Basics 1

WHAT THE BOOK IS ABOUT

Here is a short list of reasons you might want to use graphics in a technical document:

- Graphics can make it look as if you actually know what you're talking about.
- Graphics can make a plain document look more attractive.
- Graphics can be used to deceive the unwary reader.
- Graphics can make a thin report fatter, or a short paper longer.

However, if they catch you using graphics for just these reasons alone, it won't do your career any good!

As it happens, if they are done right, technical graphics can make things easier to understand. They can clarify relationships. They can allow straightforward extrapolation. They can present a lot of data concisely. For these reasons, technical documents almost always contain graphics. Why so many technical documents contain lousy graphics that make nothing seem simple is another question. Teaching you how to get the point across, and how to avoid the pitfalls, is the purpose of this book.

Along the way, we will look at the questions of style that make some graphics attractive as well as functional (and others, neither one), and we will see examples of graphics so bad they deceived even their famous authors. We will also see what kind of graphic suits what purpose, and what you can do with your software to produce the desired result. We will also note some shortcuts that can save serious amounts of time.

In brief, we assume that you are using a computer (actually, a PC or a Mac®) to produce a technical document of some kind: a report or a paper, viewgraphs for a presentation, or perhaps a drawing for a patent. We aim to help you get the best result possible with your resources, with the minimum effort on your part.

The Right Graph. By Harold Kirkham and Robin C. Dumas

SOME BASICS

Let's get started by looking at some of the terms we will use. First, the word *graphic*. For the purposes of this book, graphic is a general term that includes graphs, bar charts, diagrams, and drawings. It does not include *tables* or *equations*. There is a clue to a generalization here. For our purposes, graphics are produced by software other than your word processing software. The software you use to produce graphics therefore needs to be aware of the word processing software you use—a feature called *integration*. It is a sad fact that graphics software is usually not well integrated with word-processing software, even if they have the same manufacturer's label. We will show you some ways around the problems.

Now, what were those other terms? Graphs, bar charts, diagrams, and drawings.

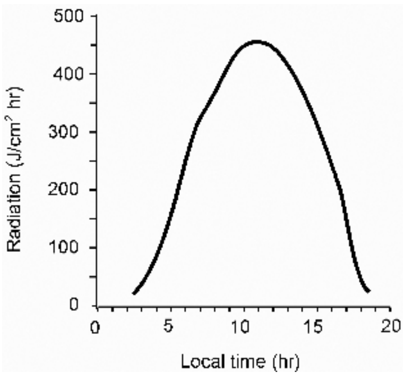


Figure 1.1

A *graph* (Fig. 1.1) is a device to show how one parameter varies as a function of another. Often, but not always, one of the parameters is *time*. For example, one might plot the intensity of the sunlight at the surface of the Earth at some particular place. Usually, but not always, the parameter of interest is arranged on the vertical axis, called the *ordinate*. Exceptions occur in a number of fields. In oceanography, for example, the depth is—sensibly—vertical, so that a graph showing temperature as a function of depth would have temperature (the parameter of interest) horizontal. The points in a graph may be connected by a line.

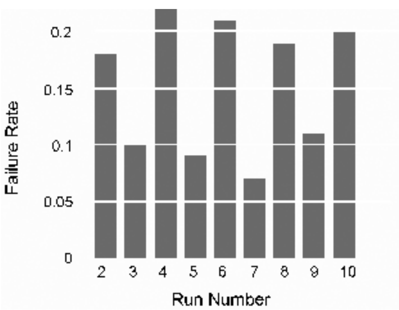


Figure 1.2

A *bar chart* (Fig. 1.2) is a device to show the differences or similarities of a number of separate things. Usually, the things themselves are separated horizontally, and their size is shown by their vertical extent. The items shown in a bar chart are not connected by a line, as there is no meaning to a point part-way between one entry in the bar chart and the next.

Some software uses the term *chart* when it means to say *graph*. Originally, chart meant the same as *map*. Nowadays, the typical chart is the *organization chart*, as in Figure 1.3. Here, a structure is shown where the vertical extent is an indication of seniority (lower levels report to higher levels) and the horizontal separation has no particular significance. In a similar way, a chart can be drawn of the branching of one species into two, and the entire history of a line of evolution can be captured. In this case, the vertical axis can represent time (usually with the more recent at

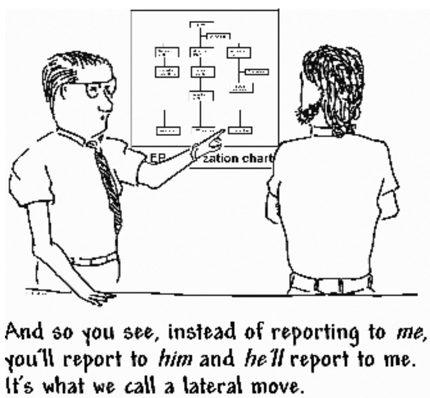


Figure 1.3

the top) and the horizontal spacing represents movement in some undefined gene space. Pie charts and flow charts are other members of the chart species.

A *drawing* is something that, before the availability of low-priced hardware and easy-to-use software, would have been produced by a draughtsman (or a draftsman) working with pen and ink. A drawing can show a machine or a landscape, or a mechanism that can be patented.

A *diagram* is literally anything marked out by lines. Sometimes, we will use the word diagram to mean any of the graphics discussed previously. Just to confuse things, we will also use *diagram* to mean graphics that have not already been described. Electrical schematics are examples of diagrams. Perhaps in this sense, the thing that distinguished a drawing from a diagram is that a diagram uses symbols.

Bearing in mind the many kinds of graphic, our aim with this book is to show you three things:

- Which form of graphic belongs with which type of information. You don't want to be using a graph if a bar chart is appropriate.
- What the particular graphic should look like, for its intended use. A diagram produced for a viewgraph may not be right for a technical paper, and vice versa.
- How to achieve the result you want most easily with the software you have, including converting files from one format to another.

We will show you some shortcuts, to save time and energy. The production of graphics should be approached with a different mind-set from the production of text, and the difference manifests itself largely in the time taken to do the job.

At the end of the book we will examine some good graphics and some bad, some graphics that didn't make it, and some that did but shouldn't have, in a series of case studies.

In the rest of this chapter, we'll continue by looking at a few *definitions*. These won't take long, but it will help if we all know the names of the things we're going to talk about. After that, we'll give some general *guidelines* on what to strive for in terms of appearance.

The next chapter shows you what kind of graph to choose for what purpose, and the one after that deals with the complicated question of joining the dots in a graph.

In a later chapter, we'll have some suggestions to help you get the most out of the software you have. If you are already familiar with all the software you use, you can skip the first part of this. However, it might be worth checking to be sure you didn't miss anything important. Other chapters will deal with using spreadsheets, making patent drawings, perspective (even if you don't consider yourself an artist), presentations, and matters of style.

DEFINITIONS

The ultimate purpose of a graph is to persuade someone of something. The graph accomplishes this by showing the relationship between two (or more) quantities; or sometimes by showing the lack of such relationship, for example, the temperature independence of a measurement device. In either case, a lot of the essentials are the same. You will end up with something like Figure 1.4.

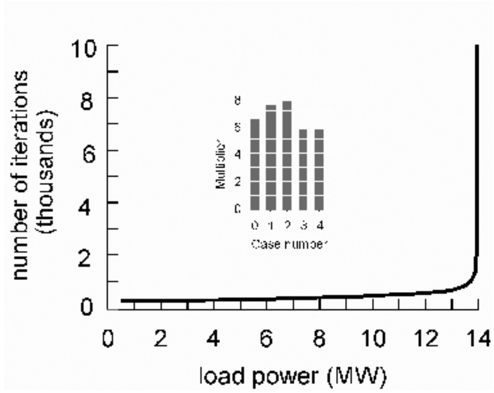


Figure 1.4

Of course, normally there would be a caption under (sometimes over) the figure. We'll discuss captions in Chapter 4. For the time being, accept that this is a curve showing the number of iterations required for a solution of an amazingly inefficient load-flow program for some particular electric power system. The graph shows how the number of iterations varies as a quantity called the load power varies.

First, let's use this example to identify all the parts of a graph; see Figure 1.5.

