Edward R. Tufte

The Visual Display of Quantitative Information

SECOND EDITION

Graphics Press · *Cheshire, Connecticut*

Published by Graphics Press LLC
Post Office Box 430, Cheshire, Connecticut 06410
www.tufte.com

Printed in the United States of America   *Second edition, eighth printing, April 2013*

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

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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.

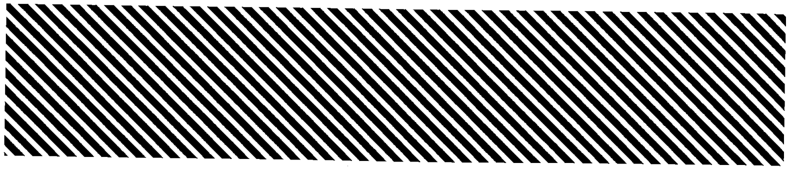
Sometimes the decoration is thought to reflect the artist's fundamental design contribution, capturing the essential spirit of the data and so on. Thus principles of artistic integrity and creativity are invoked to defend—even to advance—the cause of chartjunk. There are better ways to portray spirits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

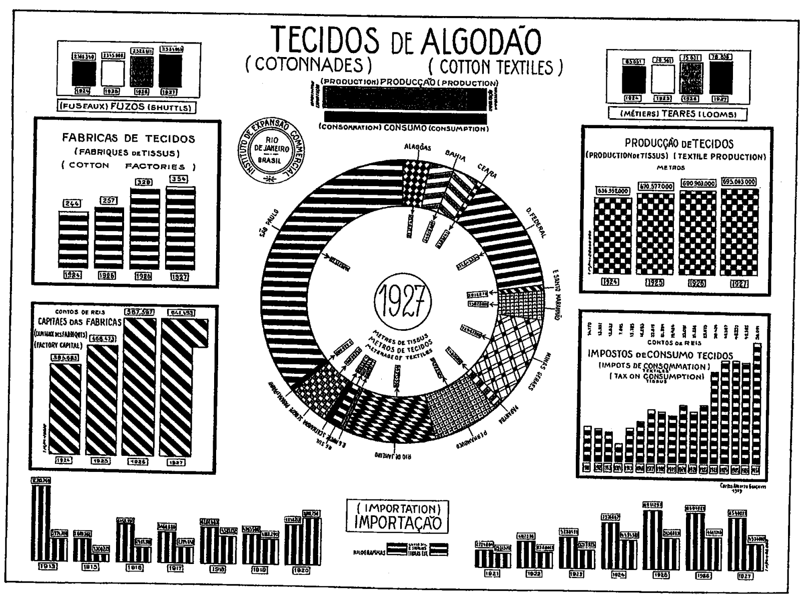
Contemporary optical art relies on moiré effects, in which the design interacts with the physiological tremor of the eye to produce the distracting appearance of vibration and movement.



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), 15.



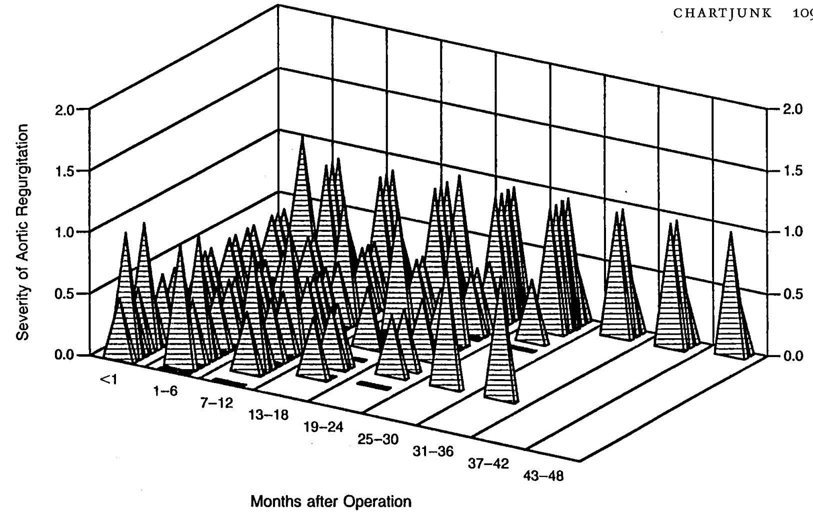
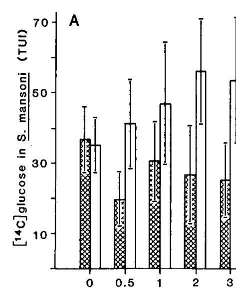
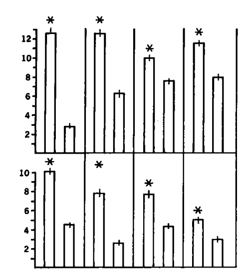


Figure 2. Serial Echocardiographic Assessments of the Severity of Regurgitation in the Pulmonary Autograft in 31 Patients.
The numerical grades were assigned according to the severity of regurgitation, as follows: 0, none; 0.5, trivial; 1.0 to 1.5, mild; 2.0, moderate; and 3.0, severe.

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), 4.

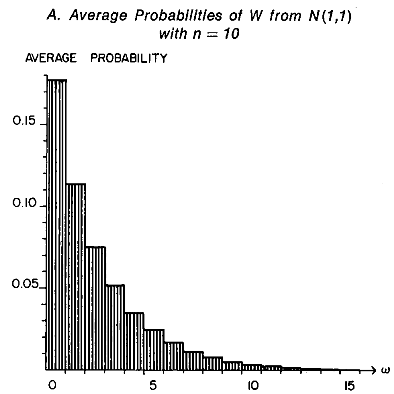




James T. Kuznicki and N. Bruce McCutcheon, "Cross-Enhancement of the Sour Taste on Single Human Taste Papillae," *Journal of Experimental Psychology: General*, 108 (1979), 76.

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":



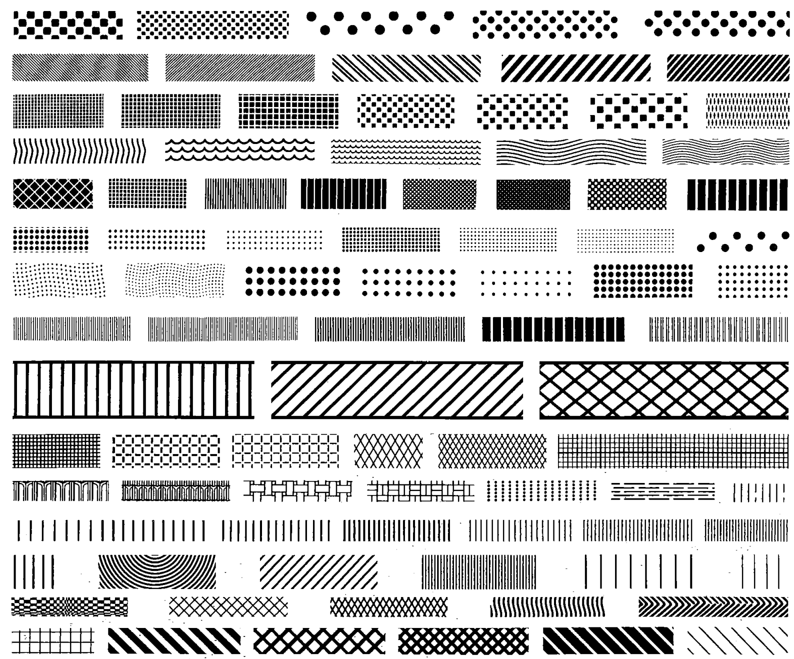
"JASA Style Sheet," *Journal of the American Statistical Association*, 71 (March 1976), 260–261.

