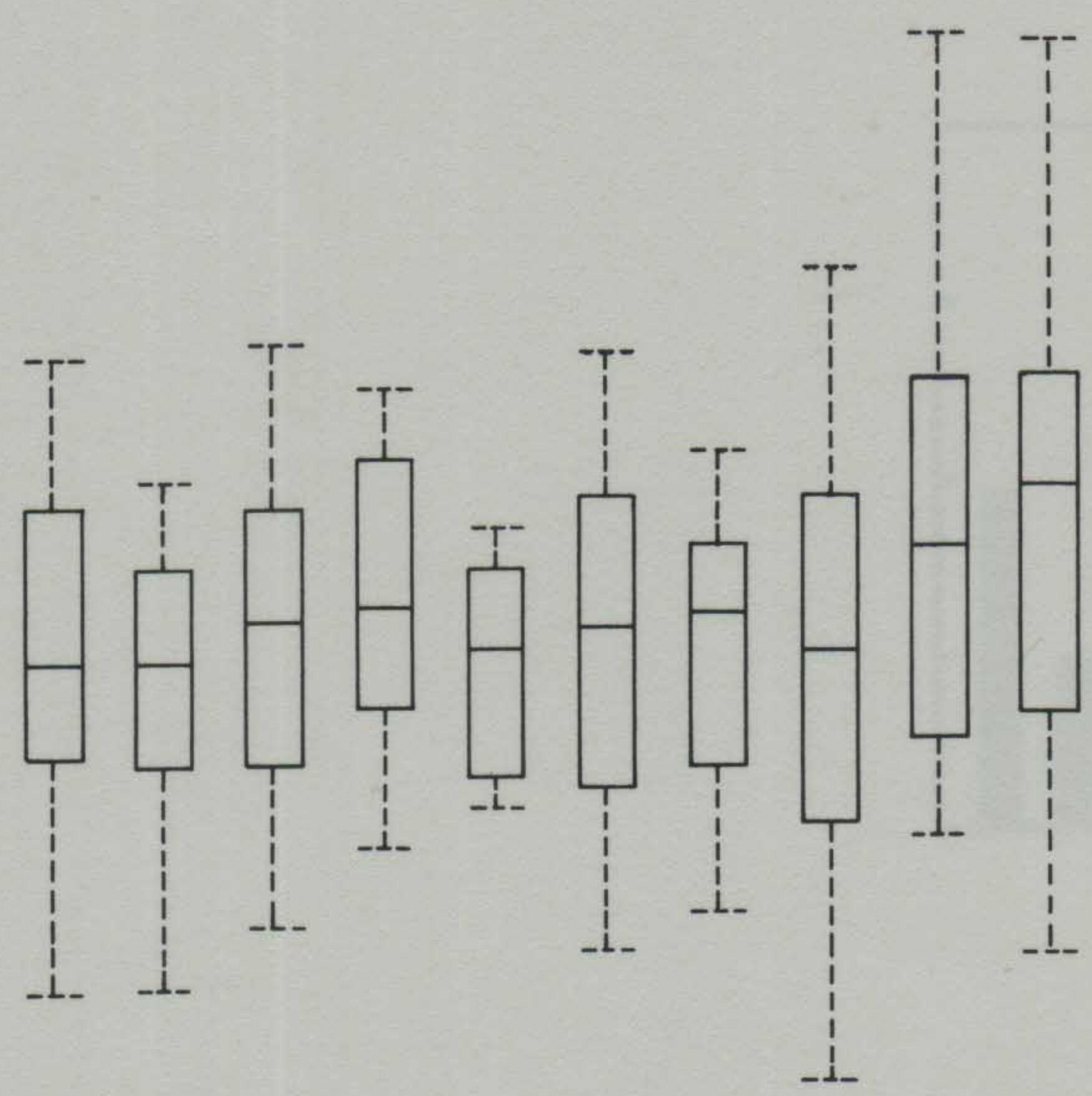
or, even better, by offsetting the middle half:



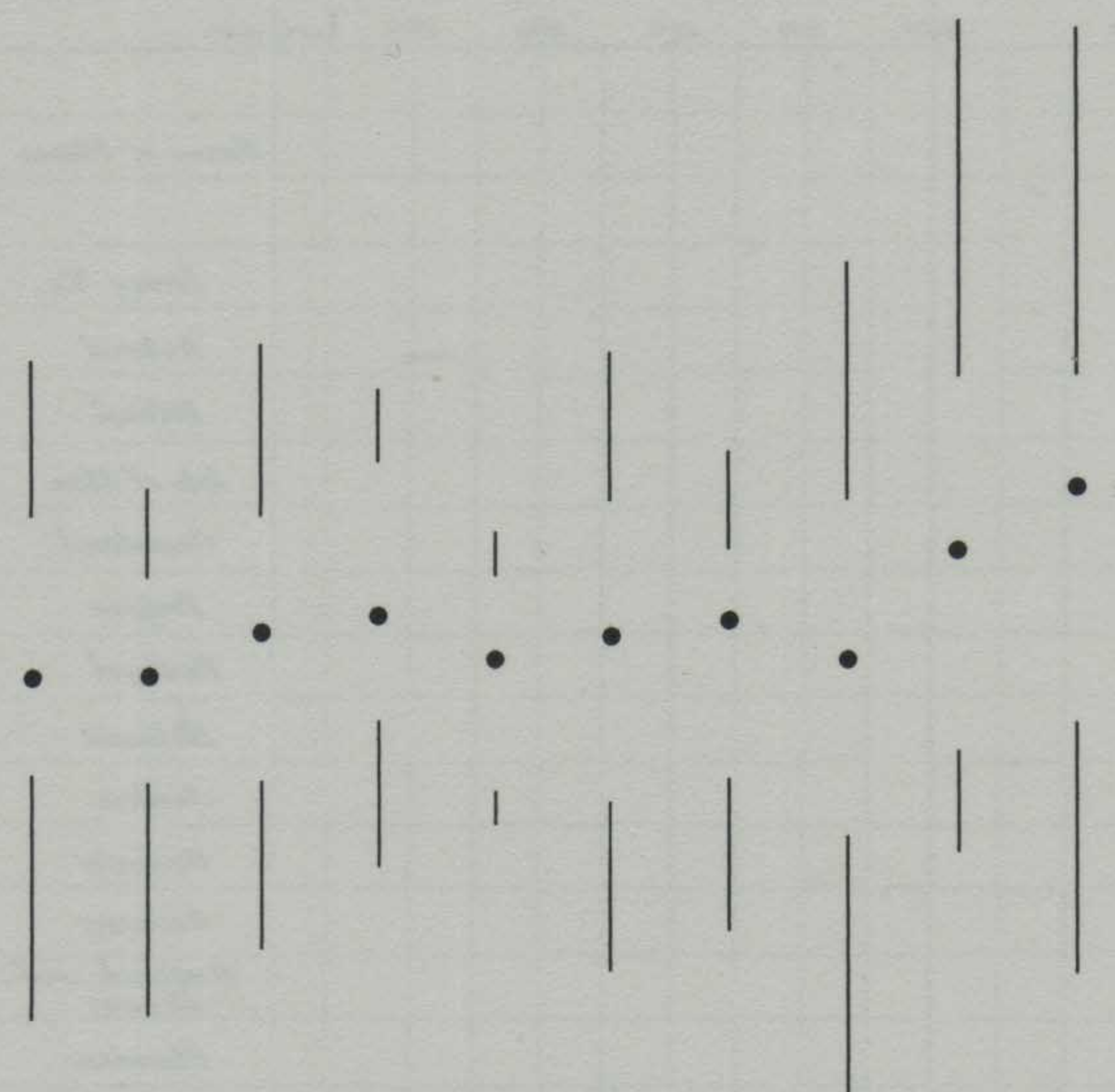
This latter design is the preferred form of the quartile plot. It uses the ink effectively and looks good.

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 placings of the straightedge, 50 horizontals and 30 verticals:



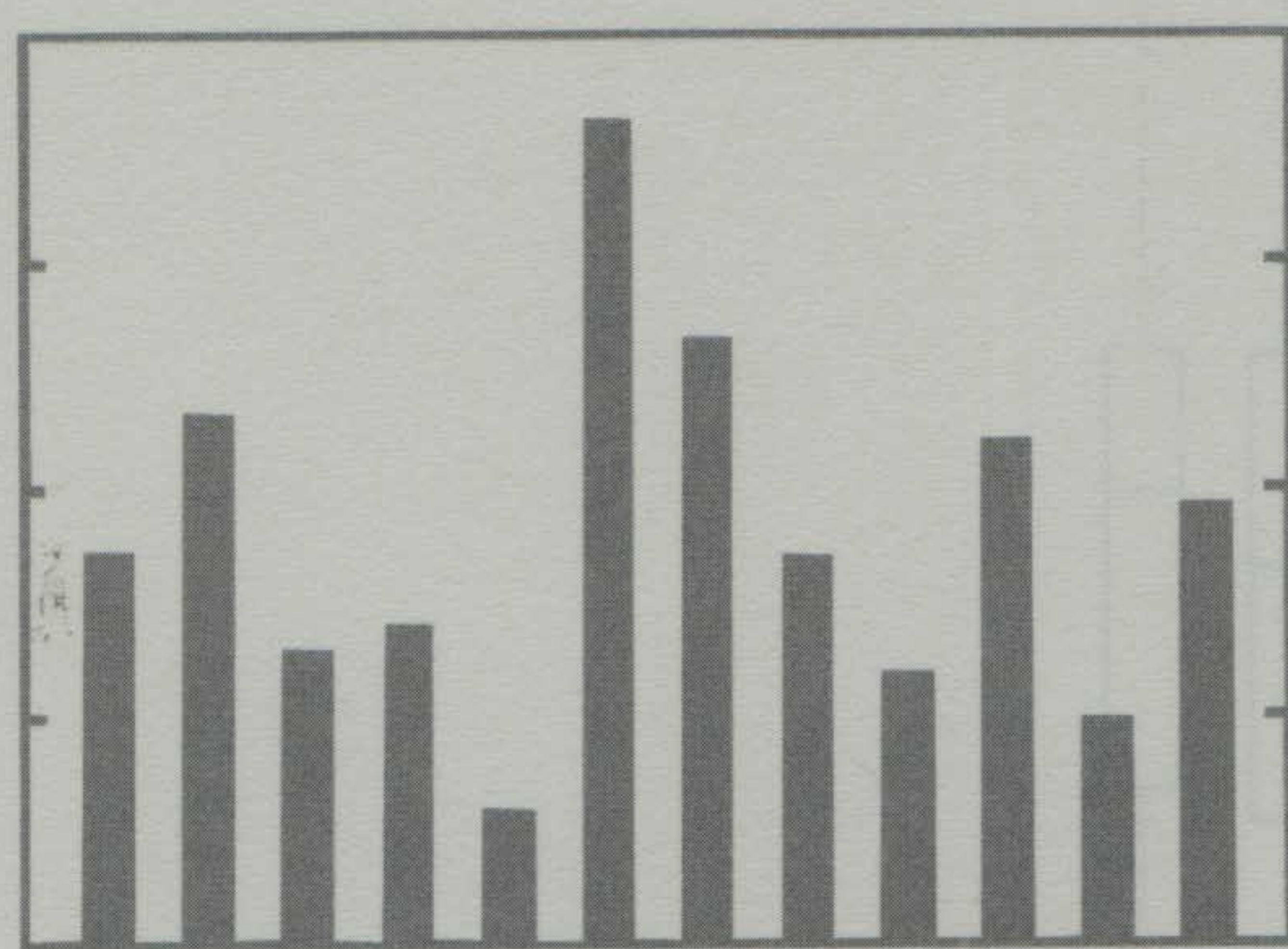
An erased version requires only 10 verticals to show the same information:



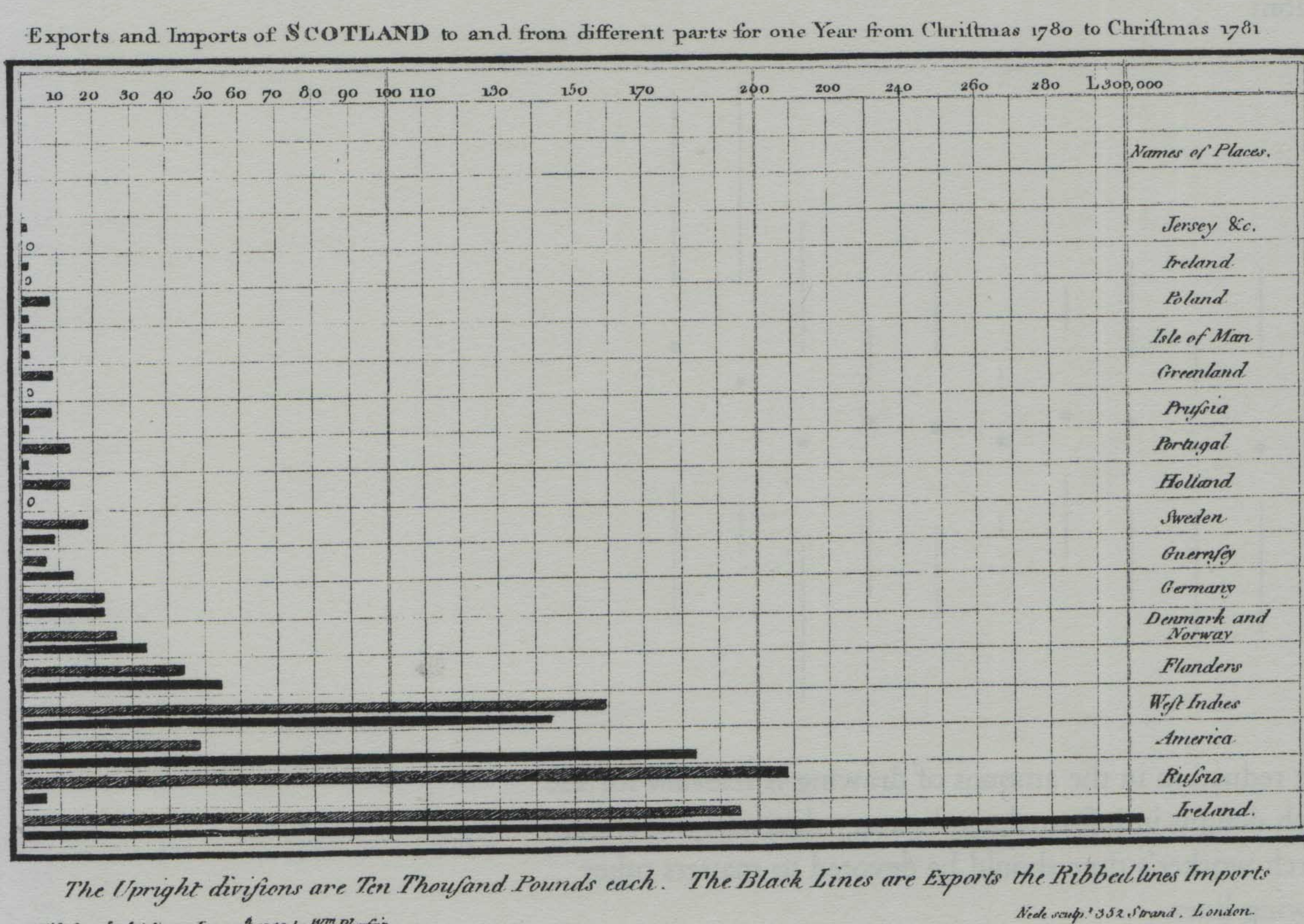
The large reduction in the amount of drawing is relevant for the use of such designs in informal, exploratory data analysis, where the research worker's time should be devoted to matters other than drawing lines.

Redesign of the Bar Chart/Histogram

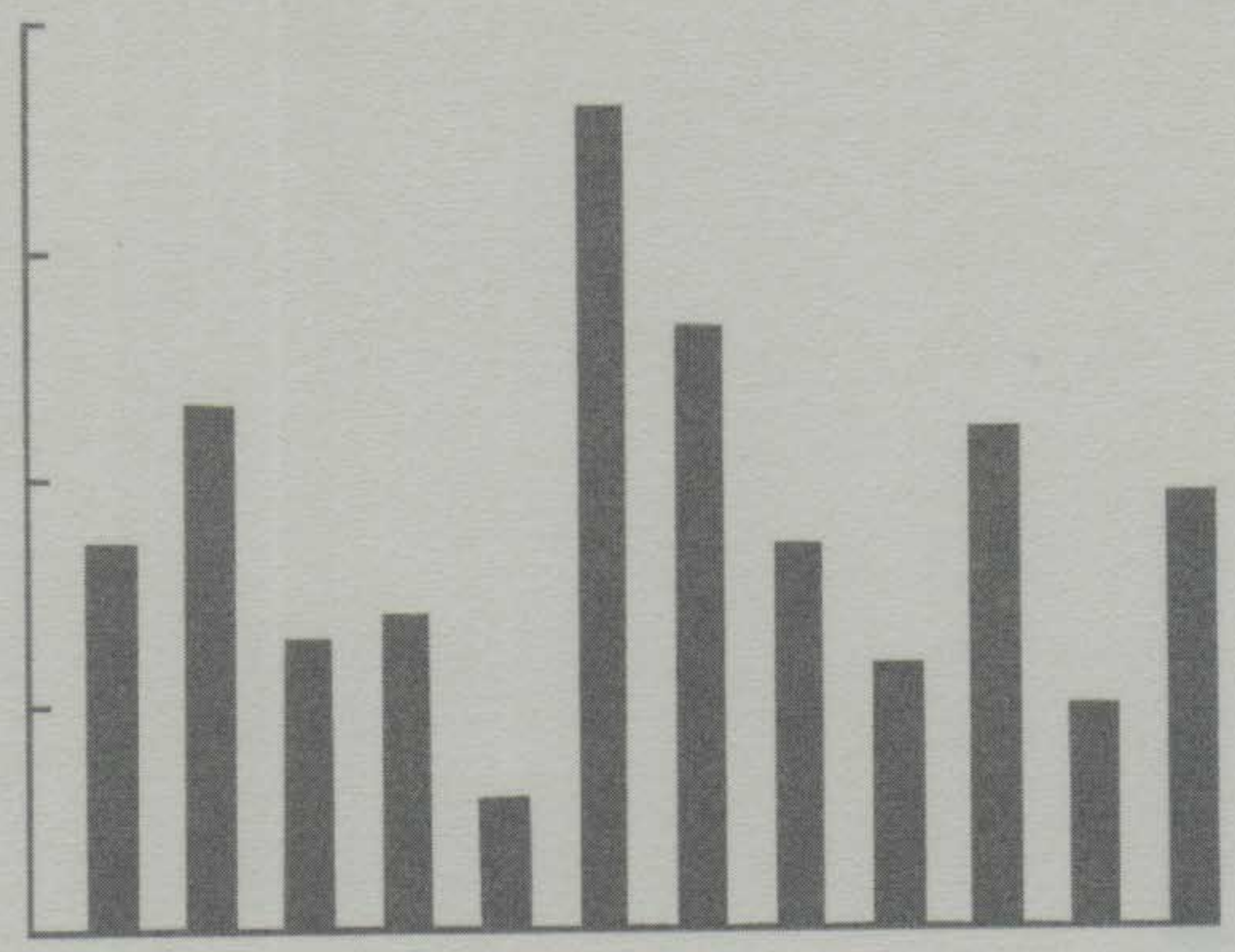
Here is the standard model bar chart, with the design endorsed by the practices and the style sheets of many statistical and scientific publications:



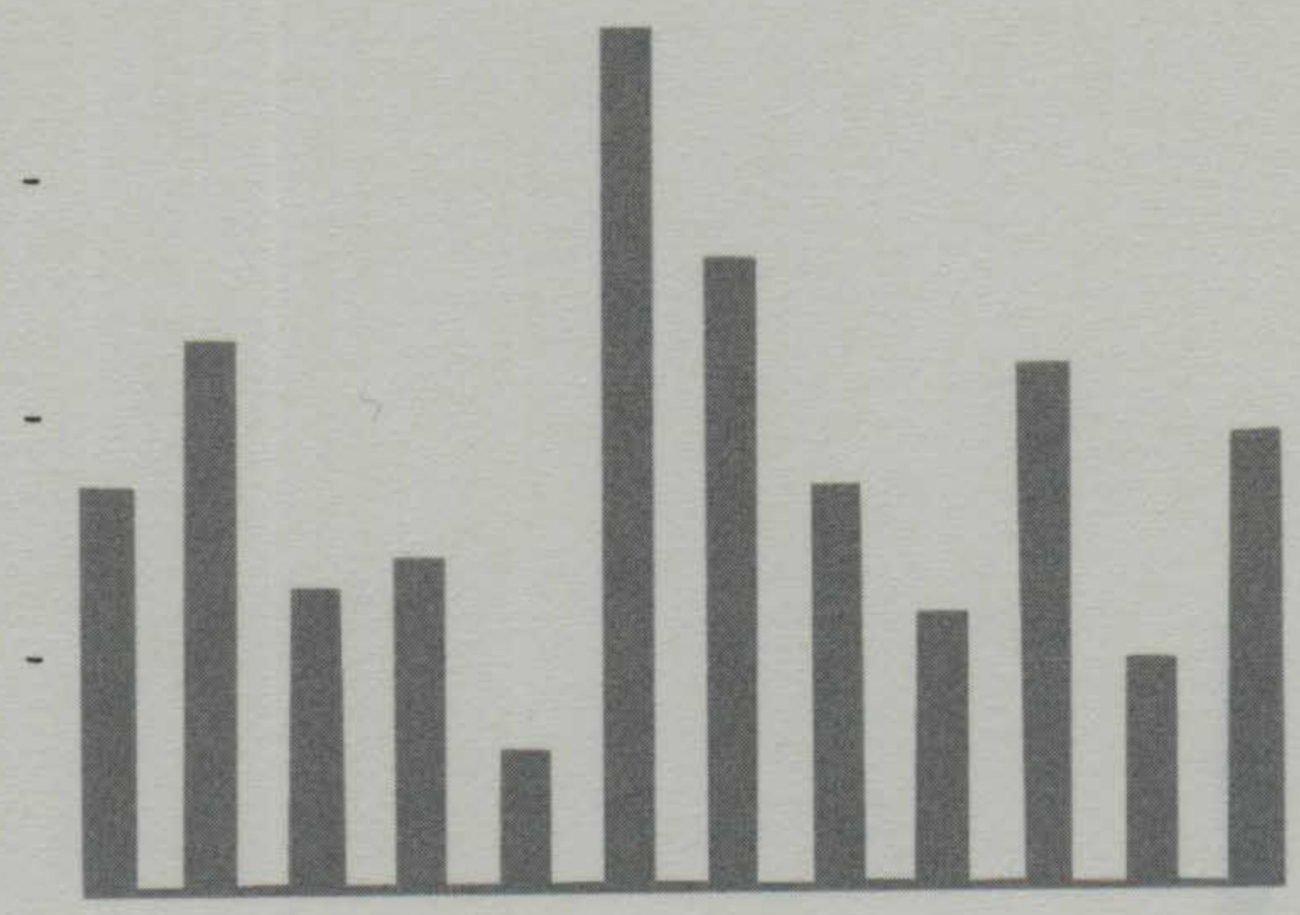
Its architecture differs little from Playfair's original design:



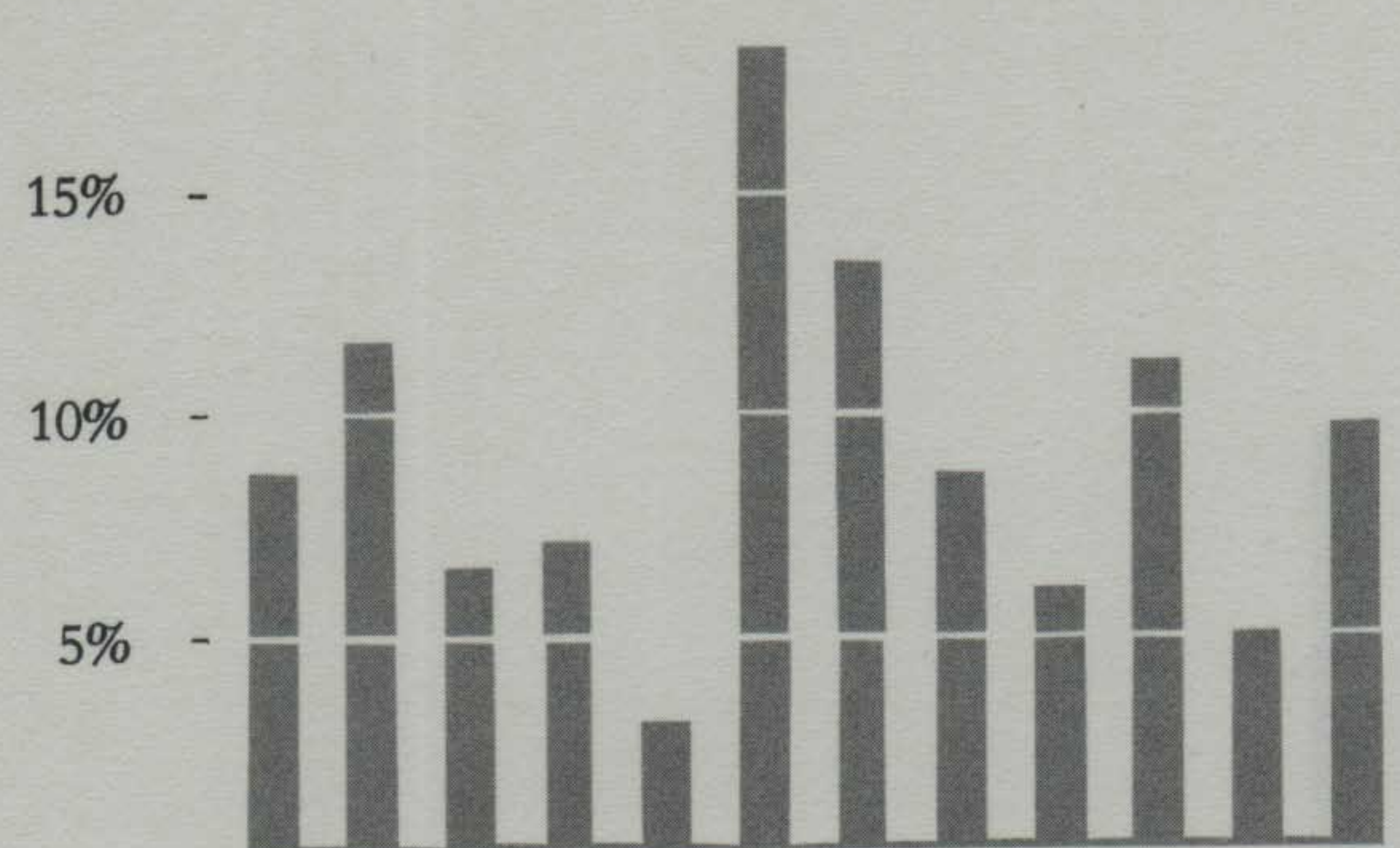
The box can be erased:



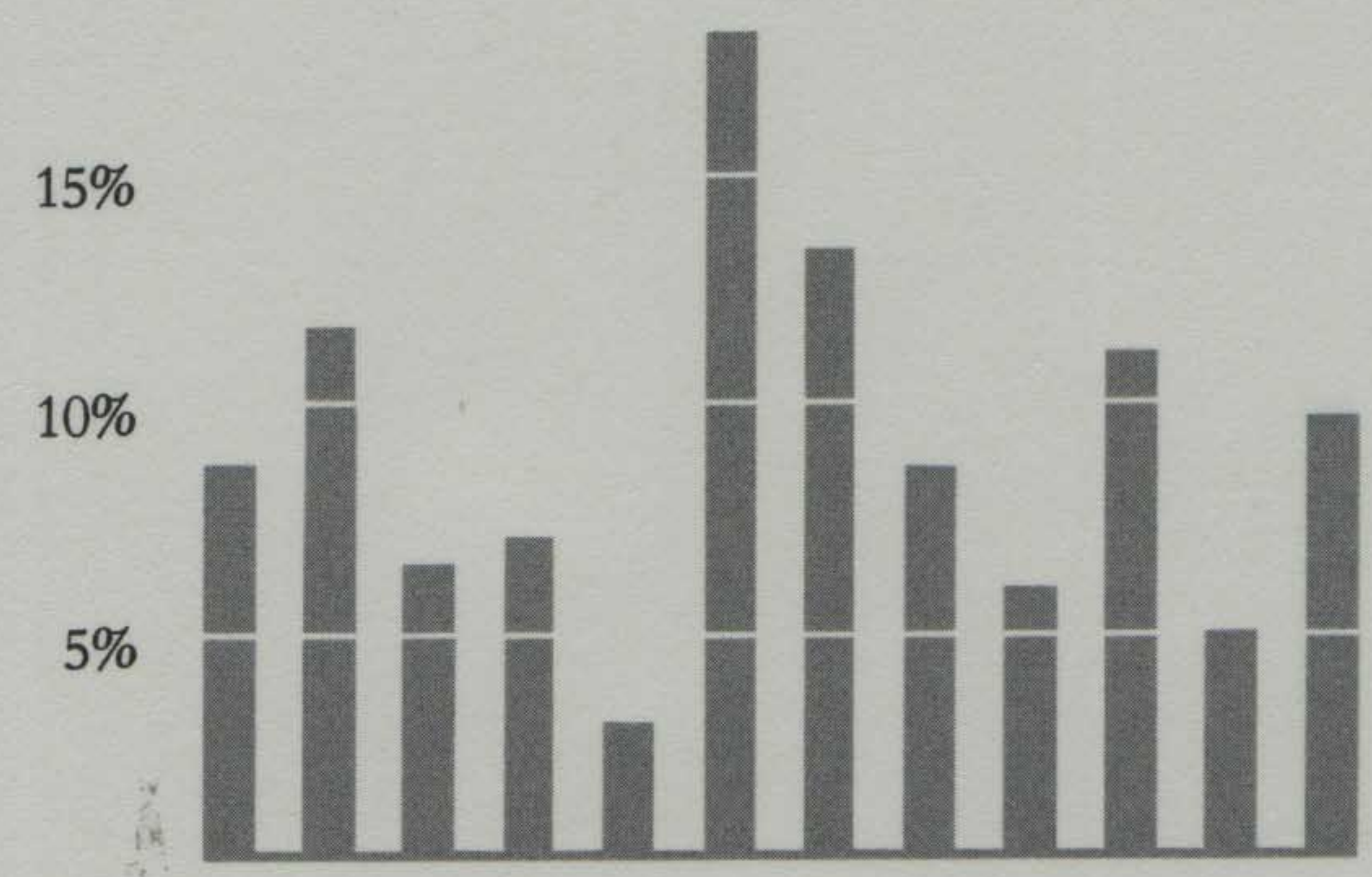
And the vertical axis, except for the ticks:



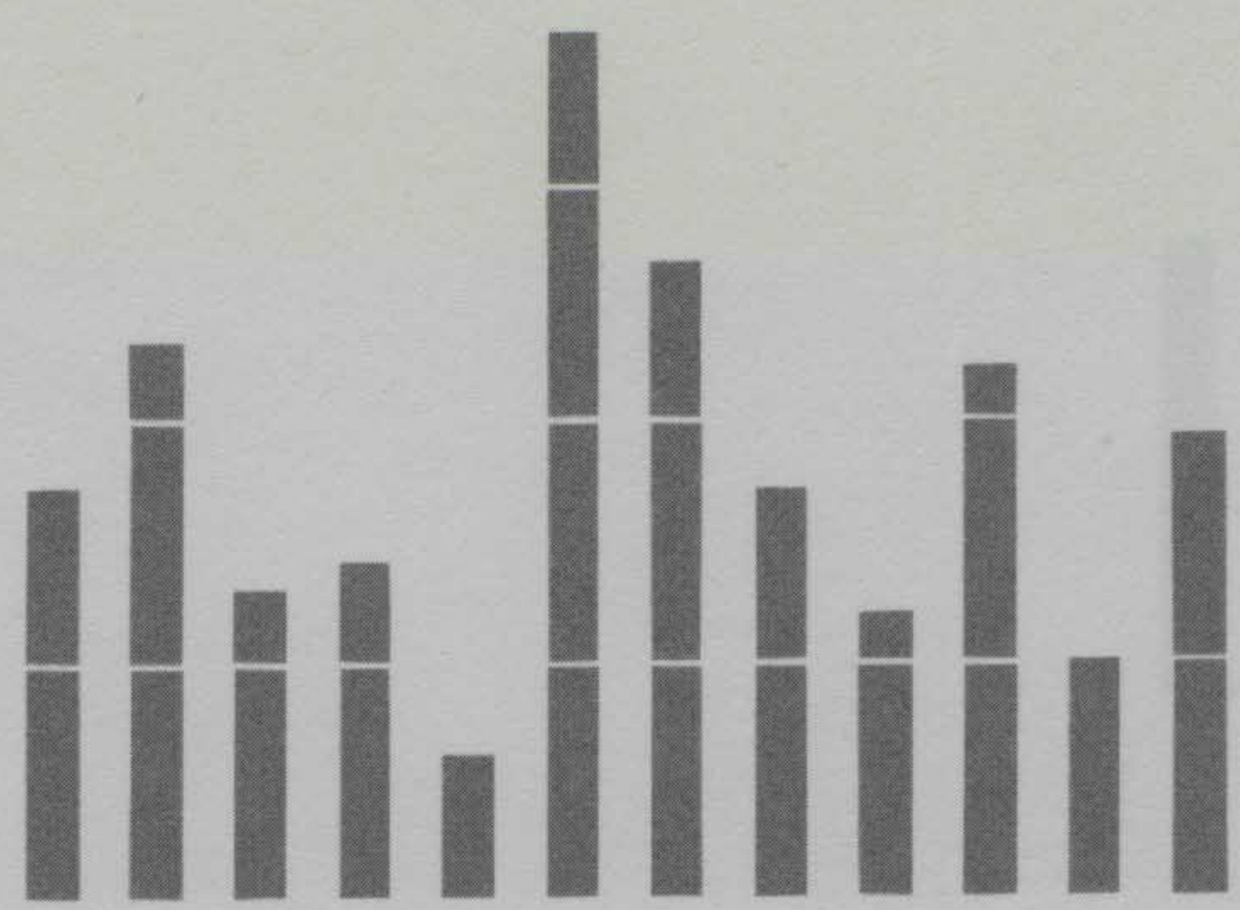
Even part of the data measures can be erased, making a *white grid*, which shows the coordinate lines more precisely than ticks alone:



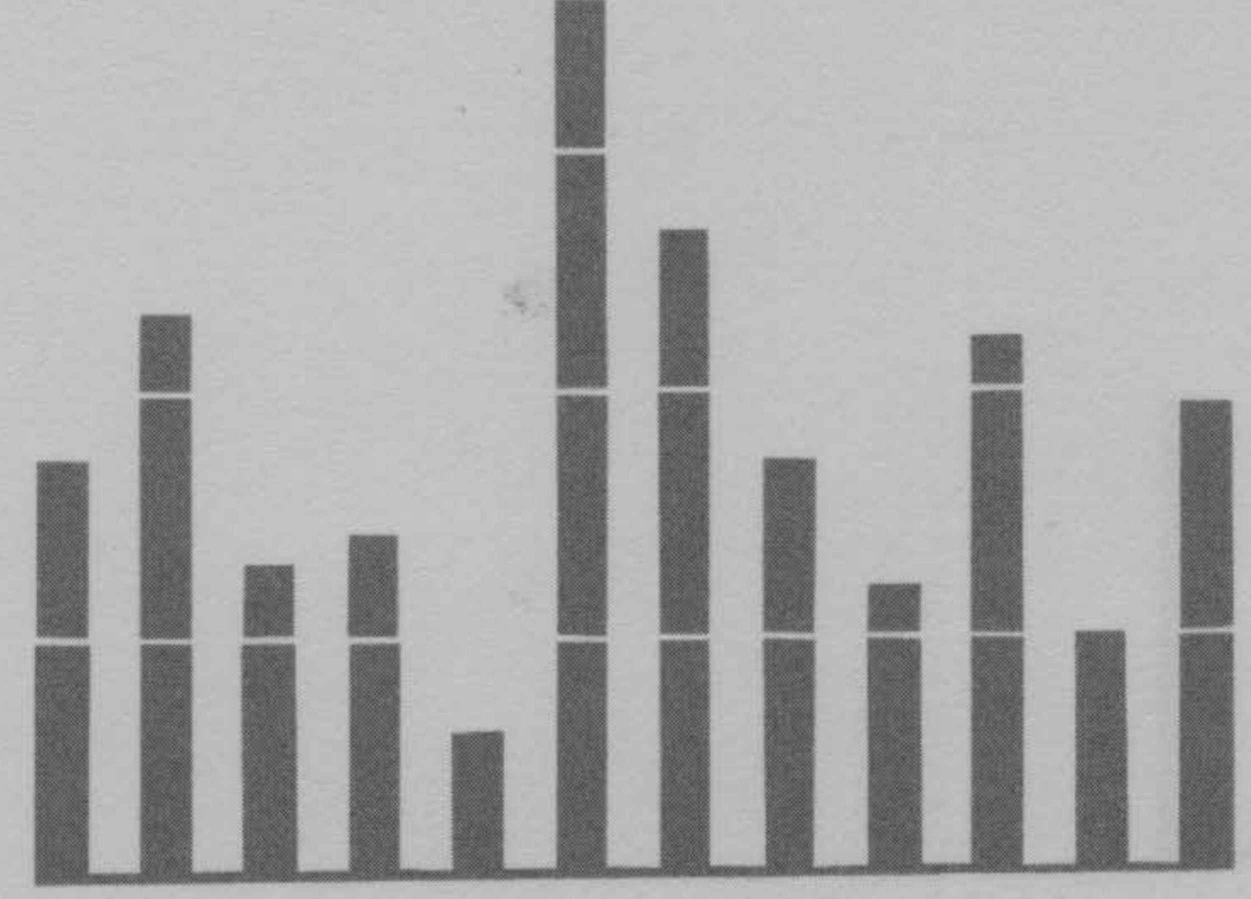
The white grid eliminates the tick marks, since the numerical labels on the vertical are tied directly to the white lines:



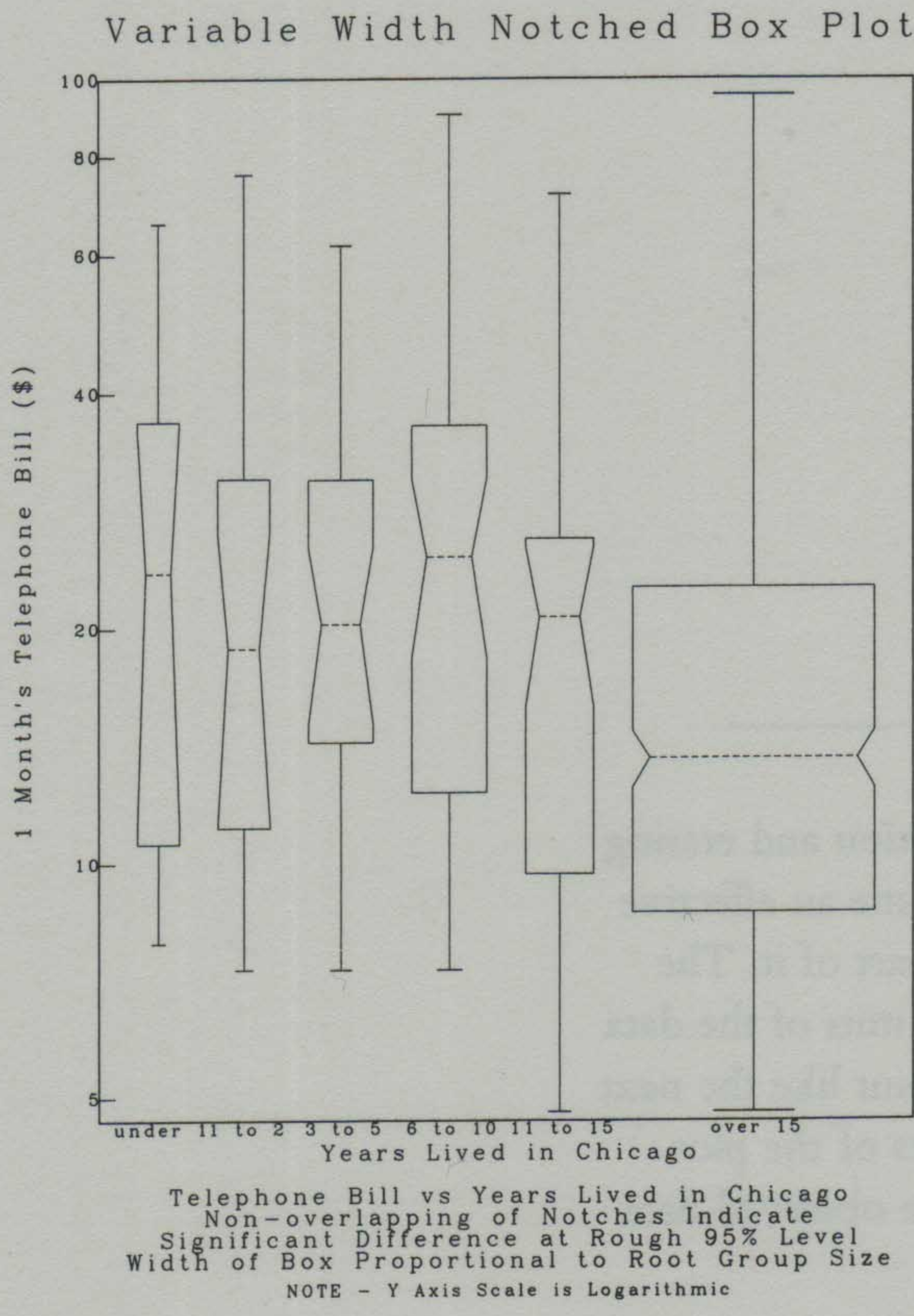
Although the intersection of the thicker bar with the thinner baseline creates an attractive visual effect (but also the optical illusion of gray dots at the intersections), the baseline can be erased since the bars define the end-point at the bottom:



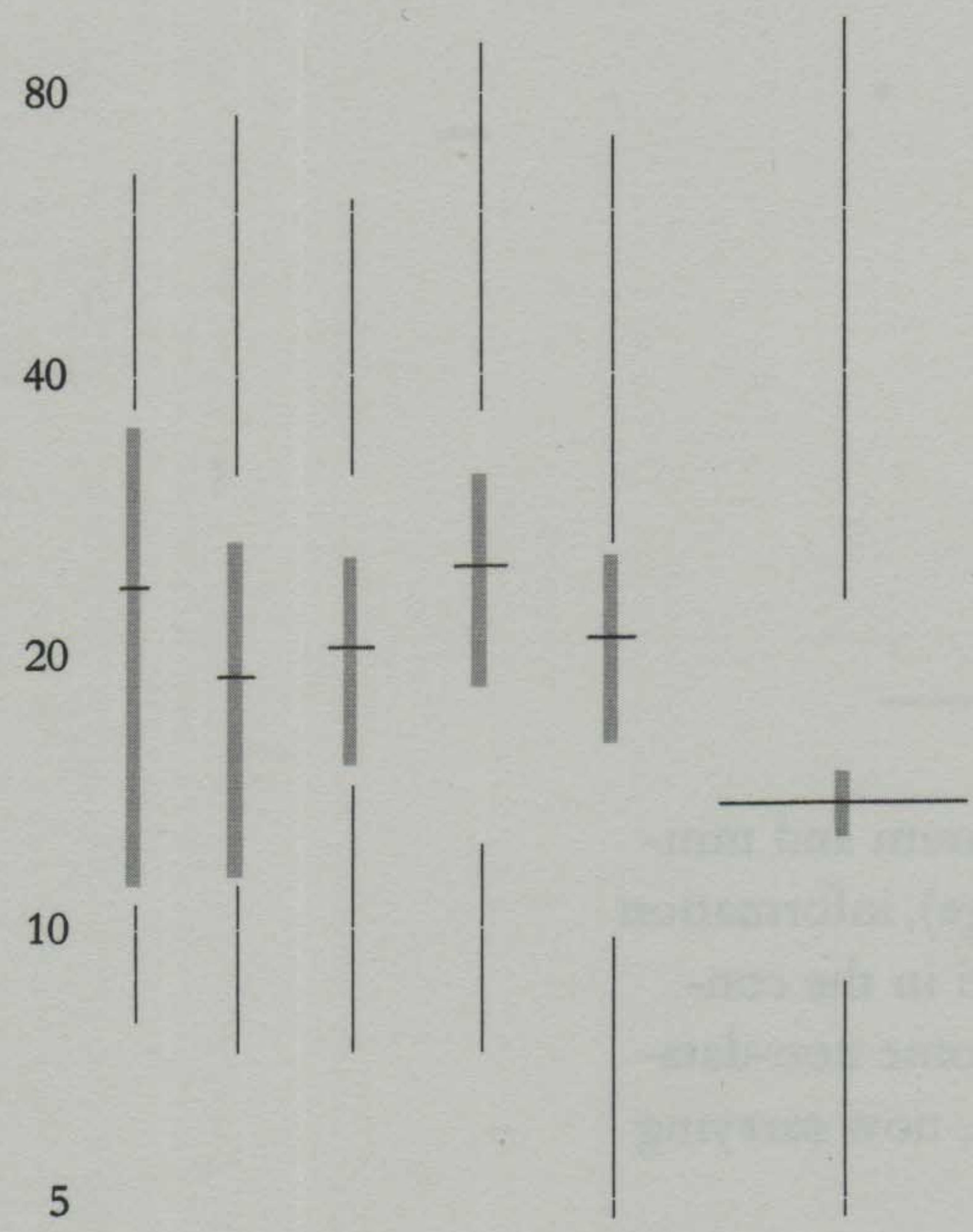
Still, a thin baseline looks good:



Erasing and data-ink maximizing have induced changes in the plain old bar chart. The techniques—no frame, no vertical axis, no ticks, and the white grid—apply to other designs:

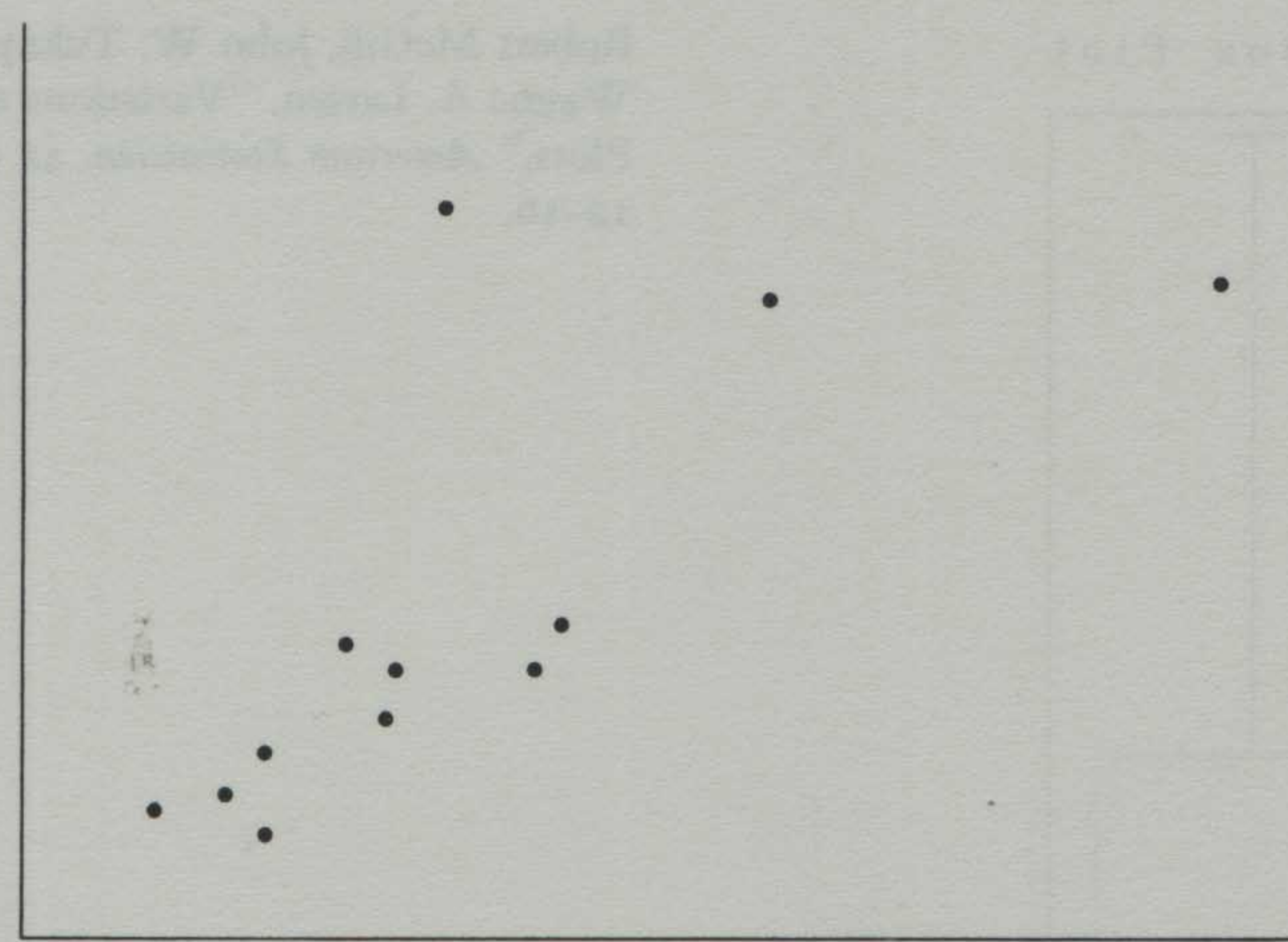


Robert McGill, John W. Tukey, and Wayne A. Larsen, "Variations of Box Plots," *American Statistician*, 32 (1978), 12–16.

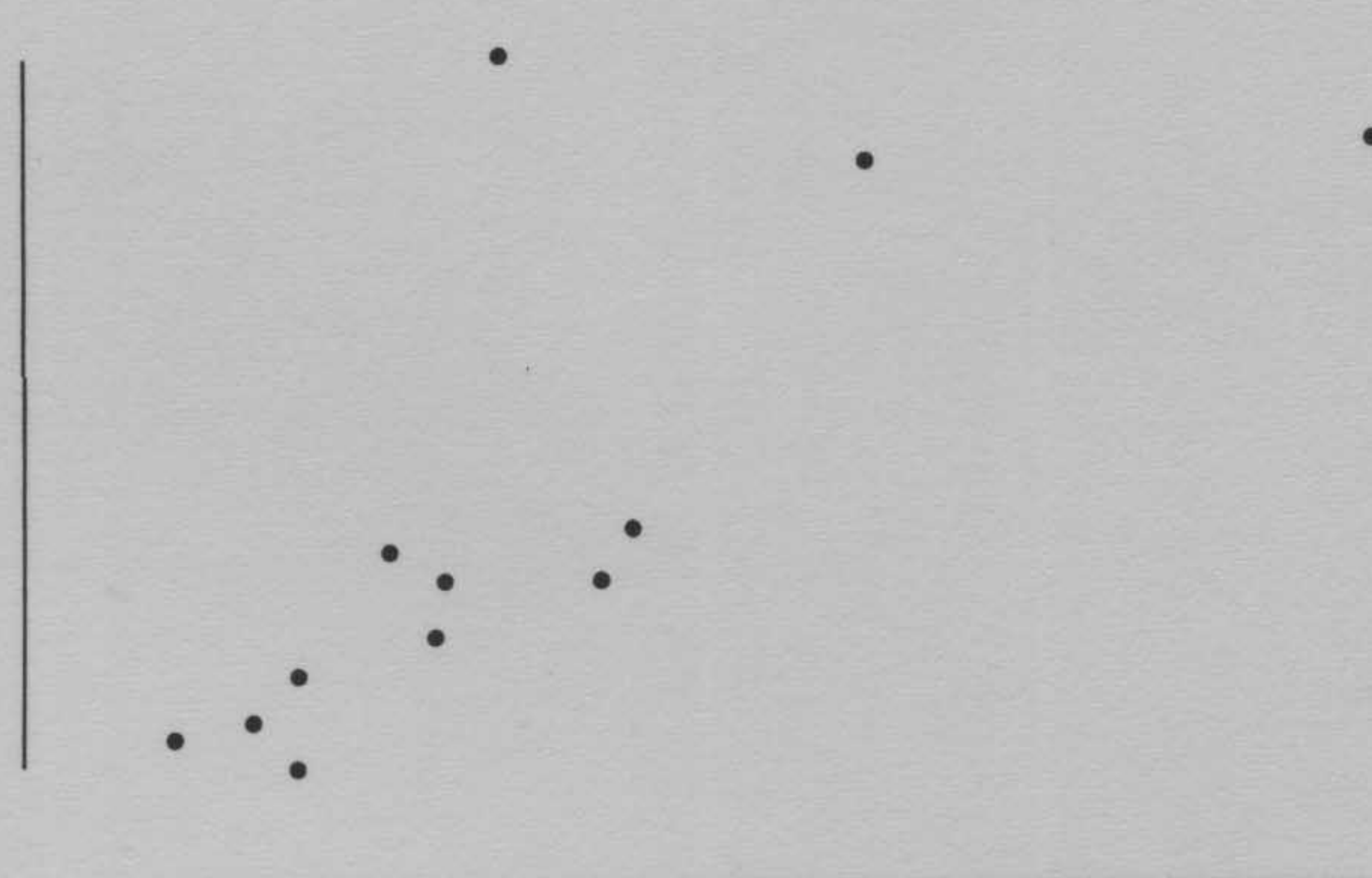


Redesign of the Scatterplot

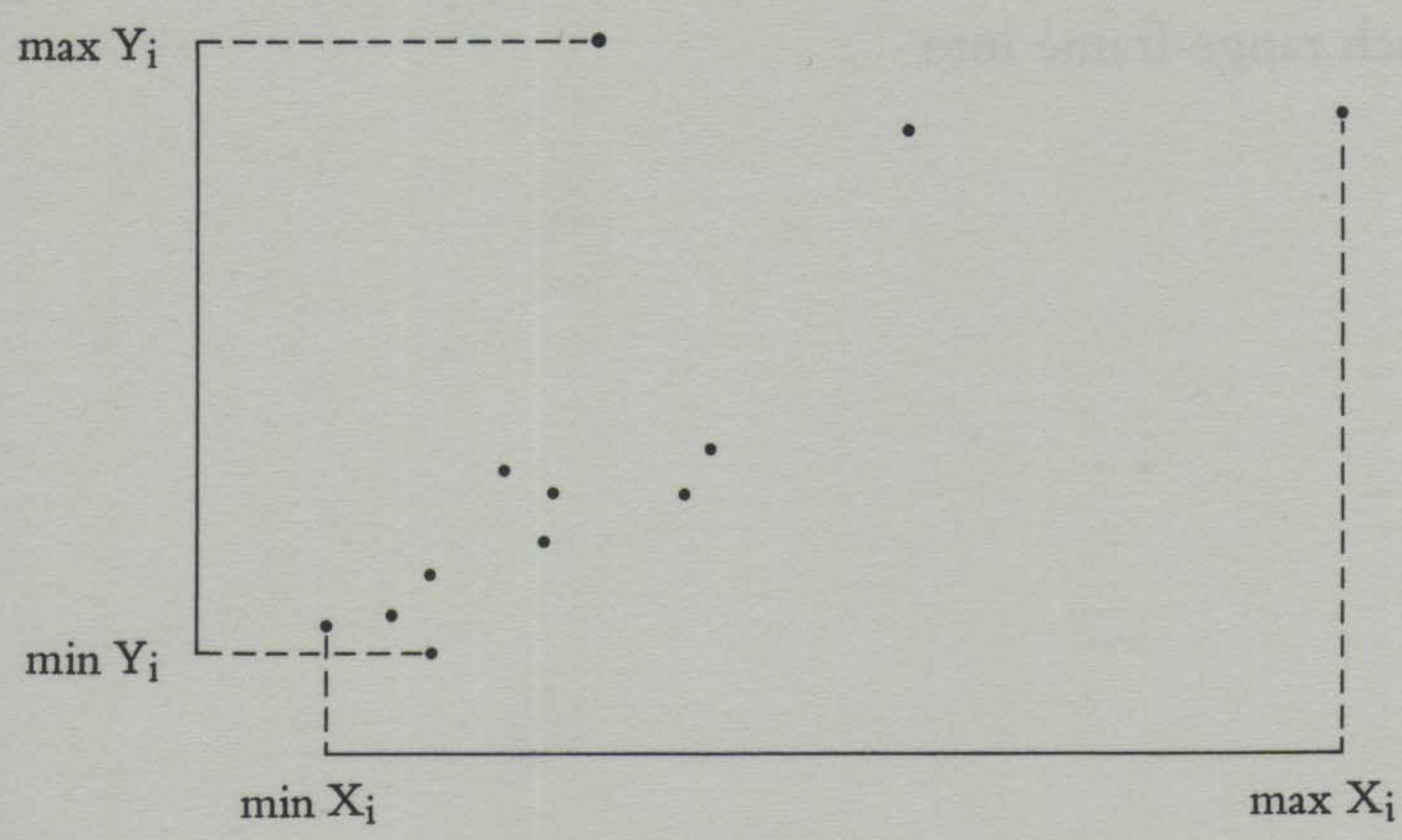
Consider the standard bivariate scatterplot:



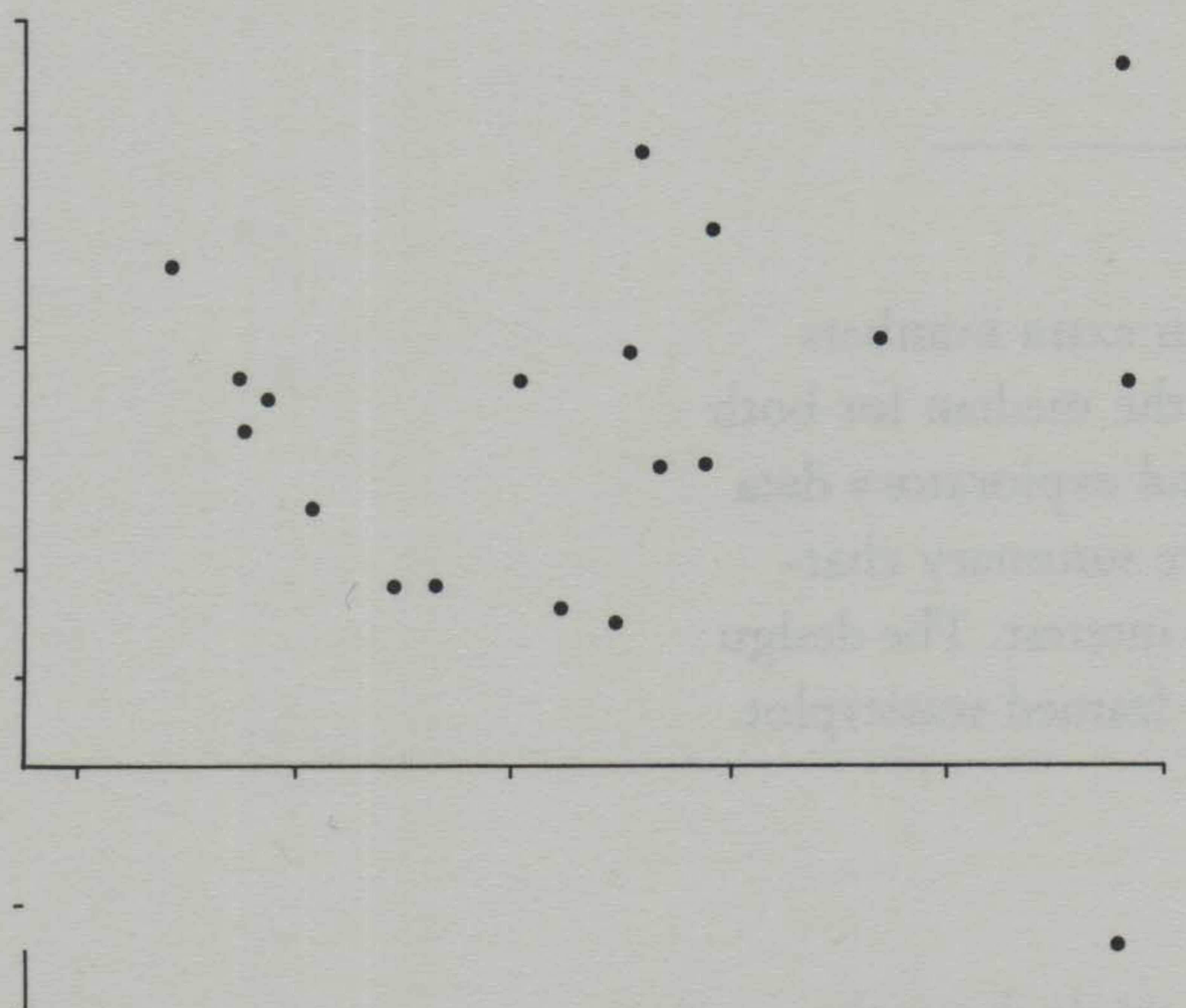
A useful fact, brought to notice by the maximization and erasing principles, is that the frame of a graphic can become an effective data-communicating element simply by erasing part of it. The frame lines should extend only to the measured limits of the data rather than, as is customary, to some arbitrary point like the next round number marking off the grid and grid ticks of the plot. That part of the frame exceeding the limits of the observed data is trimmed off:



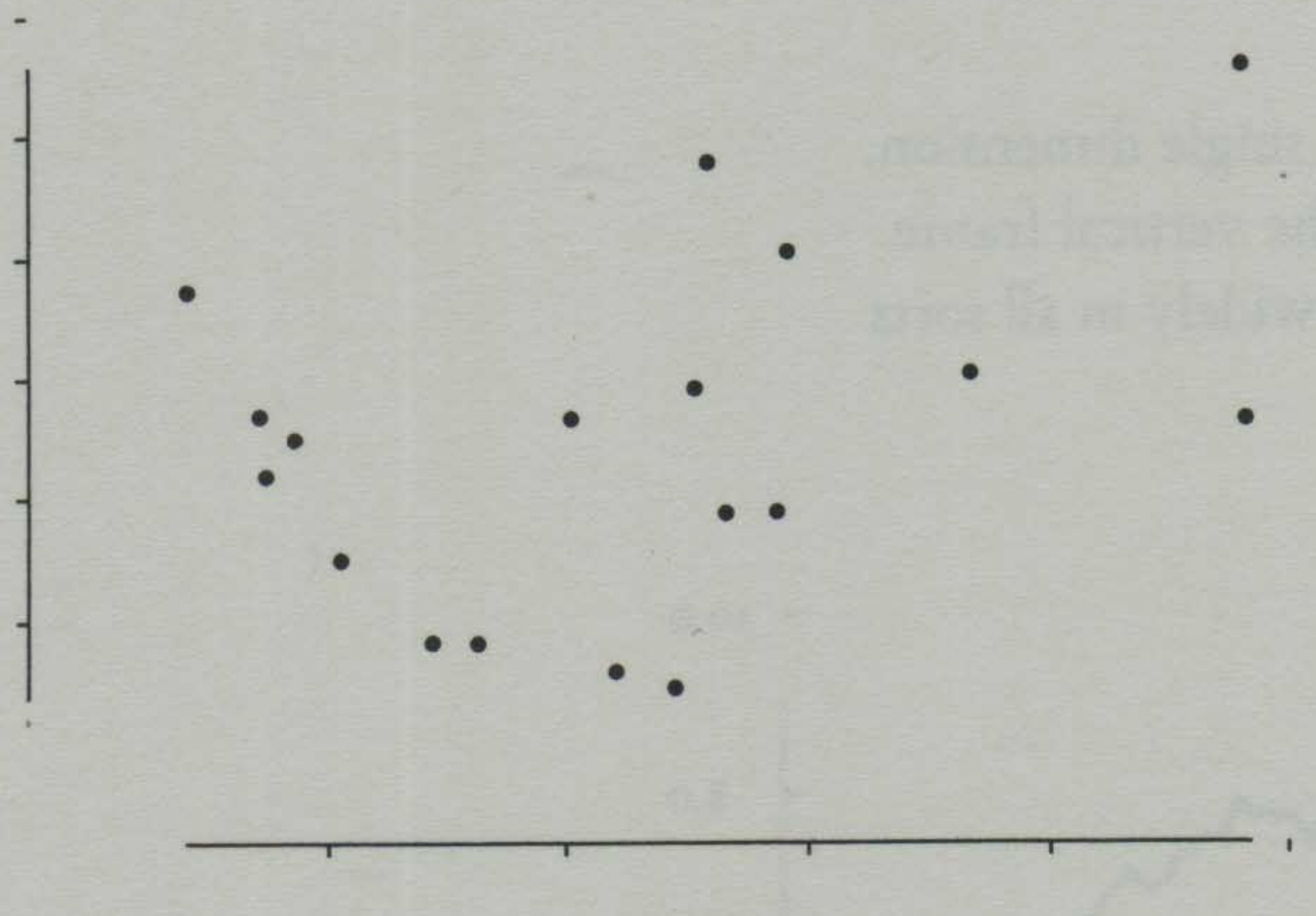
The result, a *range-frame*, explicitly shows the maximum and minimum of both variables plotted (along with the range), information available only by extrapolation and visual estimation in the conventional design. The data-ink ratio has increased: some non-data-ink has been erased, and the remainder of the frame, now carrying information, has gone over to the side of data-ink.



Nothing but the tails of the frame need change:



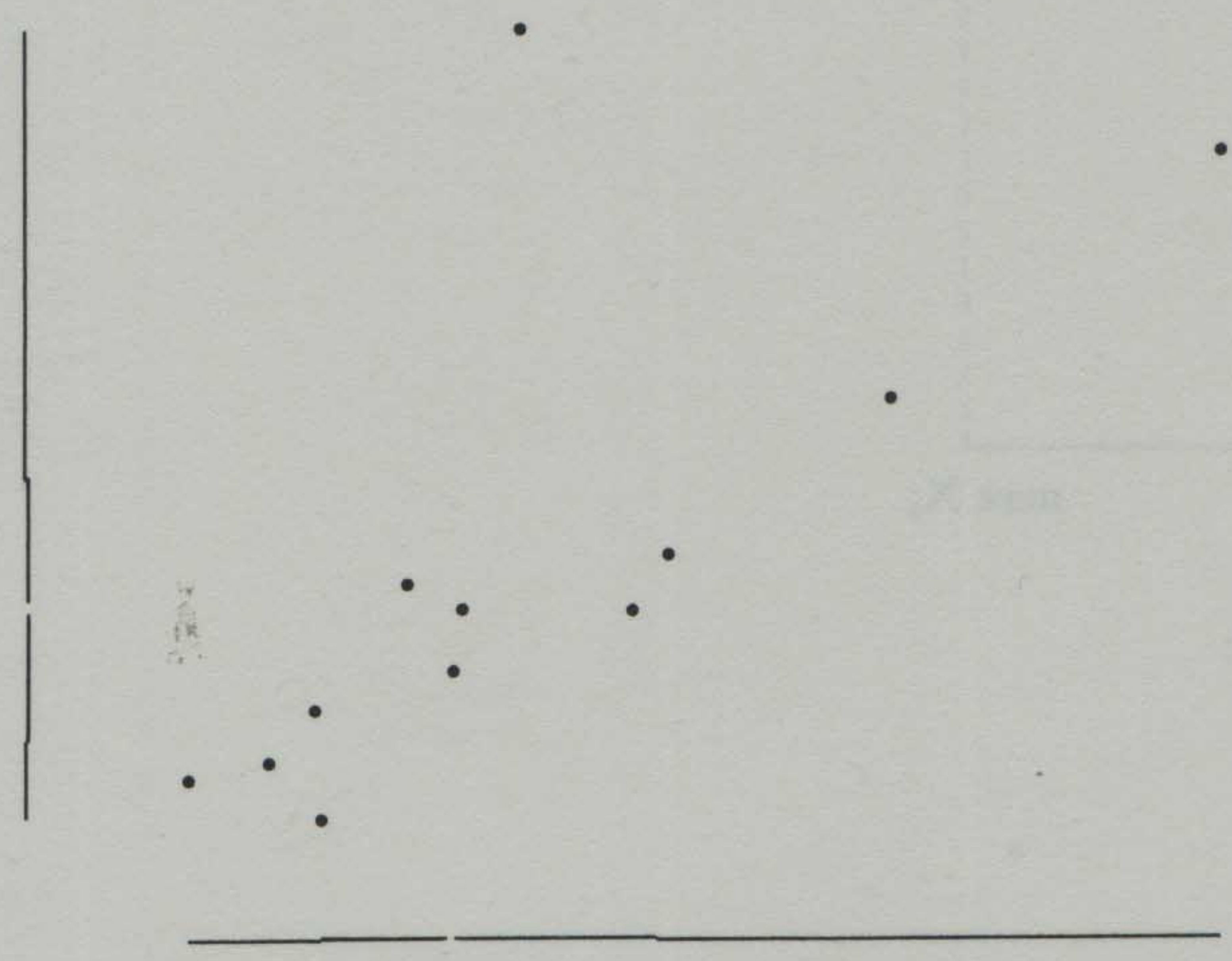
Conventional Scatterplot



Range-Frame

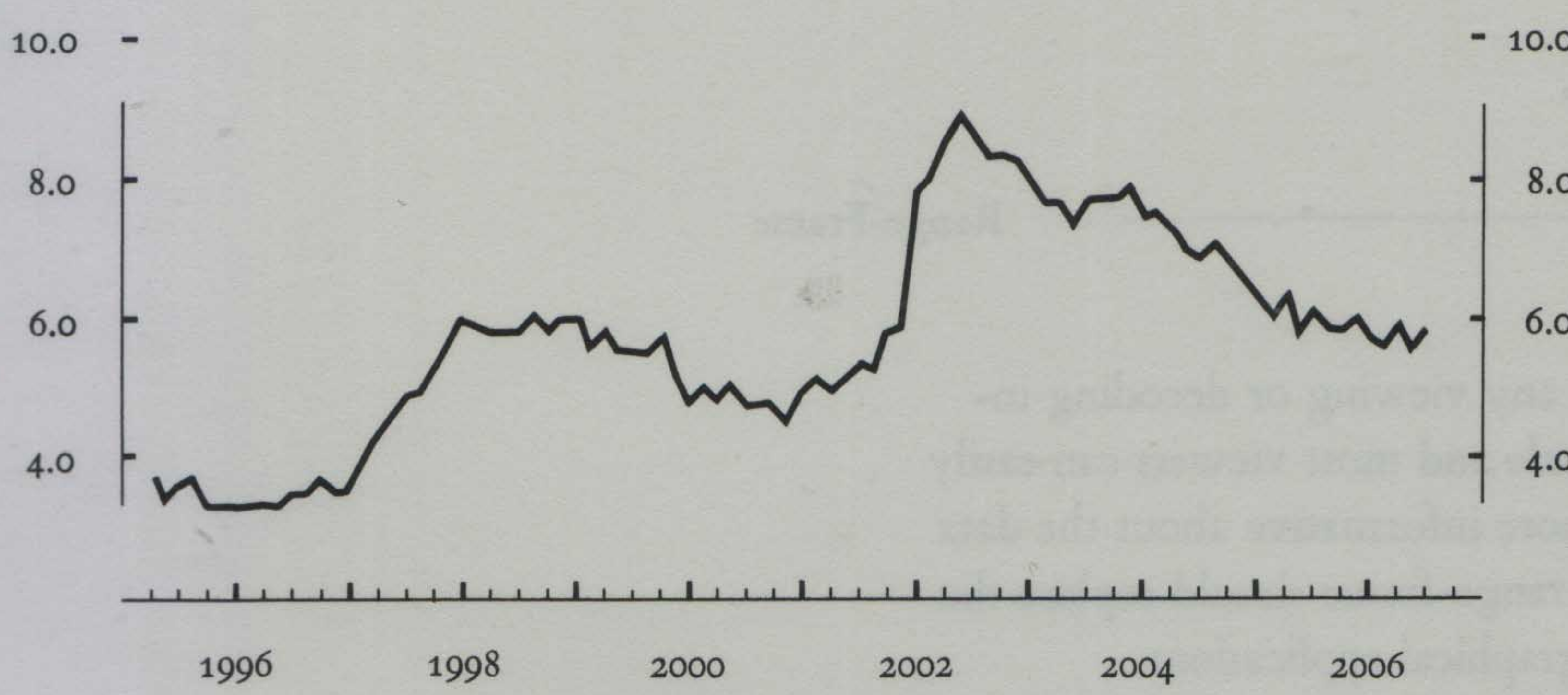
A range-frame does not require any viewing or decoding instructions; it is not a graphical puzzle and most viewers can easily tell what is going on. Since it is more informative about the data in a clear and precise manner, the range-frame should replace the non-data-bearing frame in many graphical applications.

A small shift in the remaining ink turns each range-frame into a quartile plot:



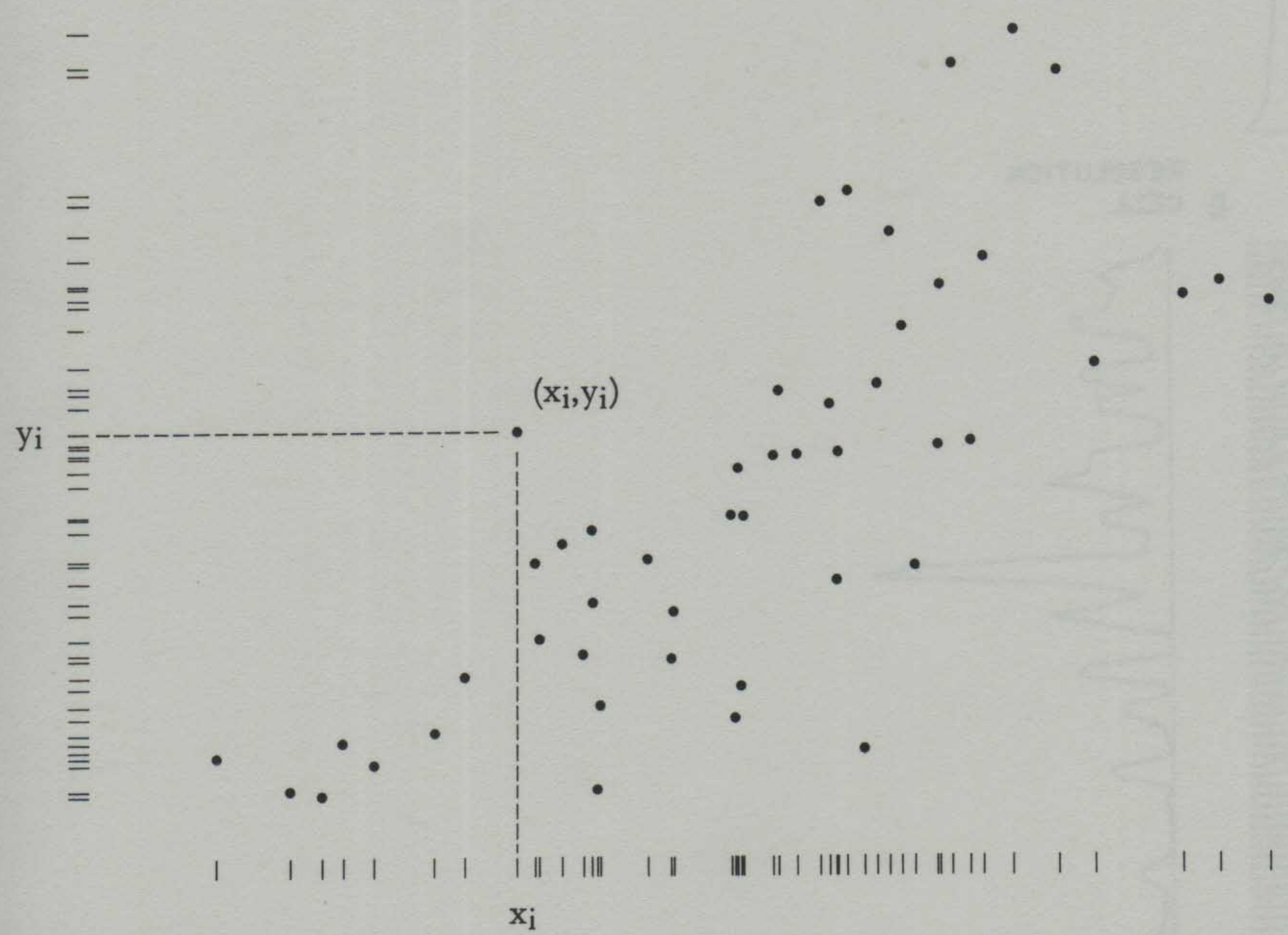
Erasing and editing has led to the display of ten extra numbers (the minimum, maximum, two quartiles, and the median for both variables). The design is useful for analytical and exploratory data analysis, as well as for published graphics where summary characterizations of the marginal distributions have interest. The design is nearly always better than the conventionally framed scatterplot.

Range-frames can also present ranges along a single dimension. Here the historical high and low are shown in the vertical frame. This is an excellent practice and should be used widely in all sorts of displays, both scientific and unscientific:



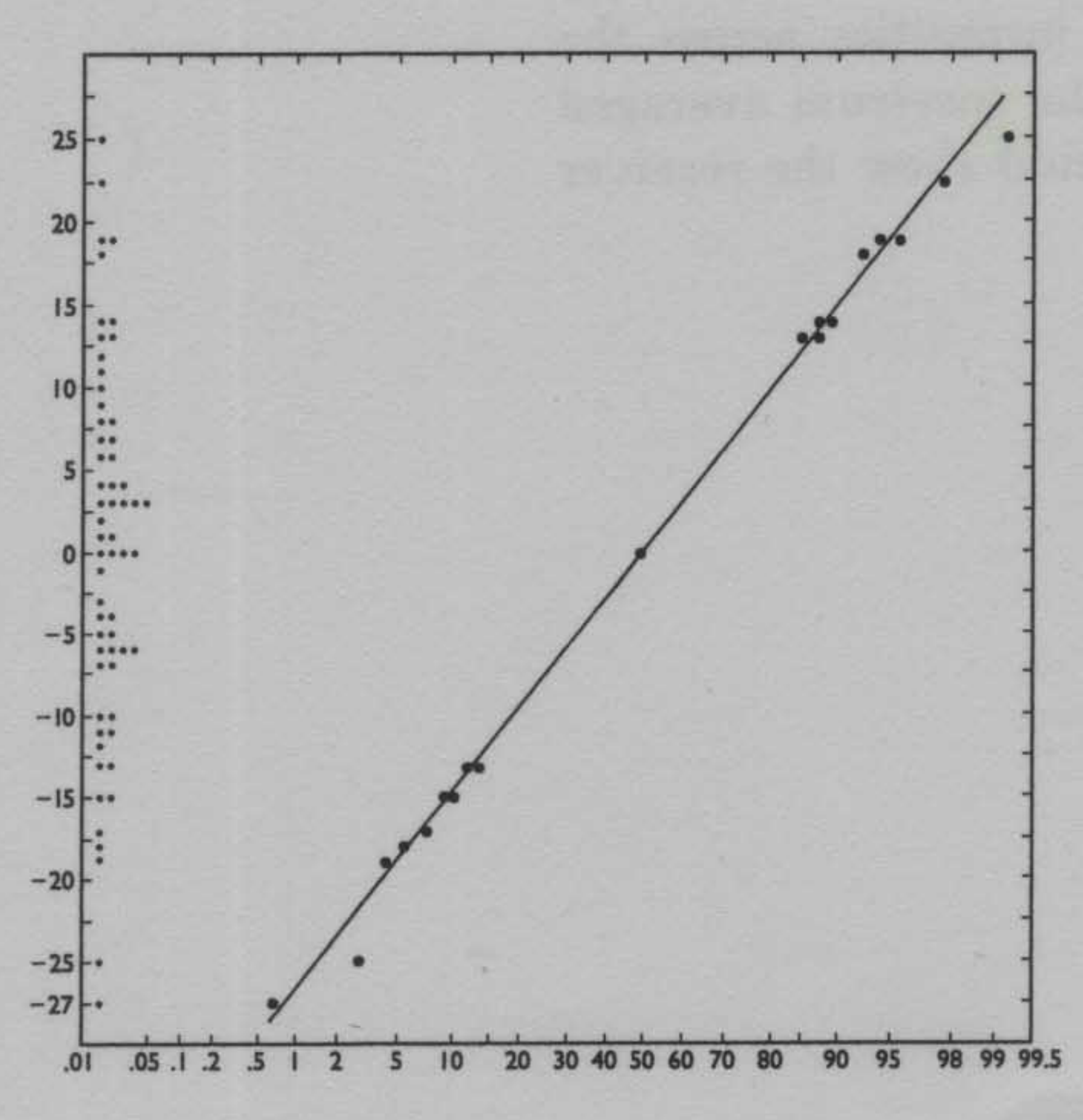
Finally, the entire frame can be turned into data by framing the bivariate scatter with the marginal distribution of each variable. The *dot-dash-plot* results.[1]

[1] The terminology follows tradition, for scatterplots were once called "dot diagrams"—for example, in R. A. Fisher's *Statistical Methods for Research Workers* (Edinburgh, 1925).