By the way, the labels added to the graph in Figure 1.5 are called *annotations*, and the lines with arrowheads from the annotations to the thing annotated

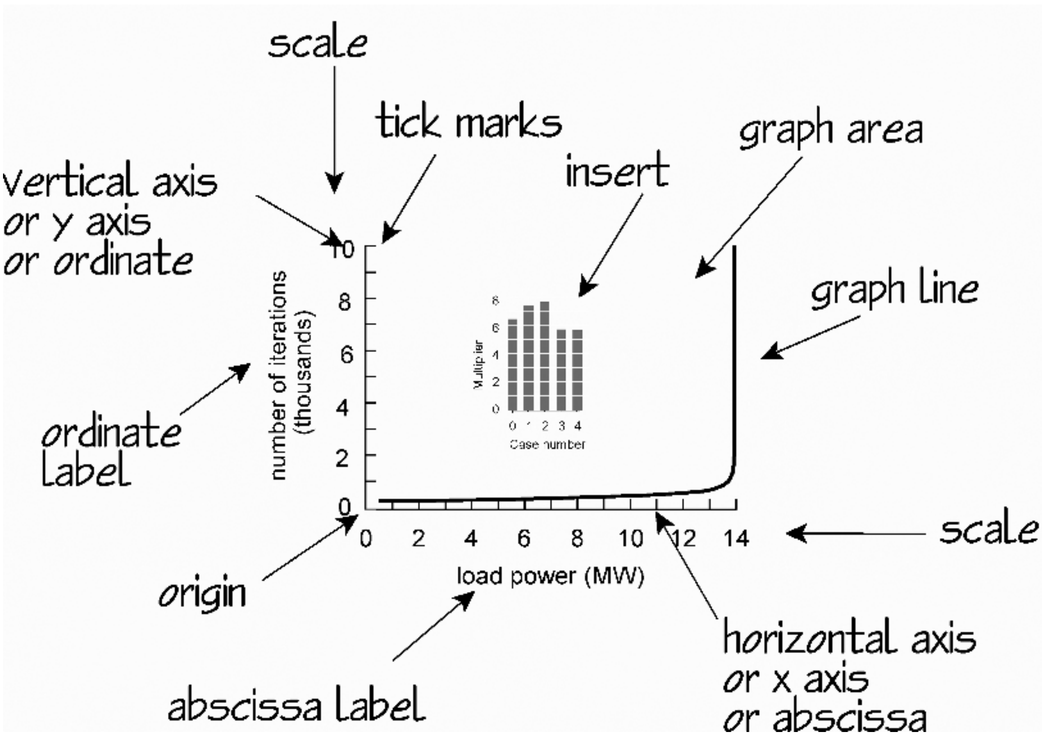


Figure 1.5

are called *leader-lines* or *leaders*. Collectively, annotations and leaders are sometimes referred to as *callouts.*

As well as identifying the major parts of a graph, what we have tried to do here is present an example of what a graph of this kind should look like; in terms of its style rather than its content. More on style in Chapter 13.

Strictly speaking, the *y*-axis need not be vertical. The *x*- and *y*-axes refer to the independent and dependent variables, and as we shall see in the next chapter, there are occasions when it makes sense to plot the independent variable vertically.

GUIDELINES

The ideas on the following pages are offered as guidelines.

Strive for a Clean, Neat Appearance. This means limiting the amount of "things" there are in the graph area. Don't clutter it up with too many labels or callouts to every single item in there. Sometimes it is convenient to put a label next to a curve, but sometimes it gives a neater appearance to put the label outside the graph area and use a leader line.

Think About Copying or Faxing. Your work is going to be reproduced, adding to your fame if not your fortune. If your work is full of fine lines and tiny symbols, it may not copy well or fax well. The symbols seen in Figure 1.6 were used in a graph generated by software that evidently tried to reproduce on a laser printer the effect of a dot-matrix printer.

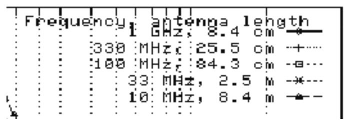


Figure 1.6

Even this original is hard to make out. Imagine, if you will, what it would look like (Fig. 1.7) after it has been copied a few times! Thus, if you use "dots" for data, make them as different as you can for different data sets, and make them big enough that they will survive even a noisy copying process.

Figure 1.7

While we are thinking about copying, a word about color is in order. While color printers are becoming fairly commonplace, for some obscure reason color copiers are not. If there is some compelling reason to use color, go ahead and do it. But it might be good to think about how your color graphic will reproduce on a monochrome copier. Convert your graph to monochrome, and make sure it still "works."

Here's an example of the sort of thing that should *never* happen. In 1975, IEEE Press reprinted an article that had appeared in *Scientific American.*[1] Like most articles in *Scientific American*, the article had made use of color in its graphics. IEEE, however, did not. When one of the graphs was reproduced, the reference to color in the caption did not make sense, as it was not possible to say which black line had been which color.

[1] Earl Cook, The flow of energy in an industrial society, in *Energy and Man: Technical and Social Aspects of Energy*, IEEE Press, 1975, New York.

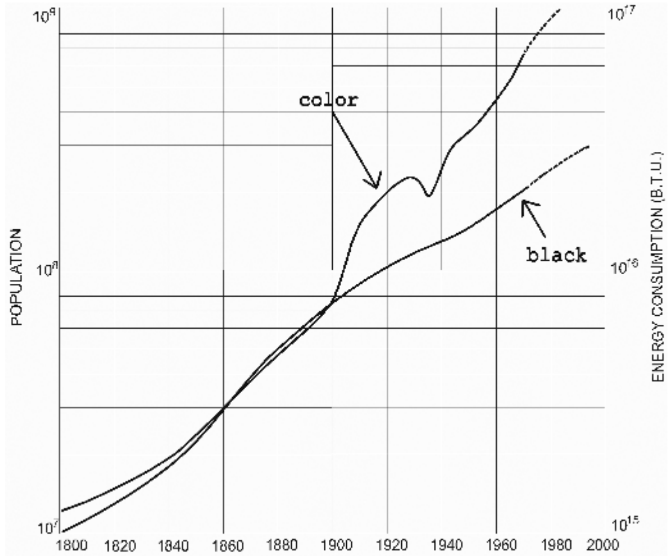


Figure 1.8

U.S. ENERGY-CONSUMPTION GROWTH (*curve in color*) **has outpaced the growth in population** (*black*) **since 1900, except during the energy cutback of the depression years.**

Some genius (presumably at IEEE Press) solved the problem by adding labels to the graph. We have reproduced it here (Fig. 1.8) complete with caption so you can see how dumb some solutions can look.

OK, OK, now you can reconstruct what the original must have looked like. But wouldn't it have made more sense to make the changes shown in Figure 1.9?

Here we have reversed the ordinate scales to simplify the placing of the big arrows that identify the curves, and rewritten the caption to remove any reference to color. An alternative approach would have been to use a dotted line for one of the curves, but this might have led to confusion with the (unlabeled) dashed section where the post 1970s estimates are shown.

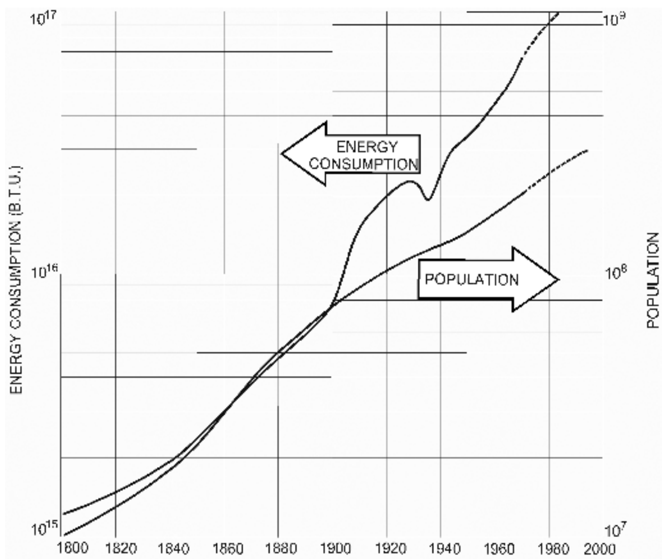


Figure 1.9

U.S. ENERGY-CONSUMPTION GROWTH (*left scale*) **has outpaced the growth in population** (*right*) **since 1900, except during the energy cutback of the depression years.**

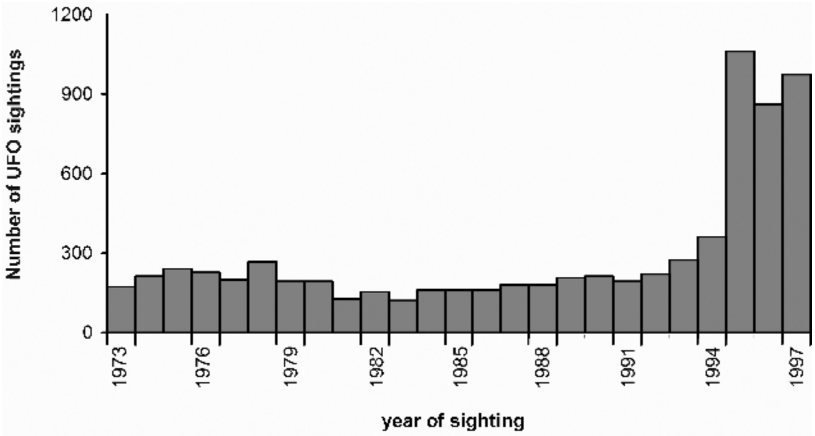


Figure 1.10

Be Careful to Limit the Number of Tick Marks on Each Axis, and Don't Feel Obliged to Put a Label on Every Tick Mark.[2] In most cases, there should be at least 5 ticks on the vertical axis, and at most 11. If there are 9 or more, label only every other one. The horizontal axis is frequently longer than the vertical one, so it can have a few more tick marks.