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:

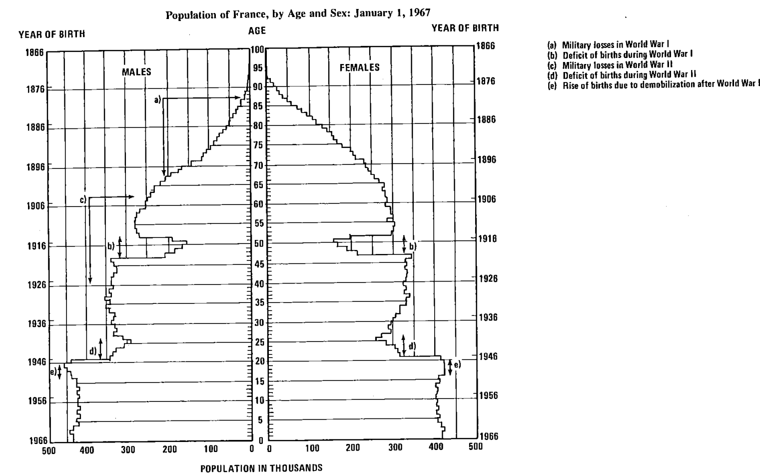
Textbooks and handbooks of statistical graphics; and manuals for computer graphics programs (ordered by date of publication)	Percentage of graphics with moiré vibration	Total number of graphics
Willard C. Brinton, *Graphic Methods for Presenting Facts* (New York, 1914)	12%	255
R. Satet, *Les Graphiques* (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, DC, 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.

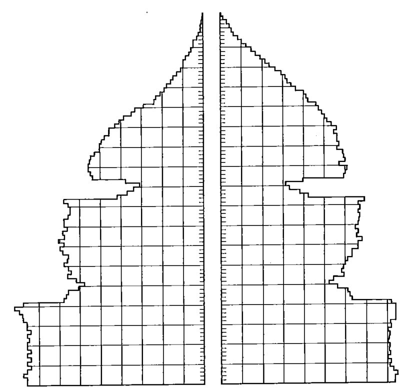
[1] Jacques Bertin, *Semiology of Graphics: Diagrams, Networks, Maps* (Madison, Wisconsin, 1983, translated by William J. Berg), 80; this book is the English translation of Bertin's important work, *Sémiologie graphique* (Paris, 1967).

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:



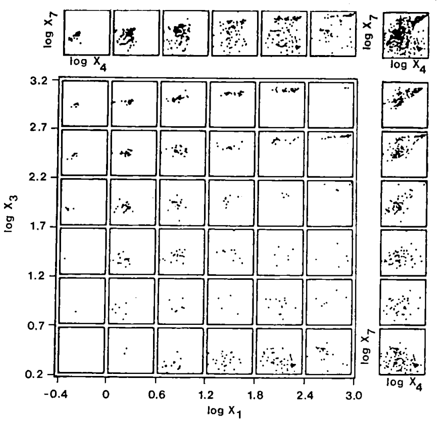
A revision quiets the grid and gives emphasis to the data:

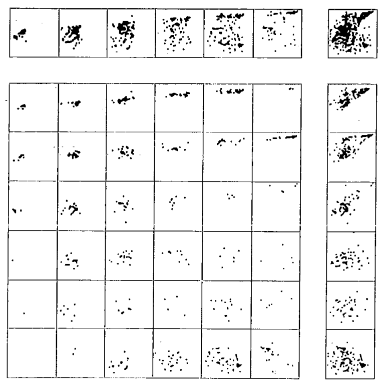


Based on data in Institut National de la Statistique et des Études Économiques, *Annuaire statistique de la France, 1968* (Paris, 1968), 32–33; redrawn in Henry S. Shryock and Jacob S. Siegel, *The Methods and Materials of Demography* (Washington, DC, 1973), vol. 1, 242.

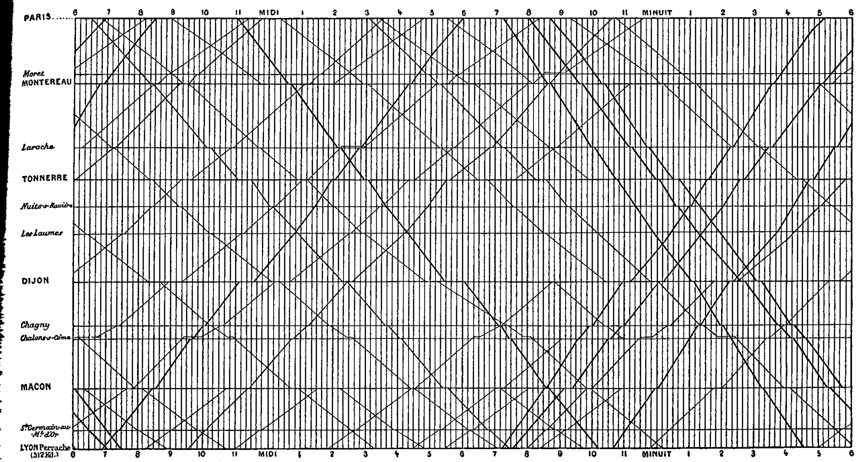
The space occupied by the doubled grid lines consumes 18 percent of the area of this otherwise most ingenious design, a "multiwindow plot." Optical white dots appear at the intersections of the grid lines. (The plot shows the following: The large square contains X_4, X_7 scatterplots for the indicated 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.