The dot-dash-plot combines the two fundamental graphical designs used in statistical analysis, the marginal frequency distribution and the bivariate distribution. Dot-dash-plots make routine what good data analysts do already—plotting marginal and joint distributions together.

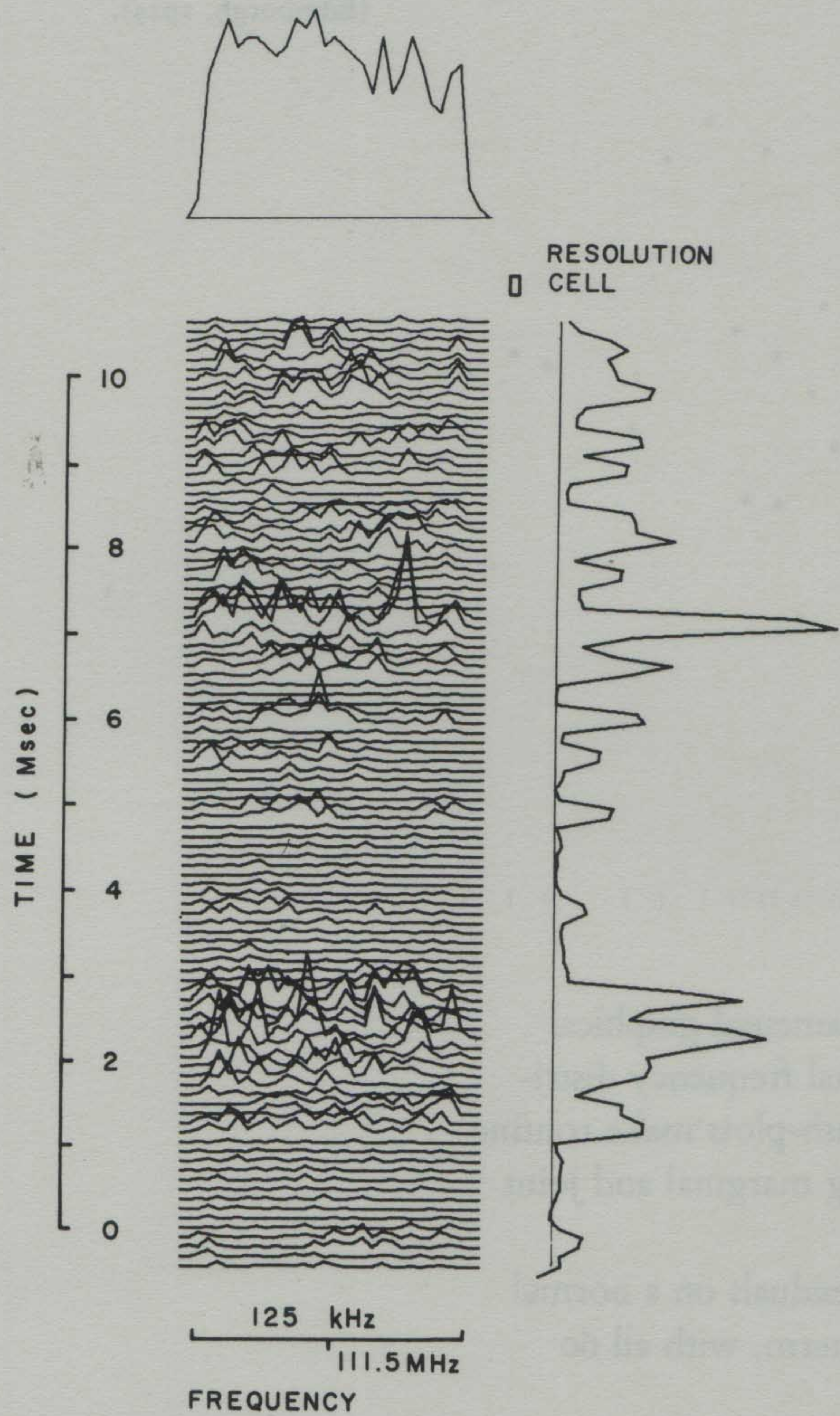
An empirical cumulative distribution of residuals on a normal grid shows the outer 18 terms plus the 30th term, with all 60 points plotted in the marginal distribution:



Cuthbert Daniel, *Applications of Statistics to Industrial Experimentation* (New York, 1976), p. 155.

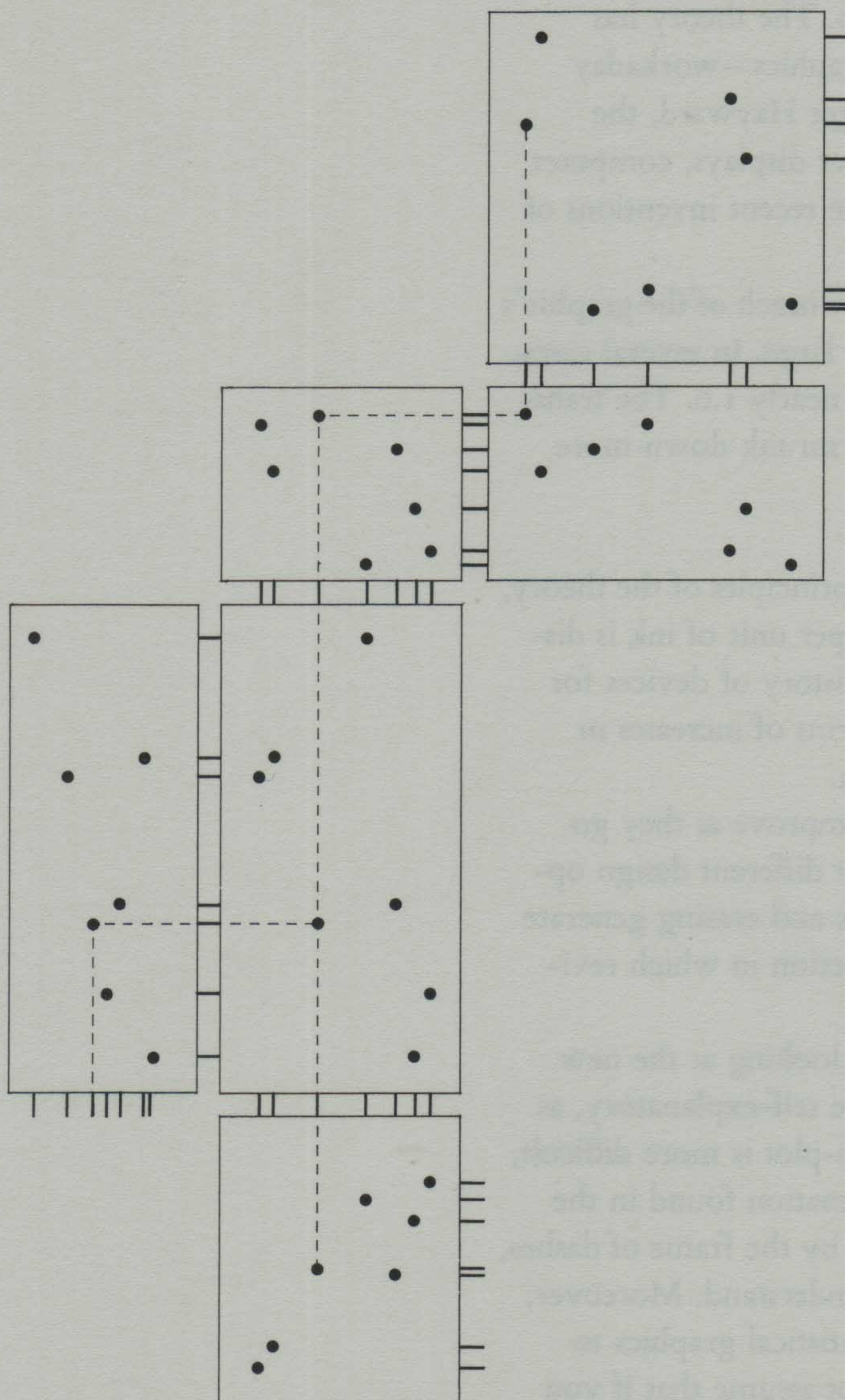
Similarly, this data-rich graphic of signals from pulsars shows both marginal distributions:

Timothy H. Hankins and Barney J. Rickett, "Pulsar Signal Processing," in Berni Alder, et al., eds., *Methods in Computational Physics, Volume 14: Radio Astronomy* (New York, 1975), p. 108.



Narrowband spectra of individual subpulses. Each point of the intensity $I_q(t)$ plotted on the right is the sum of the distribution of intensities across the receiver bandwidth shown in the center. At the top is plotted the spectrum averaged over the pulse. In the limit of many thousands of pulses this would show the receiver bandpass shape.

The fringe of dashes in the dot-dash-plot can connect a series of bivariate scatters in a *rugplot* (since it resembles a set of fringed rugs—and covers the statistical ground):



Reflecting the one-dimensional projections from each scatter, the dashes encourage the eye to notice how each plot filters and translates the data through the scatter from one adjacent plot to the next. Sometimes it is useful to think of each bivariate scatter as the imperfect empirical representation of an underlying curve that transforms one variable into another. In the rugplot, the sequence of variables can wander off as appropriate. The quantitative history of a single observation can be traced through a series of one- and two-dimensional contexts.

Conclusion

The first part of a theory of data graphics is in place. The idea, as described in the previous three chapters, is that most of a graphic's ink should vary in response to data variation. The theory has something to say about a great variety of graphics—workaday scientific charts, the unique drawings of Roger Hayward, the exemplars of graphical handbooks, newspaper displays, computer graphics, standard statistical graphics, and the recent inventions of Chernoff and Tukey.

The observed increases in efficiency, in how much of the graphic's ink carries information, are sometimes quite large. In several cases, the data-ink ratio increased from .1 or .2 to nearly 1.0. The transformed designs are less cluttered and can be shrunk down more readily than the originals.

But, are the transformed designs *better*?

(1) They are necessarily better within the principles of the theory, for more information per unit of space and per unit of ink is displayed. And this is significant; indeed, the history of devices for communicating information is written in terms of increases in efficiency of communication and production.

(2) Graphics are almost always going to improve as they go through editing, revision, and testing against different design options. The principles of maximizing data-ink and erasing generate graphical alternatives and also suggest a direction in which revisions should move.

(3) Then there is the audience: will those looking at the new designs be confused? Some of the designs are self-explanatory, as in the case of the range-frame. The dot-dash-plot is more difficult, although it still shows all the standard information found in the scatterplot. Nothing is lost to those puzzled by the frame of dashes, and something is gained by those who do understand. Moreover, it is a frequent mistake in thinking about statistical graphics to underestimate the audience. Instead, why not assume that if you understand it, most other readers will, too? Graphics should be as intelligent and sophisticated as the accompanying text.

(4) Some of the new designs may appear odd, but this is probably because we have not seen them before. The conventional designs for statistical graphics have been viewed thousands of times by nearly every reader of this book; on the other hand, the range-frame, the dot-dash-plot, the white grid, the quartile plot, the rugplot, and the half-face just a few times. With use, the new designs will come to look just as reasonable as the old.

Maximizing data ink (within reason) is but a single dimension of a complex and multivariate design task. The principle helps conduct experiments in graphical design. Some of those experiments will succeed. There remain, however, many other considerations in the design of statistical graphics—not only of efficiency, but also of complexity, structure, density, and even beauty.