If you are going to skip some numbers on the axes, label every other one, or one out of five or one out of ten. *Under no circumstances, label just every third tick mark.* For some reason, we do not do well mentally interpolating if the axis is divided this way. Look at the example in Figure 1.10.[3] Where is 1000 on the vertical axis? Or 1990 on the horizontal? Clutter control is a matter of judgment and style, so the details are up to you. But don't do the thing with the threes.

Take the example of the power system, shown with two different axes in Figure 1.11. When all the tick marks are labeled, the legibility is actually lower. But using just the even numbers works.

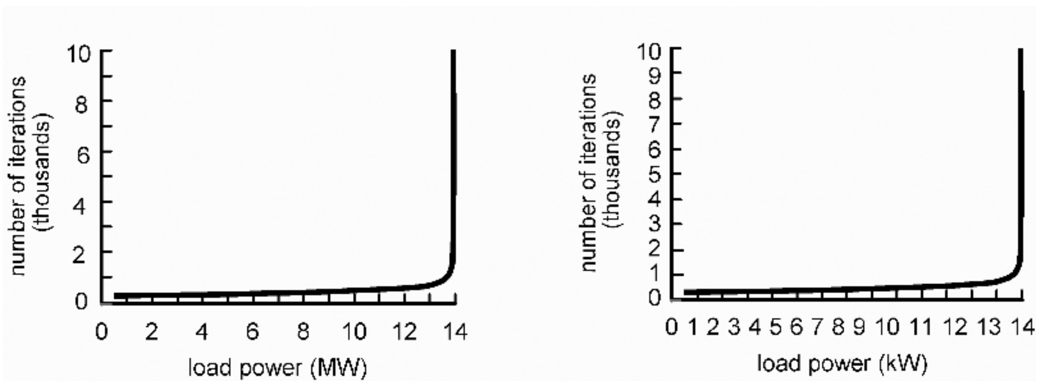


Figure 1.11

[2] By the way, the word is "tick." We have seem some authors wrongly use the word "tic." A tic is a sort of nervous twitch. The spelling comes from the French *tic douloureux*, literally *irritating (or painful) tic*. "Tick" on the other hand seems to have a Teutonic origin and means a small dot or dash made with a pen or pencil, to draw attention to something or to mark a name, figure, and so on, in a list as having been noted or checked.

[3] The graph is not an accurate representation of the numbers: both the largest two numbers were actually slightly larger than shown here, according to the website of the National UFO Reporting Center. We reduced them so that the vertical scale would stop at 1200 rather than 1500.

Don't Lie, Don't Distort the Graph. There is no rule for the ratio of the sizes of the two axes, but reason should prevail. It is perfectly possible to make the same curve give the appearance of being flat or being steep without actually changing any of the numbers: avoid the temptation! For example, the graphs in Figure 1.12 all have a slope of 1.

Of course, the "dead space" in the two graphs on the right is a bit of a give-away, so it can be removed. A little rescaling of the axes yields Figure 1.13.

It doesn't take much more than a look to see that some deception is going on here, but deception isn't always that easy to spot. How about Figure 1.14? Here, a glance at the graph gives the impression that the two curves are essentially similar, because they seem to overlap so much. Closer inspection, however, reveals that there are two vertical axes, and they are different. Not only does the left axis start at 1 instead of 0, it spans a range of 3, whereas the right axis starts at 0 and spans only a range of 2. The difference is undermined by the horizontal line at the top of the graph that repeats the tick marks of the lower horizontal axis.

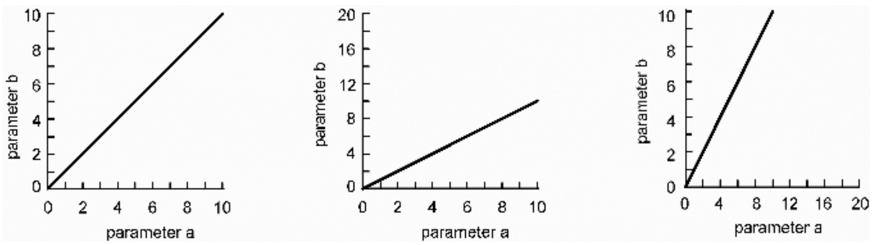


Figure 1.12

Figure 1.13

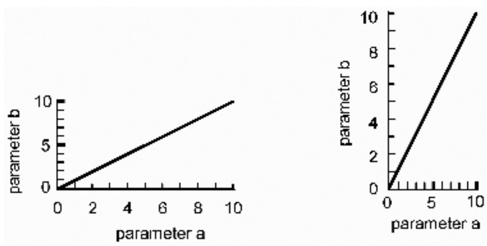
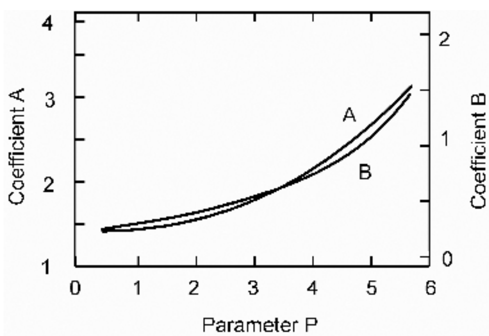


Figure 1.14



It might help to remove this line, but still the true dissimilarity of the axes would be buried under false impressions. A fairer presentation would be the version shown in Figure 1.15. Here the two curves are seen to overlap but slightly. They do appear to have generally the same shape, and it still takes a close inspection to see that they span a different amount. At least the presentation itself adds no bias.

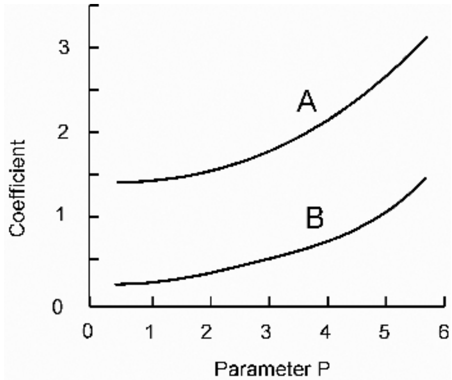


Figure 1.15

If There are Two Axes, Label Them Both! We've all seen the TV advertisements for analgesics, where the brands are compared in a bar chart. The brands associated with each bar are identified, but the performance measure (presumably the length of the bar) is not! The voice-over talks soothingly about the product being recommended by 3 doctors out of 4. In fact, one wonders if they lined up just 4 "tame" doctors and, with a consulting agreement in hand, asked them something like "For $5000, which brand would you recommend?"

But even supposed scientific writers can be guilty of this kind of error. In his 1997 book, *Why People Believe Weird Things*,[4] the professional skeptic Michael Shermer illustrates the fact that various altered states of mind exist with the curves shown in Figure 1.16.

The curves are said to be from EEG measurements, but we are not told either the horizontal scale or the vertical, despite the fact that there is a marker at the end of each of the supposed recordings. Perhaps each vertical marker

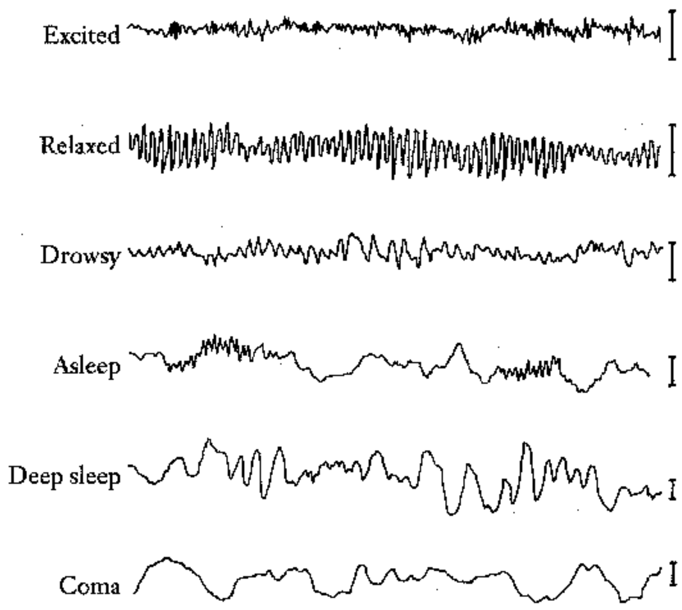


FIGURE 7:
EEG recordings for six different states of consciousness.