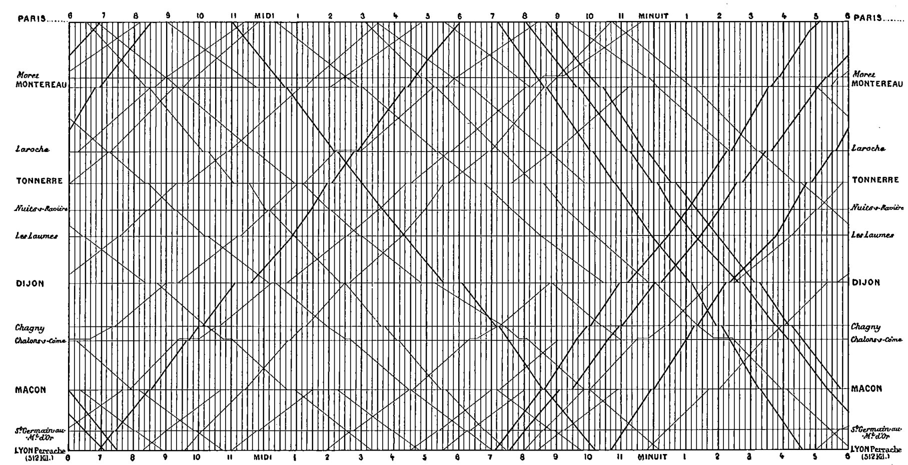




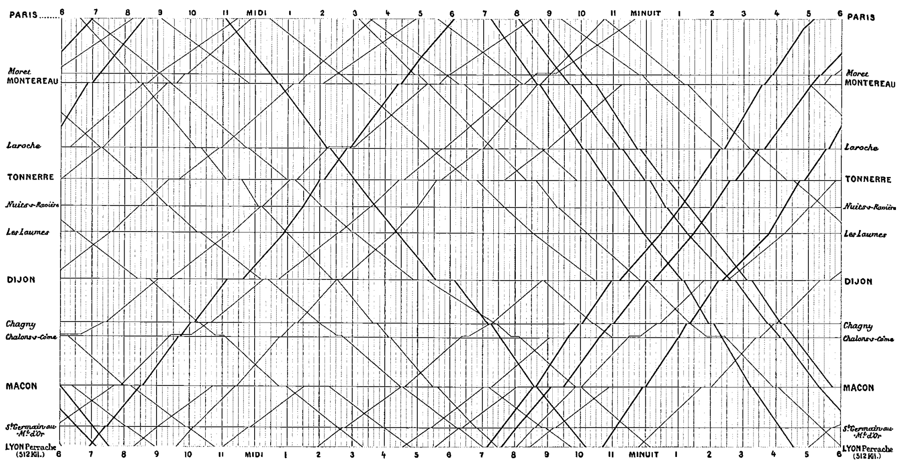
The grid in the classic Marey train schedule is very active:



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.

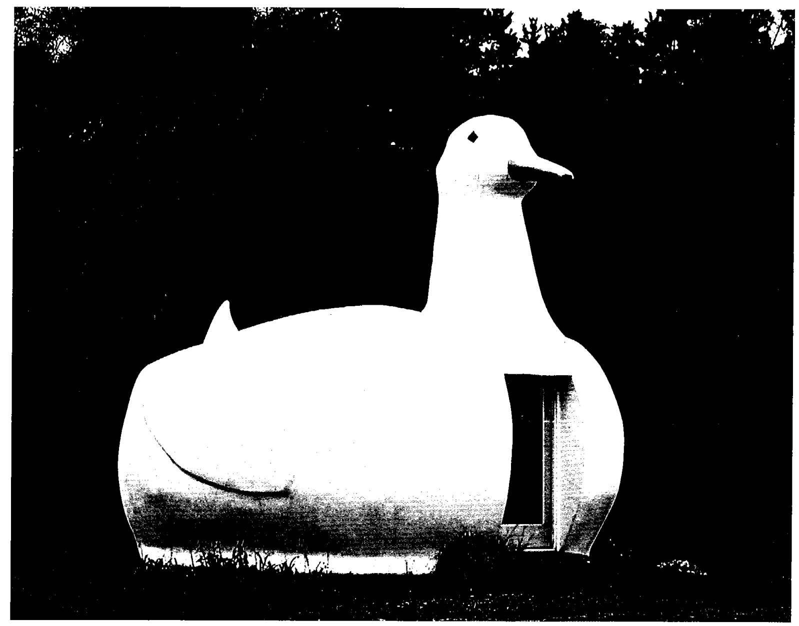
Self-Promoting Graphics: The Duck

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]

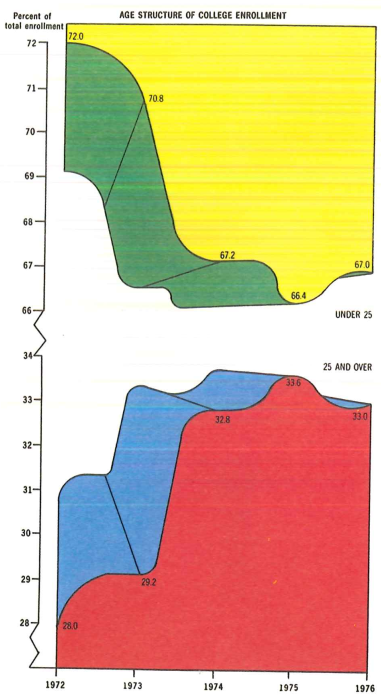
[2] Robert Venturi, Denise Scott Brown, and Steven Izenour, *Learning from Las Vegas* (Cambridge, revised edition, 1977), 163. The initial statement of the duck concept is found on 87–103.



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

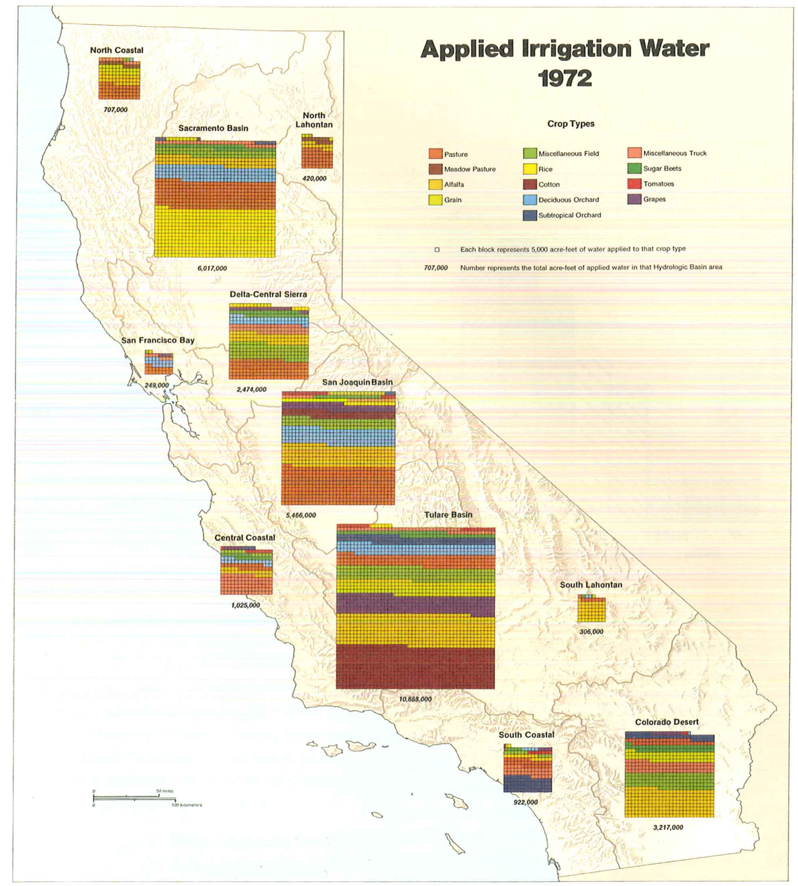
The addition of a fake perspective to the data structure clutters many graphics. This variety of chartjunk, now at high fashion in the world of Boutique Data Graphics, abounds in corporate annual reports, the phony statistical studies presented in advertisements, the mass media, and the more muddled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