Figure 1.16

[4] MJF Press, New York. The figure is on page 76.

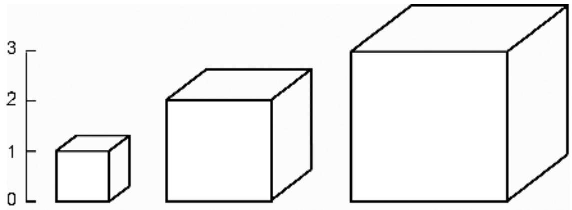


Figure 1.17

indicates the same quantity—in which case the curves would be more easily compared if the scales were such that equal magnitudes were represented by equal lengths. But we are not told. The lack of such information undermines the case being made. A reasonable observer could be forgiven for wondering if, for example, the slow undulations labeled "coma" are simply the fast undulations of "relaxed" at a different time scale.

Don't Use Areas or Volumes in Simple Numerical Comparisons. This advice applies mostly to bar charts. Since some bar charts produced by spreadsheet programs will often gratuitously add a "depth" dimension, you should pay attention to the output of such programs.

Worse, however, is the "bar" chart that, instead of having a *bar* whose height represents the magnitudes in question, has a three-dimensional box, as in Figure 1.17, each of whose sides varies with the magnitude. Suppose we have something—a single parameter—with magnitudes 1, 2, and 3 sampled at some interval.

The addition of a couple of lines, as in Figure 1.18, reveals that the linear dimensions of the cubes are indeed in the ratio 1 : 2 : 3, but there is no doubt that the much larger volume of the right cube, and the fact that it protrudes so far above the labeled axis, helps it create the impression of much larger size.

The proper way to show the relative sizes, of course, is to use the *height* of the bar only, as in Figure 1.19. For some reason, this approach creates the impression that the taller boxes are thinner than the shorter ones. In fact, they are the same. At least, there is no deception here.

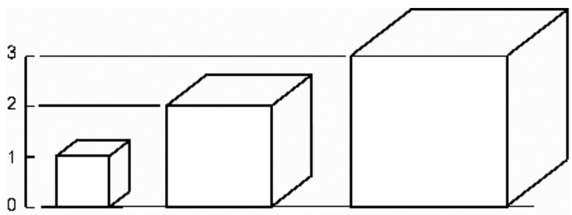


Figure 1.18

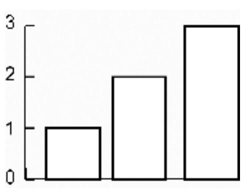


Figure 1.19

As we will see throughout the book, there are several ways graphs can deceive the reader. Deliberate deception is usually detectable—the blank space or the suppressed zero in a graph can be a signal—but some deceptions may not be noticed. These are caused by the almost accidental impressions created by the graph, the optical "illusions."

It turns out that if we have two bars in a bar chart, for example, we may make a reasonable judgment about their relative size. (If the bars are close enough to the axis that we can estimate their values, we can

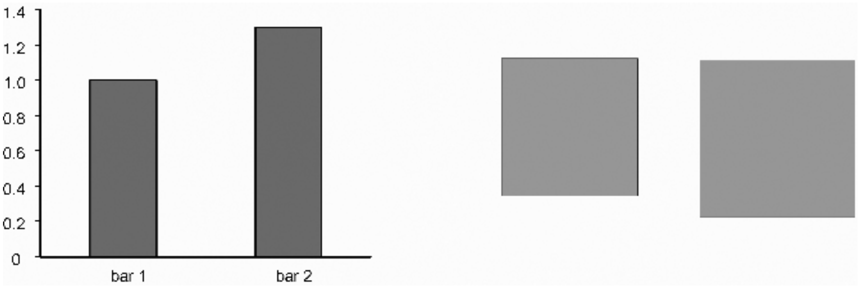


Figure 1.20

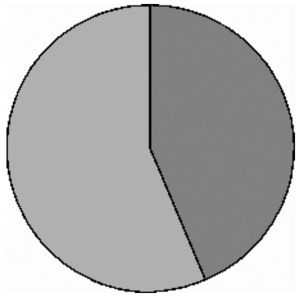


Figure 1.21

confirm our estimate.) However, we do not do so well comparing two *areas*, and it is hard to have an axis for comparison.

In Figure 1.20, the lengths of the bars on the left are in the ratio 1 : 1.3. That is, the large one is 30% larger. The same ratio applies to the *areas* on the right. Most viewers would judge the rectangles reasonably well, because the widths are the same, and only the length has changed between bars. Most of us would imagine the squares to be much closer in relative size.

We do not do well with angles, either. In the pie chart of Figure 1.21, the ratio of the areas of the two pieces of the pie is also 1 : 1.3.

Some things we can judge accurately. One of use (HK) is a twin. His parents brought up the twins in a "You divide, and you choose" environment. As a result, the accuracy with which he can divide a pie into two equal parts is truly incredible (typically a few ppm, he says). But even he does not do well with unequal quantities and unusual shapes.

Keep the Graph Line Within the Rectangle Formed by the Axes. Any automatic graphing software will have this feature, and it seems such an obvious thing to say, but once in a while you can see a graph that doesn't obey this rule.

A graph very much like the one in Figure 1.22 appeared on page 993 of the second edition of a well-known electronics book, *The Art of Electronics*, by

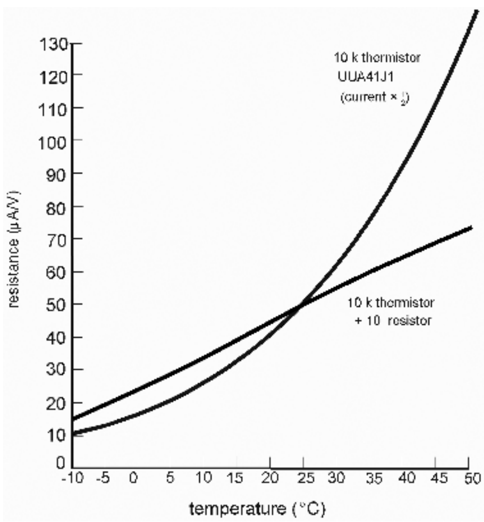


Figure 1.22

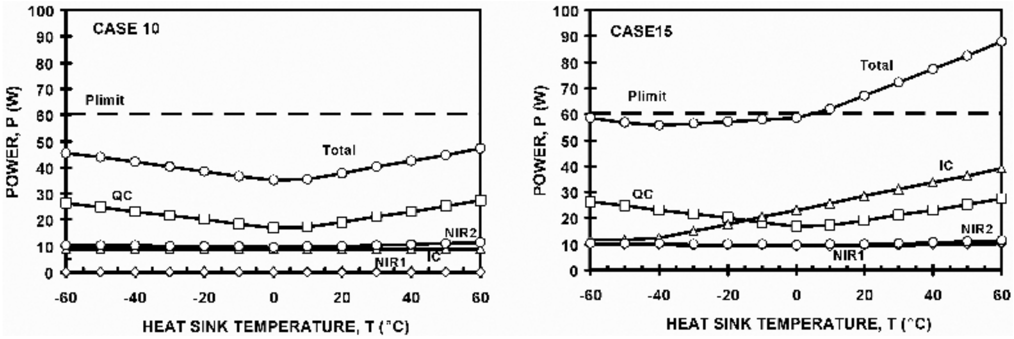


Figure 1.23

Horowitz and Hill (Cambridge University Press, 1989). For some reason the curved line of the uncorrected thermistor characteristic was drawn as if the vertical axis went as far as 140 or 150, instead of the 130 that it actually spans. Perhaps we are used to graphs that look as if they were drawn on graph paper. Whatever the reason, it looks odd to see the graph line "outside the box."

We will return to this graph for further discussion in Chapter 4.