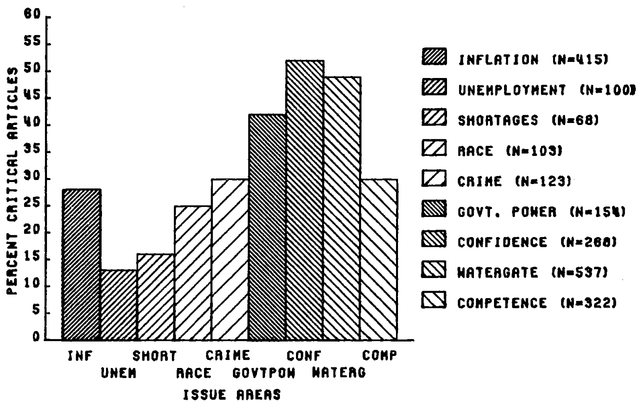


There are some superbly produced ducks:

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

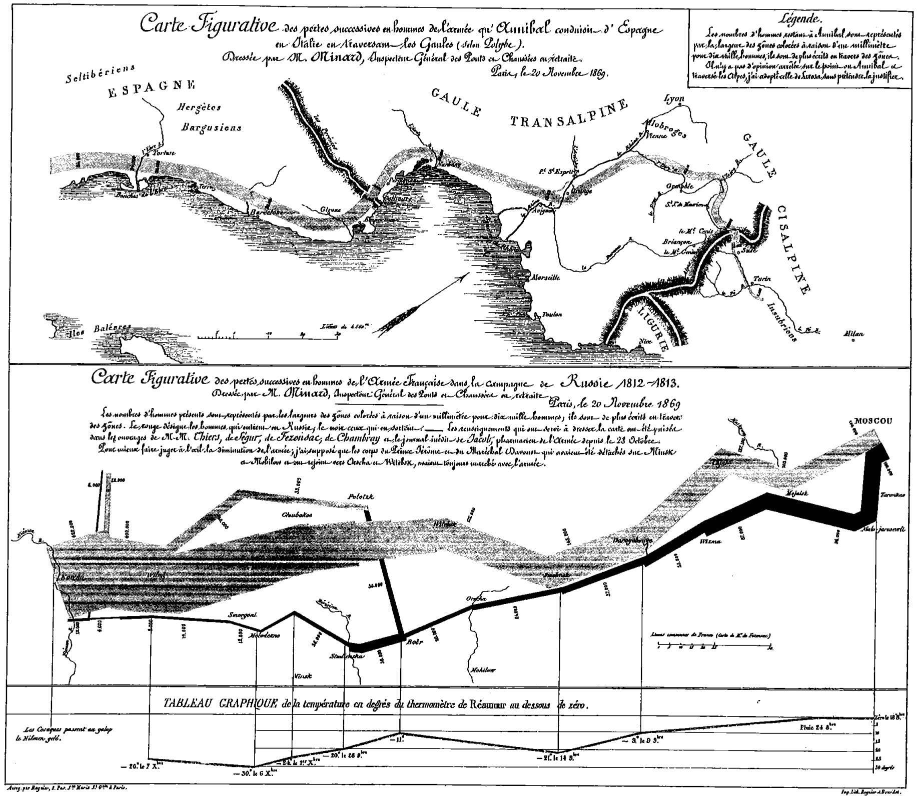
Arthur H. Miller, Edie N. Goldenberg, and Lutz Erbring, "Type-Set Politics: Impact of Newspapers on Public Confidence," *American Political Science Review*, 73 (1979), 67–84.

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 pubic 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.



9 *Aesthetics and Technique in Data Graphical Design*

Along with the amazing graphic of the French losses in the Russian invasion, Minard includes a second "Carte Figurative." It portrays Hannibal's fading elephant campaign in Spain, Gaul, and Northern Italy. Minard uses a light transparent color for flow-lines, allowing the underlying type to show through. This refined use of color to depict more information contrasts with the garish tones too often seen in modern graphics.

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

What makes for such graphical elegance? What accounts for the quality of Minard's graphics, of those of Playfair and Marey, and of some recent work, such as the new view of the galaxies? Good design has two key elements:

> Graphical elegance is often found in simplicity of design and complexity of data.

Visually attractive graphics also gather power from content and interpretations beyond the immediate display of some numbers. The best graphics are about the useful and important, about life and death, about the universe. Beautiful graphics do not traffic with the trivial.

On rare occasions graphical architecture combines with the data content to yield a uniquely spectacular graphic. Such performances can be described and admired but there are no easy compositional principles on how to create that one wonderful graphic in millions. As Barnett Newman once said, "Aesthetics is for the artist like ornithology is for the birds."

What can be suggested, though, are some guides for enhancing the visual quality of routine, workaday designs. Attractive displays of statistical information

- have a properly chosen format and design
- use words, numbers, and drawing together
- reflect a balance, a proportion, a sense of relevant scale
- display an accessible complexity of detail
- often have a narrative quality, a story to tell about the data
- are drawn in a professional manner, with the technical details of production done with care
- avoid content-free decoration, including chartjunk.

The Choice of Design: Sentences, Text-Tables, Tables, Semi-Graphics, and Graphics

The substantive content, extensiveness of labels, and volume and ordering of data all help determine the choice of method for the display of quantitative materials. The basic structures for showing data are the sentence, the table, and the graphic. Often two or three of these devices should be combined.

The conventional sentence is a poor way to show more than two numbers because it prevents comparisons within the data. The linearly organized flow of words, folded over at arbitrary points (decided not by content but by the happenstance of column width), offers less than one effective dimension for organizing the data. Instead of:

> Nearly 53 percent of the type A group did something or other compared to 46 percent of B and slightly more than 57 percent of C.