The "opposite"of this problem might be the graph that occupies too little of the space indicated by the scales. Normally, the scale should have the same range as the data, or a little more, in both the vertical and horizontal directions. Given that you should have "nice" numbers on the tick marks (1-2-3-4 or 5-10-15-20 and so on), you sometimes will have a little space left over at the end of the data. This blank space should not be large. The exception to that rule is that if you have a series of graphs (perhaps even on separate pages) that you wish to compare and contrast, they could have the same scale as one another *even if it meant creating blank space.*

Figure 1.23 is an example of this situation. Only the graph of Case 15 uses anything like all the vertical space. Case 10, typical of most of the graphs in this particular series, has a lot of empty space at the top. But since at least part of the idea of presenting the data like this is to show that the other cases remain below the threshold temperature of 60 °C, the fact that the axes are consistent from case to case makes sense.

Avoid Picture-Coding Schemes If You Can. The simplest (and most common) coding scheme is the use of different shaped symbols to identify different parameters on a graph. For example, curves can be identified by open or closed circles or squares or triangles, as in Figure 1.24.

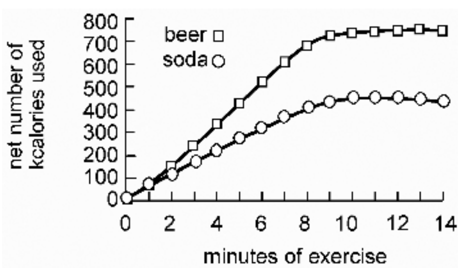


Figure 1.24

This graph purports to show the benefit of short but vigorous exercise and alcohol consumption in terms of burning off calories. However, the little squares would not copy well, and the real meaning of the graph might be lost. The version in Figure 1.25, however, will copy well.

Even after several reproductions, the beneficial effect of a beer before exercise can clearly be seen. The pointlessness of a prolonged workout is also evident. (OK, this is a book about graphics.

Thermodynamic truth can sometimes be sacrificed to make a graphics point!)

While we're on the subject of coding schemes, don't use cute little images, as in Figure 1.26, to emphasize the kind of quantity being represented. You are not writing for your high school magazine, but for an audience of your professional peers.

Come to think of it though, that might not make a bad viewgraph. We can all think of meetings where a round of beers at the beginning would have had a beneficial effect!

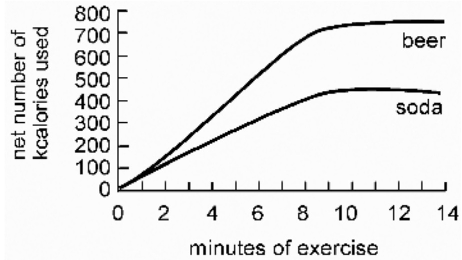


Figure 1.25

Be Concise. We do not want to make the reader spend a lot of time working out what it is we are trying to say. Don't let the design get in the way. Graphs don't necessarily speak for themselves, especially if you clutter them up. So it pays to be simple, and visually obvious. It's OK to hit the reader in the face with your message.

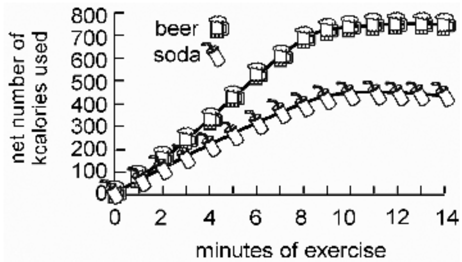


Figure 1.26

Figure 1.27 is an example of what you might have expected if you were doing graphics in the middle of the 20th century. A graph similar to this

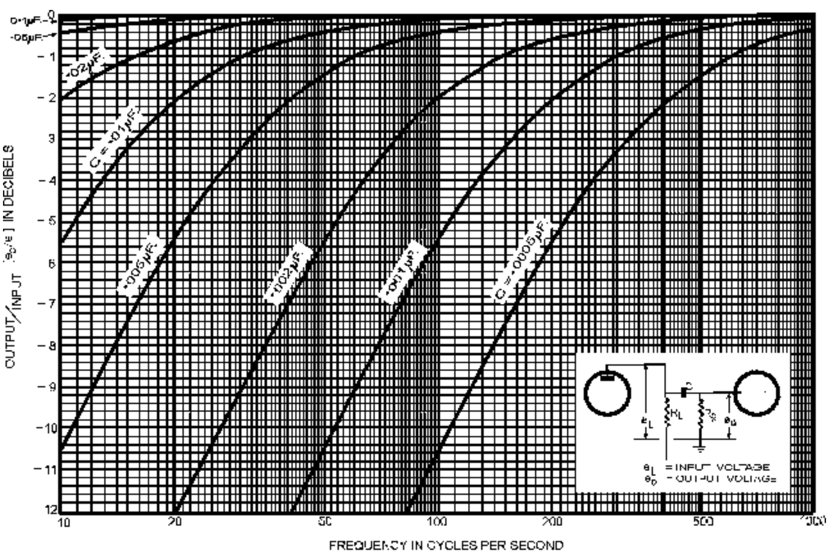


Figure 8. Frequency characteristics due to grid coupling condenser with a grid resistor (Rg) 1.0 megohm. It is assumed that the plate resistance and load resistance in parallel of the preceding valve are negligibly small in comparison with Rg. When this does not hold (as with a pentode valve in the preceding stage), the attenuation is less than is shown by the curves, but may be obtained accurately by making Rg represent the grid resistor in series with r_p and R_L in parallel. These curves may be applied to any value of Rg by multiplying the values of C shown on the curves by a factor equal to that by which Rg is reduced (e.g., for Rg = 0.5 megohm multiply values of C by 2.).

Figure 1.27

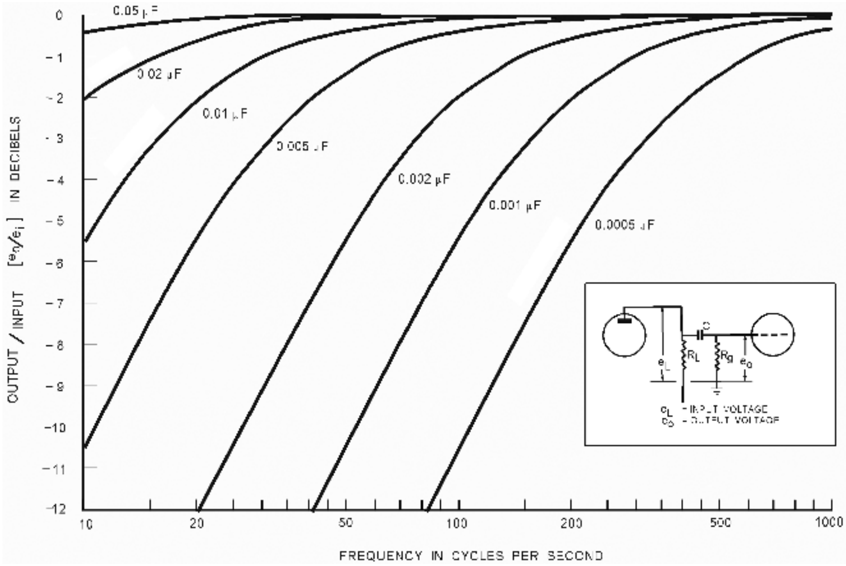


Figure 1.28

appeared in the first British edition, ca 1940, of *Radio Designers Handbook*, originally published in Australia as *Radiotron Designers Handbook*. (Ever wonder what a Radiotron was?) Let's look at how things have changed.

First, the background of this graph is so *busy* it looks a bit like a pattern that might have been rejected by Hart Schaffner Marx, or Moss Bros. That is because it was originally produced on real graph paper. There was a time when graph paper was in common use. The lines of the graph paper were useful when the graph was being drawn by hand, and it was not the style of the times to remove them afterwards. The labels on each curve, and the insert, look as if they were typed on slips of paper that were pasted on top of the graph—a simple but effective approach.

Some graphs—including this one to judge by the caption—were drawn so that numerical values of the quantities being plotted could be extracted. That would not be common these days: the point of a graph is more often to show the variation in the data, or the correlation, but not to indicate the exact numbers.

If we remove the background lines, and relabel the curves, we get a much simpler appearance, as in Figure 1.28.

It may be that the text should all be reproduced larger, and the circuit diagram in the insert on the right removed. If these changes are made, the result is really quite presentable—see Figure 1.29.

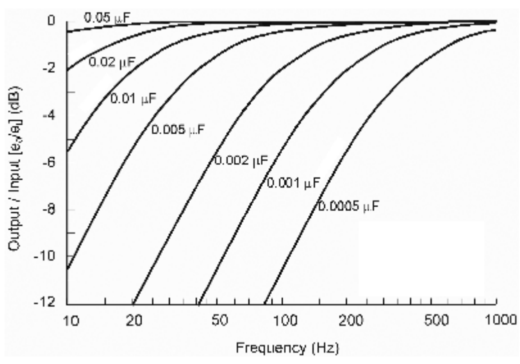


Figure 1.29

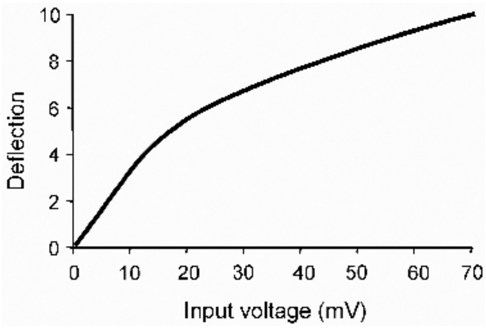


Figure 1.30

Note also that since the text is larger relative to the graph, the whole thing can be reproduced at a smaller scale, so it takes up less space.

Try to avoid the lines across the graph area. Generally, the result will be a neater, cleaner graph, with adequate detail. Figure 1.30 is another example; it represents the deflection obtained on an analog meter as the input drive is changed.

The meter deflection is quite nonlinear. (In fact, it was designed this way. The meter is the indicator for a bridge, and higher sensitivity near zero deflection makes good sense.) Perhaps if you were designing a replacement, and needed to understand the exact levels at which things changed, a few lines across the graph area, as in Figure 1.31, would help. For most purposes, that level of detail should suffice. More would be clutter, as in the "Radiotron" graph.

For some reason, the designers of spreadsheets seem to think clutter is a Good Thing, and it can fairly be said that a more up-to-date version of graphical clutter is readily obtained by using a spreadsheet. For example, the graph of Figure 1.32 was obtained from a spreadsheet without any hard work at all.

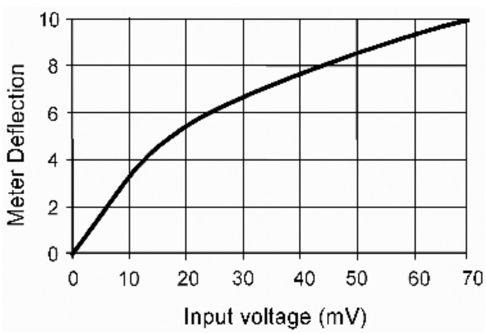


Figure 1.31

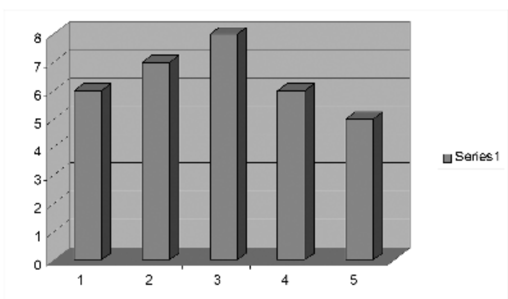


Figure 1.32

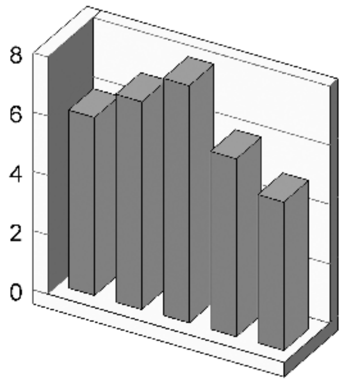


Figure 1.33

The numbers 6, 7, 8, 6, 5 were entered into the spreadsheet, and one of the standard bar charts drawn. The numbers 1 to 5 along the horizontal axis were generated by the software, evidently in an attempt to help us keep one entry separate from the others. The tag "Series 1" was added, although it is hard to see why, in the absence of any other series. The columns of the chart are a lovely blue, though the shading makes it hard to guess where the illumination is coming from.

The columns of the bar chart were then corralled by a wall with lines on it, so we could see the sizes of our data entries. However, since the whole thing has been drawn with perspective, it is not obvious that the data are actually integers.

A different spreadsheet does not come off much differently; see Figure 1.33.

Now the corral has thickness! Here the data are not separately identified, and the unnecessary series number label does not appear. However, the perspective problem is no better, and the whole thing has acquired a distortion (it is narrower here than it is in the spreadsheet) in the process of exporting to a file. (More on this in the chapters on spreadsheets.) The columns are still blue, though it is now clear that they are illuminated from above.

It seems that the software for spreadsheet graphics is being written by the Marketing Departments. Look, it's a job. Just because these people did not graduate top of their class, does not mean they don't need work! There are just not that many jobs for people who can decide that bar charts should be red. (As a winemaker friend once said, "The first duty of any wine is to be red!" He had no opinion on the color of bar charts.)

You *can* get what you want out of these programs, it just won't be the default. Spreadsheets are such an interesting and useful way of graphing data that we've dedicated several chapters to them. Meanwhile, Figure 1.34 is an example of how the same data could be presented in a clean, uncluttered way.

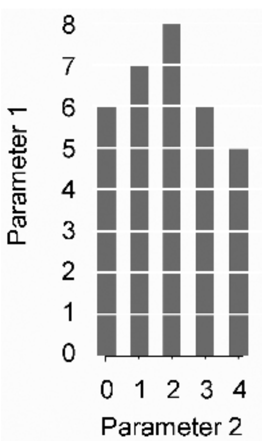


Figure 1.34

Note that the two axes are labeled, and that there is no perspective. The lines from the ordinate numbers are in white, and on top of the columns of the chart. We have chosen to have the columns presented as gray bars with no line around them. This is purely a matter of style. Almost equally acceptable (in our view) is the version shown in Figure 1.35.

The main "problem" with the graph of Figure 1.35 is the need to decide how long to make the horizontal tick marks. The white lines of the graph of Figure 1.35 do not show against the paper, and so can be any length greater than the width of the space occupied by the columns.

Let the Data Make the Case. Focus on values, and variations, but don't feel that you always have to smooth or otherwise reduce the amount of data in order to make a point. Most software will handle large quantities of data, so show the data by all means, if that would help support the case you are trying to make.

For example, back in the late 1970s it was well known that a wet high-voltage power transmission line produced an audible noise. The exact mechanism was not well understood, and while the factors that contributed to changing the noise level were known (the voltage, the conductor surface condition, the rain intensity), the relationship between them was not known. A paper was written that showed measured noise data as a function of rainfall rate. A graph from it is redrawn here as Figure 1.36.

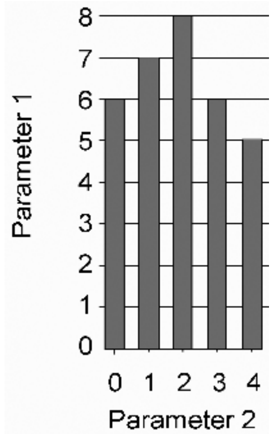


Figure 1.35

This version differs from the original[5] only in that the dots are bigger. Bearing in mind the relatively primitive state of interactive computer graphics when the original work was done, the result is quite satisfactory. There are nearly 500 data points shown here. (The conditions for selecting them were explained in the paper.) Because each point is no more than a dot, the density of dots can be inferred quite well from the presentation.

One can make some interesting observations, based on this presentation. At rainfall rates above about 1 mm/hr, the noise is relatively high, and somewhat independent of the rainfall rate. At low rain rates, the noise is lower, more variable, and quite dependent on the rain rate. That the noise was so complex a function was a new finding and prompted further analytical work.

Strive for Artistic Balance, and Reasonable Proportions. What are reasonable proportions? You probably never thought of television as having anything to do with balance or reasonableness but, roughly speaking, the aspect ratio of a graph should be the same as the aspect ratio of a TV screen. That may be a bit vague.

Ours is a changing time. For many decades the aspect ratio of TV screens was 4 : 3 (width to height). Then, when it seemed everyone who was going to get a TV had already got one, or two, or more, and solid-state technology and quality control techniques meant that TVs were not breaking down all the time,

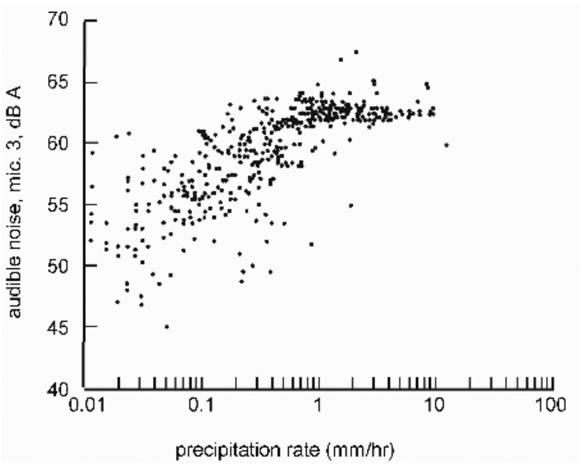


Figure 1.36

[5] H. Kirkham, instantaneous rainfall rate: its measurement and its influence on high voltage transmission lines, *Journal of Applied Meteorology* **19**(1), 35–40 (January 1980).