Arrange the type to facilitate comparisons, as in this *text-table*:

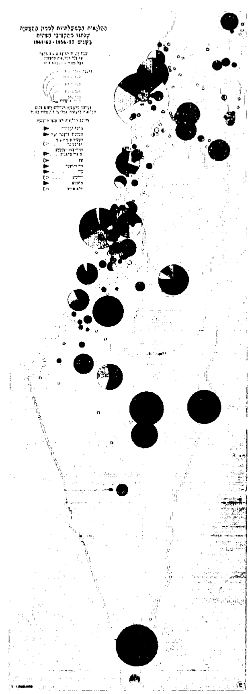
The three groups differed in how they did something or other:

Group A	53%
Group B	46%
Group C	57%

There are nearly always better sequences than alphabetical—for example, ordering by content or by data values:

Group B	46%
Group A	53%
Group C	57%

Tables are clearly the best way to show exact numerical values, although the entries can also be arranged in semi-graphical form. Tables are preferable to graphics for many small data sets.[1] A table is nearly always better than a dumb pie chart; the only worse design than a pie chart is several of them, for then the viewer is asked to compare quantities located in spatial disarray both within and between pies, as in this heavily encoded example from an atlas. Given their low data-density and failure to order numbers along a visual dimension, pie charts should never be used.[2]



Department of Surveys, Ministry of Labour, *Atlas of Israel* (Jerusalem, 1956–), vol. 8, 8.

[1] On the design of tables, see A.S.C. Ehrenberg, "Rudiments of Numeracy," *Journal of the Royal Statistical Society*, A, 140 (1977), 277–297.

[2] This point is made decisively in Jacques Bertin, *Graphics and Graphic Information Processing* (Berlin, 1981). Bertin describes multiple pie charts as "completely useless" (p. 111).

Tables also work well when the data presentation requires many localized comparisons. In this 410-number table that I designed for the *New York Times* to show how different people voted in presidential elections in the United States, comparisons between the elections of 1980 and 1976 are read across each line; within-election analysis is conducted by reading downward in the clusters of three to seven lines. The horizontal rules divide the data into topical paragraphs; the rows are ordered so as to tell an ordered story about the elections. This type of elaborate table, a *supertable*, is likely to attract and intrigue readers through its organized, sequential detail and reference-like quality. One supertable is far better than a hundred little bar charts.

How Different Groups Voted for President

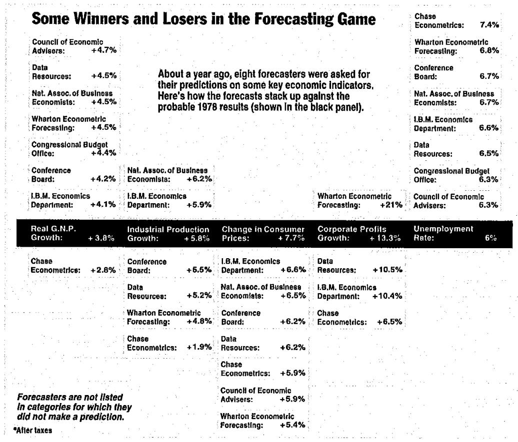
Based on 12,782 interviews with voters at their polling places. Shown is how each group divided its vote for President and, in parentheses, the percentage of the electorate belonging to each group.

	CARTER	REAGAN	ANDERSON	CARTER-FORD In 1976
Democrats (43%)	66	26	6	77 - 22
Independents (23%)	30	54	12	43 - 54
Republicans (28%)	11	84	4	9 - 90
Liberals (17%)	57	27	11	70 - 26
Moderates (46%)	42	48	8	51 - 48
Conservatives (28%)	23	71	4	29 - 70
Liberal Democrats (9%)	70	14	13	86 - 12
Moderate Democrats (22%)	66	28	6	77 - 22
Conservative Democrats (8%)	53	41	4	64 - 35
Politically active Democrats (3%)	72	19	8	—
Democrats favoring Kennedy in primaries (13%)	66	24	8	—
Liberal Independents (4%)	50	29	15	64 - 29
Moderate Independents (12%)	31	53	13	45 - 53
Conservative Independents (7%)	22	69	6	26 - 72
Liberal Republicans (2%)	25	66	9	17 - 82
Moderate Republicans (11%)	13	81	5	11 - 88
Conservative Republicans (12%)	6	91	2	6 - 93
Politically active Republicans (2%)	5	89	6	—
East (32%)	43	47	8	51 - 47
South (27%)	44	51	3	54 - 45
Midwest (20%)	41	51	6	48 - 50
West (11%)	35	52	10	46 - 51
Blacks (10%)	82	14	3	82 - 16
Hispanics (2%)	54	36	7	75 - 24
Whites (88%)	36	55	8	47 - 52
Female (49%)	45	46	7	50 - 48
Male (51%)	37	54	7	50 - 48
Female, favors equal rights amendment (22%)	54	32	11	—
Female, opposes equal rights amendment (15%)	29	66	4	—
Catholic (25%)	40	51	7	54 - 44
Jewish (5%)	45	39	14	64 - 34
Protestant (46%)	37	56	6	44 - 55
Born-again white Protestant (17%)	34	61	4	—
18 - 21 years old (6%)	44	43	11	48 - 50
22 - 29 years old (17%)	43	43	11	51 - 46
30 - 44 years old (31%)	37	54	7	49 - 49
45 - 59 years old (23%)	39	55	6	47 - 52
60 years or older (18%)	40	54	4	47 - 52
Family Income				
Less than $10,000 (13%)	50	41	6	58 - 40
$10,000 - $14,999 (14%)	47	42	8	55 - 43
$15,000 - $24,999 (30%)	38	53	7	48 - 50
$25,000 - $50,000 (24%)	32	58	8	36 - 62
Over $50,000 (5%)	25	65	8	—
Professional or manager (40%)	33	56	9	41 - 57
Clerical, sales or other white-collar (11%)	42	48	8	46 - 53
Blue-collar worker (17%)	46	47	5	57 - 41
Agriculture (3%)	29	66	3	—
Looking for work (3%)	55	35	7	65 - 34
Education				
High school or less (39%)	46	48	4	57 - 43
Some college (28%)	35	55	8	51 - 49
College graduate (27%)	35	51	11	45 - 55
Labor union household (26%)	47	44	7	59 - 39
No member of household in union (62%)	35	55	8	43 - 55
Family finances				
Better off than a year ago (16%)	53	37	8	30 - 70
Same (40%)	46	46	7	51 - 49
Worse off than a year ago (34%)	25	64	8	77 - 23
Family finances and political party				
Democrats, better off than a year ago (7%)	77	16	6	69 - 31
Democrats, worse off than a year ago (13%)	47	39	10	94 - 6
Independents, better off (3%)	45	36	12	—
Independents, worse off (9%)	21	65	11	—
Republicans, better off (4%)	18	77	5	3 - 97
Republicans, worse off (11%)	6	89	4	24 - 76
More important problem				
Unemployment (39%)	51	40	7	75 - 25
Inflation (44%)	30	60	9	35 - 65
Feel that U.S. should be more forceful in dealing with Soviet Union even if it would increase the risk of war (54%)	28	64	6	—
Disagree (31%)	56	32	10	—
Favor equal rights amendment (46%)	49	38	11	—
Oppose equal rights amendment (35%)	26	68	4	—
When decided about choice				
Knew all along (41%)	47	50	2	44 - 55
During the primaries (13%)	30	60	8	57 - 42
During conventions (8%)	36	55	7	51 - 48
Since Labor Day (8%)	30	54	13	49 - 49
In week before election (23%)	38	46	13	49 - 47

Source: 1976 and 1980 election day surveys by The New York Times/CBS News Poll and 1976 election day survey by NBC News.