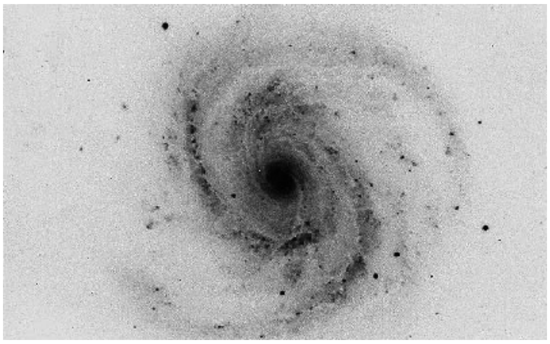


Figure 1.37

high-definition digital TV came along. Well, it had to, or Sony and Panasonic and all the rest of them were going down the tubes. And guess what, you couldn't watch HDTV on your regular screen, because the aspect ratio was different. Now it's 16 : 9. (Somebody was into squares.)

In England, in the first part of this century, you could buy a TV that would let you watch any of the current standards. That's pretty useful. It would also let you (separately) choose the aspect ratio of the image. So if you wanted you could watch a movie at a 16 : 9 ratio that was shot with a 4 : 3 ratio. OK, so the engineers said they could do it, and there was nobody in the marketing department smart enough to see how stupid this would look. Which makes more sense, a letterbox or a stretch?

Don't be doing the same thing to your graphics, just to get them to have some particular aspect ratio! You really don't want to convert the image of galaxy M100 shown in Figure 1.37 into the distorted version of Figure 1.38 even if it *is* technically possible! An error like that would be hard to spot, too, since galaxies are at various angles to the Earth, including edge-on.

Exceptions to this guideline should be made, of course, as necessitated by the page layout (of which there is more in Chapter 5). A two-column format can accept a graph one-column wide with the 5 : 4 aspect ratio, or it can accept a tall, thin graph without looking odd. Tall thin bar charts are often the best way to

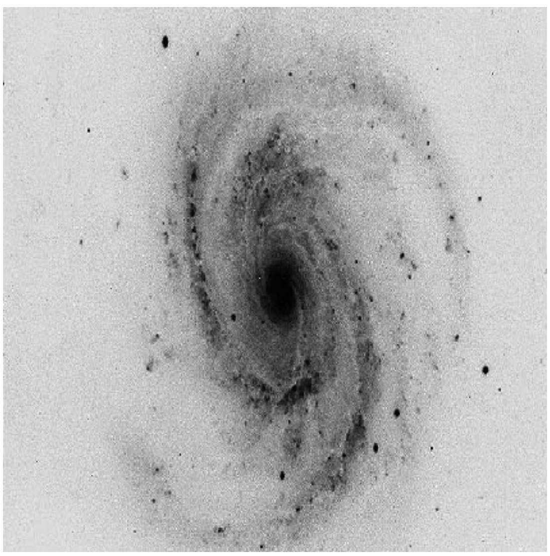


Figure 1.38

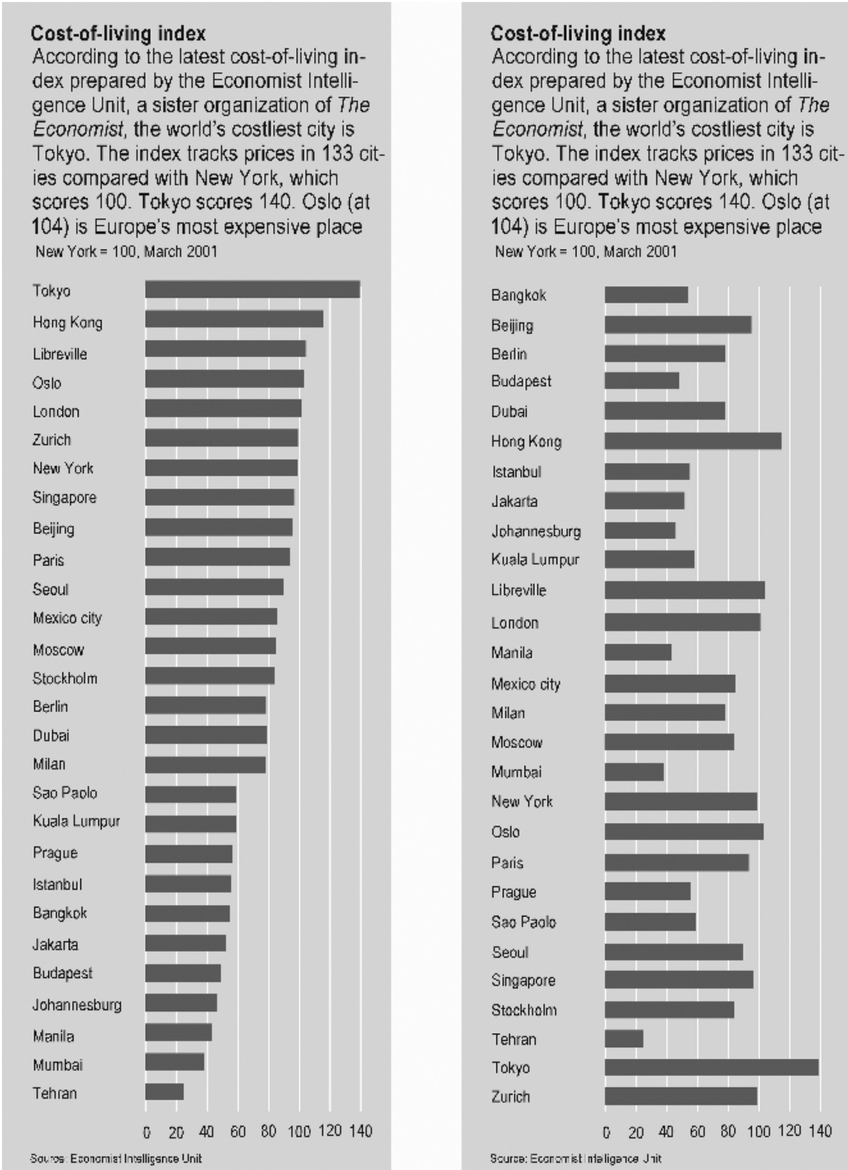


Figure 1.39

present a lot of data, as in the example in Figure 1.39 from *The Economist* (July 7–13, 2001).

Here the individual entries have reasonable size and proportions: it's just the overall collection that takes up a lot of vertical space.

Note that if you are going to do a really unusual bar chart such as this, it makes sense to spend a moment considering the order in which the entries will appear. *The Economist* always puts such things in rank order, as on the left of Figure 1.39, rather than alphabetical order. See how it looks organized by the coincidence of the English name for the city and you can see why.

Well, the second presentation brings out the absence of an alphabetical bias in the cost of living, but it hides everything else! It is no longer obvious which is the most expensive city, or the least. How does Moscow compare with Stockholm, or Berlin with Milan?