New York Times, November 9, 1980, A-28.

For sets of highly labeled numbers, a wordy data graphic—coming close to straight text—works well. This table of numbers is nicely organized into a graphic:



New York Times, January 2, 1979, D-3.

Making Complexity Accessible: Combining Words, Numbers, and Pictures

Explanations that give access to the richness of the data make graphics more attractive to the viewer. Words and pictures are sometimes jurisdictional enemies, as artists feud with writers for scarce space. An unfortunate legacy of these craft-union differences is the artificial separation of words and pictures; a few style sheets even forbid printing on graphics. What has gone wrong is that the techniques of production instead of the information conveyed have been given precedence.

Words and pictures belong together. Viewers need the help that words can provide. Words on graphics are data-ink, making effective use of the space freed up by erasing redundant and non-data-ink. It is nearly always helpful to write little messages on the plotting field to explain the data, to label outliers and interesting data points, to write equations and sometimes tables on the graphic itself, and to integrate the caption and legend into the design so that the eye is not required to dart back and forth between textual material and the graphic. (The size of type on and around graphics

can be quite small, since the phrases and sentences are usually not too long—and therefore the small type will not fatigue viewers the way it does in lengthy texts.)

The principle of *data/text integration* is

> Data graphics are paragraphs about data and should be treated as such.

Words, graphics, and tables are different mechanisms with but a single purpose—the presentation of information. Why should the flow of information be broken up into different places on the page because the information is packaged one way or another? Sometimes it may be useful to have multiple story-lines or multiple levels of presentation, but that should be a deliberate design judgment, not something decided by conventional production requirements. Imagine if graphics were replaced by paragraphs of words and those paragraphs scattered over the pages out of sequence with the rest of the text—that is how graphical and tabular information is now treated in the layout of many published pages, particularly in scientific journals and professional books.

Tables and graphics should be run into the text whenever possible, avoiding the clumsy and diverting segregation of "See Fig. 2," (figures all too often located on the back of the adjacent page).[3] If a display is discussed in various parts of the text, it might well be printed afresh near each reference to it, perhaps in reduced size in later showings. The principle of text/graphic/table integration also suggests that the same typeface be used for text and graphic and, further, that ruled lines separating different types of information be avoided. Albert Biderman notes that illustrations were once well-integrated with text in scientific manuscripts, such as those of Newton and Leonardo da Vinci, but that statistical graphics became segregated from text and table as printing technology developed:

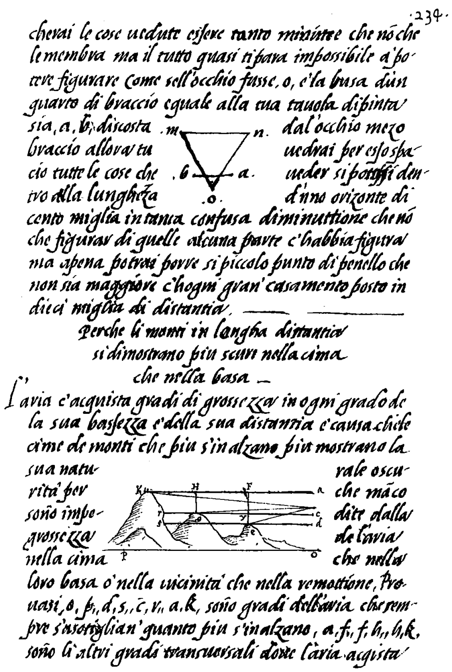
> The evolution of graphic methods as an element of the scientific enterprise has been handicapped by their adjunctive, segregated, and marginal position. The exigencies of typography that moved graphics to a segregated position in the printed work have in the past contributed to their intellectual segregation and marginality as well. There was a corresponding organizational segregation, with decisions on graphics often passing out of the hands of the original analyst and communicator into those of graphic specialists—the commercial artists and designers of graphic departments and audio-visual aids shops, for example, whose predilections and skills are usually more those of cosmeticians and merchandisers than of scientific analysts and communicators.[4]

[3] "Fig.," often used to refer to graphics, is an ugly abbreviation and is not worth the two spaces saved.

[4] Albert D. Biderman, "The Graph as a Victim of Adverse Discrimination and Segregation," *Information Design Journal*, 1 (1980), 238.

Page after page of Leonardo's manuscripts have a gentle but thorough integration of text and figure, a quality rarely seen in modern work:

Leonardo da Vinci, *Treatise on Painting* [*Codex Urbinas Latinus 1270*], vol. 2, facsimile (Princeton, 1956), 234, paragraph 827.


·234·
chevai le cose uedute essere tanto minime che nó che
le membra ma il tutto quasi ti para impossibile a po-
tere figurare come sell'occhio fusse, o, e la busa d'un
quarto di braccio equale alla tua tauola dipinta
sia, a, b, discosta dal'occhio mezo
braccio allora tu uedrai per esso spa-
cio tutte le cose che ueder si possi den-
tro dalla lunghezza d'uno orizonte di
cento miglia in tanta confusa diminuttione che nó
che figurar di quelle alcuna parte c'habbia figura
ma apena potrai porre si piccolo punto di penello che
non sia maggiore c'hogni gran casamento posto in
dieci miglia di distantia.

Perche li monti in langha distantia
si dimostrano piu scuri nella cima
che nella basa —

L'aria c'acquista gradi di grossezza in ogni grado de
la sua basezza e della sua distantia e causa che le
cime de monti che piu s'inalzano piu mostrano la
sua natu- rale oscu-
rita per che máco
sono impe- dite dalla
grossezza de l'aria
nella cima che nella
loro basa o nella uicinita che nella remottione, Pro-
uasi, o, p,, d, s,, c, r,, a, k, sono gradi dell'aria che sem-
pre s'assottiglian quanto piu s'inalzano, a, f,, f, h,, h, k,
sono li altri gradi transuersali doue l'aria acqista

Finally, a caveat: the use of words and pictures together requires a special sensitivity to the purpose of the design—in particular, whether the graphic is primarily for communication and illustration of a settled finding or, in contrast, for the exploration of a data set. Words on and around graphics are highly effective—sometimes all too effective—in telling viewers how to allocate their attention to the various parts of the data display.[5] Thus, for graphics in exploratory data analysis, words should tell the viewer *how* to read the design (if it is a technically complex arrangement) and not *what* to read in terms of content.

[5] Experiments in visual perception indicate that word instructions substantially determine eye movements in viewing pictures. See John D. Gould, "Looking at Pictures," in Richard A. Monty and John W. Senders, eds., *Eye Movements and Psychological Processes* (Hillsdale, New Jersey, 1976), 323–343.

Accessible Complexity: The Friendly Data Graphic

An occasional data graphic displays such care in design that it is particularly accessible and open to the eye, as if the designer had the viewer in mind at every turn while constructing the graphic. This is the *friendly data graphic*.

There are many specific differences between friendly and unfriendly graphics:

Friendly	Unfriendly
words are spelled out, mysterious and elaborate encoding avoided	abbreviations abound, requiring the viewer to sort through text to decode abbreviations
words run from left to right, the usual direction for reading occidental languages	words run vertically, particularly along the Y-axis; words run in several different directions
little messages help explain data	graphic is cryptic, requires repeated references to scattered text
elaborately encoded shadings, cross-hatching, and colors are avoided; instead, labels are placed on the graphic itself; no legend is required	obscure codings require going back and forth between legend and graphic
graphic attracts viewer, provokes curiosity	graphic is repellent, filled with chartjunk
colors, if used, are chosen so that the color-deficient and color-blind (5 to 10 percent of viewers) can make sense of the graphic (blue can be distinguished from other colors by most color-deficient people)	design insensitive to color-deficient viewers; red and green used for essential contrasts
type is clear, precise, modest; lettering may be done by hand	type is clotted, overbearing
type is upper-and-lower case, with serifs	type is all capitals, sans serif

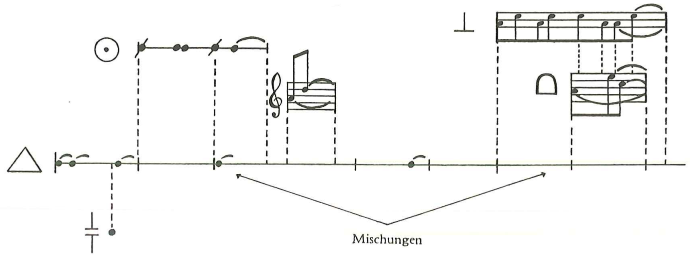
With regard to typography, Josef Albers writes:

> The concept that "the simpler the form of a letter the simpler its reading" was an obsession of beginning constructivism. It became something like a dogma, and is still followed by "modernistic" typographers. . . . Ophthalmology has disclosed that the more the letters are differentiated from each other, the easier is the reading. Without going into comparisons and details, it should be realized that words consisting of only capital letters present the most difficult reading—because of their equal height, equal volume, and, with most, their equal width. When comparing serif letters with sans-serif, the latter provide an uneasy reading. The fashionable preference for sans-serif in text shows neither historical nor practical competence.[6]

[6] Josef Albers, *Interaction of Color* (New Haven, 1963, revised edition 1975), 4.

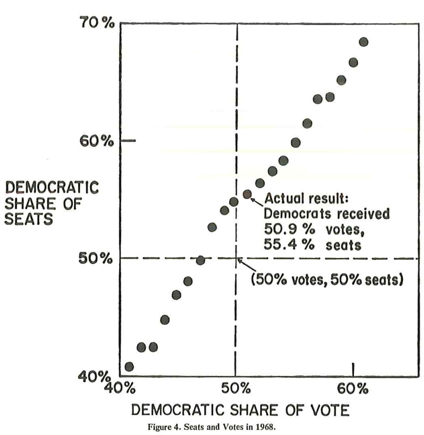
Proportion and Scale: Line Weight and Lettering

Graphical elements look better together when their relative proportions are in balance. An integrated quality, an appropriate visual linkage between the various elements, results. This musical score of Karlheinz Stockhausen exhibits such a visual balance:



Karlheinz Stockhausen, *Texte*, vol. 2 (Cologne, 1964), 82, from the score of "Zyklus für einen Schlagzeuger."

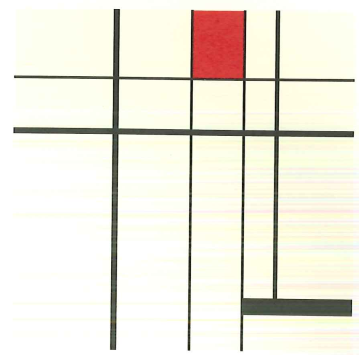
In contrast, this next design is heavy handed, with nearly every element out of balance: the clotted ink, the poor style of lettering, the puffed-up display of a small data set, the coarse texture of the entire graphic, and the mismatch between drawing and surrounding text:



Edward R. Tufte, "The Relationship Between Seats and Votes in Two-Party Systems," *American Political Science Review*, 67 (June 1973), 551.

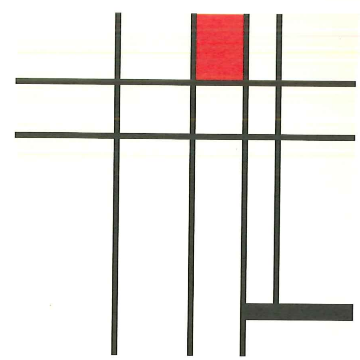
Lines in data graphics should be thin. One reason eighteenth- and nineteenth-century graphics look so good is that they were engraved on copper plates, with a characteristic hair-thin line. The drafting pens of twentieth-century mechanical drawing thickened linework, making it clumsy and unattractive.

An effective aesthetic device is the orthogonal intersection of lines of different weights:

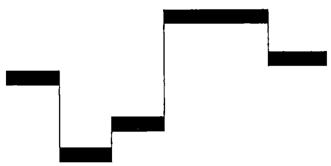


Poster for the exhibition "Mondrian and Neo-Plasticism in America," Yale University Art Gallery, October 18 to December 2, 1979. The original painting was done in 1941 by Diller; see Nancy J. Troy, *Mondrian and Neo-Plasticism in America* (New Haven, 1979), 28.

Nearly every intersection of the lines in this design (based on a painting by Burgoyne Diller) involves lines of differing weights, and it makes a difference, for the painting's character is diluted with lines of constant width:



Likewise, data graphics can be enhanced by the perpendicular intersections of lines of differing weights. The heavier line should be a data measure. In a time-series, for example:



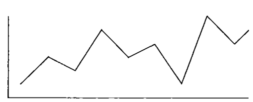
The contrast in line weight represents contrast in meaning. The greater meaning is given to the greater line weight; thus the data line should receive greater weight than the connecting verticals. The logic here is a restatement, in different language, of the principle of data-ink maximization.

Proportion and Scale: The Shape of Graphics

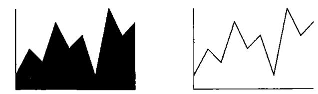
Graphics should tend toward the horizontal, greater in length than height:

Several lines of reasoning favor horizontal over vertical displays.

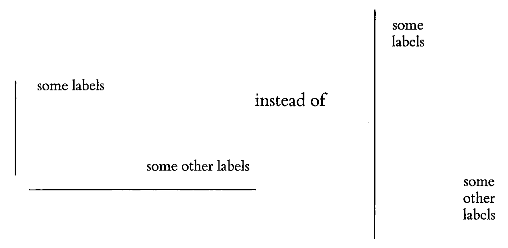
First, analogy to the horizon. Our eye is naturally practiced in detecting deviations from the horizon, and graphic design should take advantage of this fact. Horizontally stretched time-series are more accessible to the eye:



The analogy to the horizon also suggests that a shaded, high contrast display might occasionally be better than the floating snake. The shading should be calm, without moiré effects.



Second, ease of labeling. It is easier to write and to read words that read from left to right on a horizontally stretched plotting-field:



Third, emphasis on causal influence. Many graphics plot, in essence,

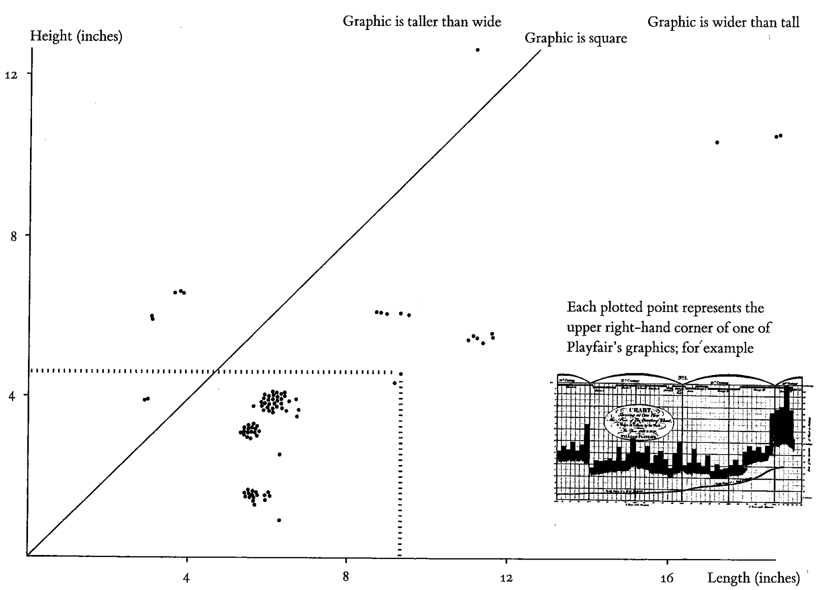
and a longer horizontal helps to elaborate the workings of the causal variable in more detail.

Fourth, Tukey's counsel.

> Most diagnostic plots involve either a more or less definite dependence that bobbles around a lot, or a point spatter. Such plots are rather more often better made *wider* than tall. Wider-than-tall shapes usually make it easier for the eye to follow from left to right.
>
> Perhaps the most general guidance we can offer is that smoothly-changing curves can stand being taller than wide, but a wiggly curve needs to be wider than tall. . . .[7]

And, finally, Playfair's example. Of the 89 graphics in six different books by William Playfair, most (92 percent) are wider than tall. Several of the exceptions are his skyrocketing government debt displays. This plot shows the dimensions of each of those 89 graphics:

[7] John W. Tukey, *Exploratory Data Analysis* (Reading, Massachusetts, 1977), 129.



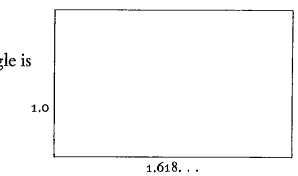
If graphics should tend toward the horizontal rather than the vertical, then how much so? A venerable (fifth-century B.C.) but dubious rule of aesthetic proportion is the Golden Section, a "divine division" of a line.[8] A length is divided such that the smaller is to the greater part as the greater is to the whole:

a b

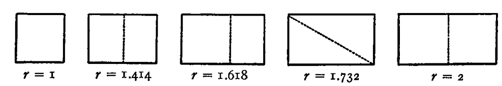
$$\frac{a}{b} = \frac{b}{a+b}$$

Solving the quadratic when $a = 1$ yields $b = \frac{\sqrt{5}+1}{2} = 1.618\ldots.$

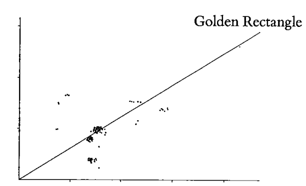
In turn the Golden Rectangle is



The nice geometry of the Golden Rectangle is not unique; Birkhoff points out that at least five other rectangles (including the square) have one simple mathematical property or another for which aesthetic claims might be made:[9]



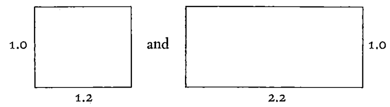
Playfair favored proportions between 1.4 and 1.8 in about two-thirds of his published graphics, with most of the exceptions moving more toward the horizontal than the golden prescription:



[8] The combination of geometry and mysticism surrounding the Golden Rectangle can be seen in Miloutine Borissavliévitch, *The Golden Number and the Scientific Aesthetics of Architecture* (New York, 1958) and Tons Brunés, *The Secrets of Ancient Geometry* (Copenhagen, 1967), vols. 1 and 2.

[9] George D. Birkhoff, *Aesthetic Measure* (Cambridge, 1933), 27–30.

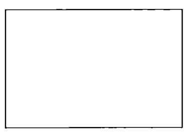
Visual preferences for rectangular proportions have been studied by psychologists since 1860, but, even given the implausible assumption that such studies are relevant to graphic design, the findings are hardly decisive. A mild preference for proportions near to the Golden Rectangle is found among those taking part in the experiments, but the preferred height/length ratios also vary a great deal, ranging between



And, as is nearly always the case in experiments in graphical perception, viewer responses were found to be highly context-dependent.[10]

The conclusions:

- If the nature of the data suggests the shape of the graphic, follow that suggestion.
- Otherwise, move toward horizontal graphics about 50 percent wider than tall:



[10] I have relied on Leonard Zusne, *Visual Perception of Form* (New York, 1970), ch. 10, for a summary of the immense literature.

Epilogue: Designs for the Display of Information

Design is choice. The theory of the visual display of quantitative information consists of principles that generate design options and that guide choices among options. The principles should not be applied rigidly or in a peevish spirit; they are not logically or mathematically certain; and it is better to violate any principle than to place graceless or inelegant marks on paper. Most principles of design should be greeted with some skepticism, for word authority can dominate our vision, and we may come to see only through the lenses of word authority rather than with our own eyes.

What is to be sought in designs for the display of information is the clear portrayal of complexity. Not the complication of the simple; rather the task of the designer is to give visual access to the subtle and the difficult—that is,

the revelation of the complex.