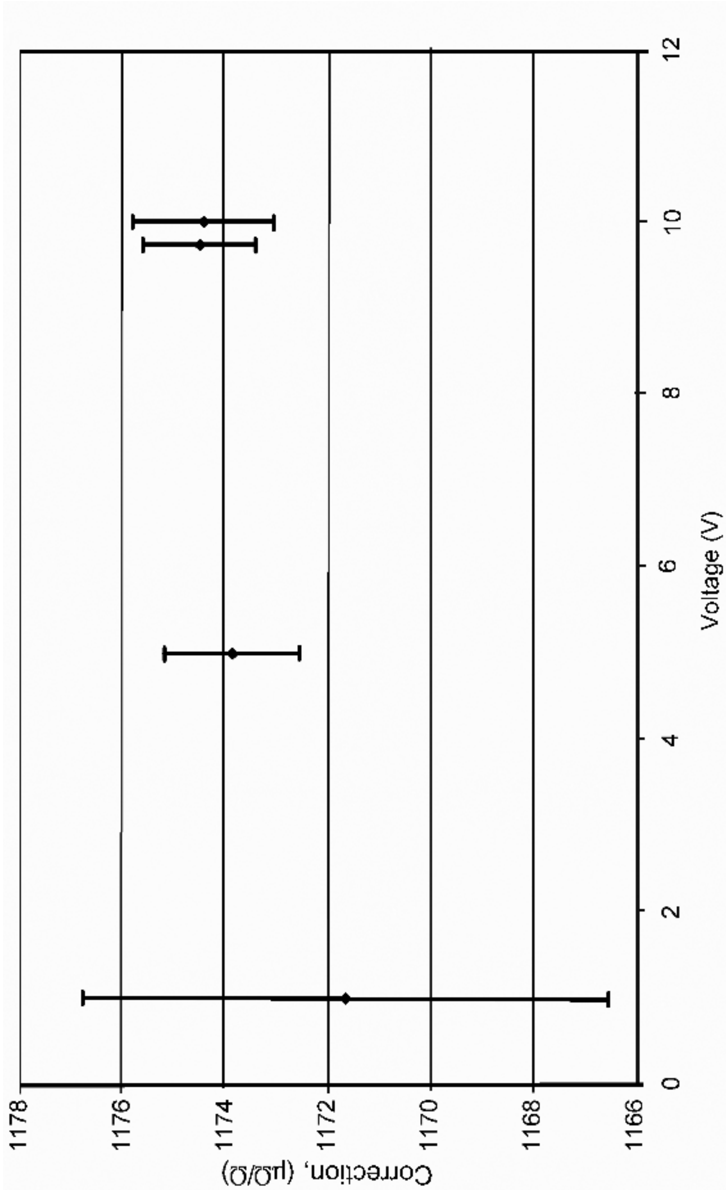


Figure 1.40

With the Aspect Ratio of Your Graph Fixed, *Size* it to Suit the Content. Just for the fun of it, see how small you can make it, before things start to look bad. Seriously!

Here's an example of an actual graph from a journal, reproduced here (Fig. 1.40) actual size. Considering the information content of the graph, the presentation is a waste of space. Figure 1.41 gives the same information, packed a little more densely, and with the horizontal lines removed. Just as useful, and only one fifth the area.

Consider an Alternative to a Graph. Sometimes, we get so accustomed to producing graphs that we don't consider whether a graph is the best way to present the data. In fact, for the graph in Figure 1.41, with only four data points,

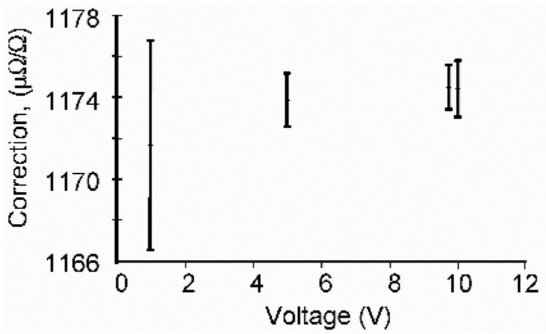


Figure 1.41

showing just one thing as a function of another, it hardly seems worth using a graph. The following is a table that presents all the information in the graph:

Voltage (V)	Correction (μΩ/Ω)	Uncertainty (μΩ/Ω)
1	1171.70	±5.05
5	1172.85	±1.25
9.7	1174.50	±1.55
10	1174.45	±1.35

Without the addition of the uncertainty numbers, the table would be even smaller, whereas the graph would be about the same size.

For a large number of points, or a more involved set of relationships, a graph is usually a clear choice. For a small number of points, and a simple interrelationship, a table may be a more compact and effective way to present the data. Presumably, somewhere in the middle—a modestly large data set and a fairly complex interrelation—there is a number of points and a degree of complexity that would be equally well served either way.

You will have to decide for yourself where that dividing line is. Don't let the habit of making graphs win every time!

Adjust the Line Weights in Graphs. As with font sizes, with most graphics packages line weights (the "official" term for line widths) change when you scale an entire image. With some, you have the option to fix the width or let it scale. Either way, the line width should be adjusted carefully, so as to preserve a reasonable balance to the graph.

The table below summarizes our suggestions.

	Two Column		Single Column		Viewgraph	
	thousandths	points	thousandths	points	thousandths	points
Axis lines	8–10	0.6–0.7	12–15	0.8–1.1	15–25	1–2
Tick marks	6–8	0.4–0.6	8–10	0.6–0.7	12–20	0.8–1.5
Graph lines	10–20	0.7–1.4	15–30	1.1–2.2	20–40	1.5–3
Leader-lines	7–10	0.5–0.7	10–12	0.7–0.9	15–20	0.8–1.4

Viewgraph, in this context, applies to the computer-based presentation as well as the one based on a transparency. It used to be that, a few years ago, a formal presentation required a 35-mm slide. For a less formal occasion everyone used viewgraphs. (There was once a retirement party for a colleague, and the speakers honoring him used viewgraphs.)

The original viewgraph was based on a transparent film about $8\frac{1}{2}$ by 11 inches, sometimes with a cardboard frame. If you were an engineer, the viewgraph was arranged landscape (i.e., with the long side horizontal) and had been done by the graphics department, sometimes at great expense overnight. If you were a scientist, the viewgraph was portrait (long side vertical) and was hand drawn, often during the presentation of the previous speaker, and sometime in real time during the presentation.

These days, things are much better. Almost everyone is using the computer for presentations, formal or informal, and almost everyone prepares the "slides" ahead of time. Nobody has figured out how to turn the screen sideways, so even scientists now make landscape presentations.

Chapter 6 discusses presentations in more detail.

Think About Not Connecting the Axes. Because graphs were historically drawn on graph paper, the axes were always joined. Now that graphs are drawn on a computer, that little implementation detail is no longer a requirement. The two graphs in Figure 1.42 convey the same information, after all.

If one or both of the axes do not go to zero, it might make good sense to ensure the lines were not connected, or even aligned. In essence, the separation of the axes could be thought of as a special case of a scale break. Which reminds us. . .

Avoid Scale Breaks If You Can. Scale breaks, which can involve changes in scale factor as well as simple offsets, tend to give the reader the wrong impression about the data. Fortunately, most software does not readily produce scales with breaks, so you would have to make some effort in order to create a graph that

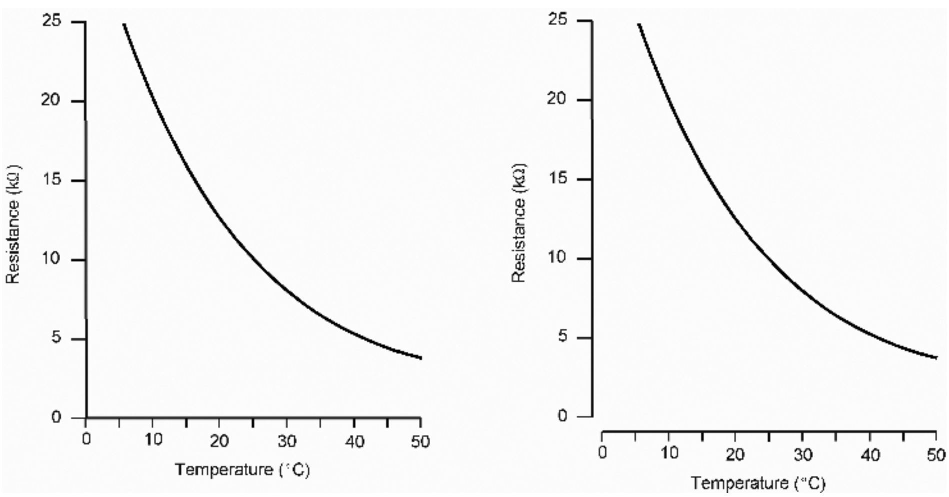


Figure 1.42

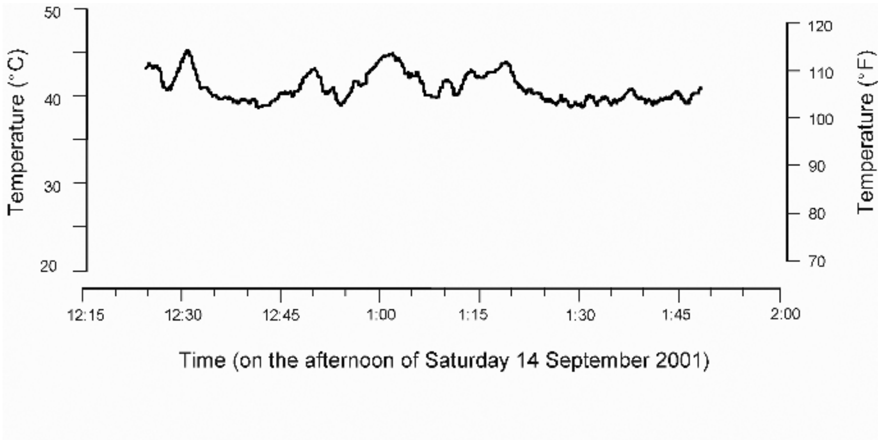


Figure 1.43

uses one. If you decide you absolutely cannot avoid using one, be sure the break is obvious, and under no circumstances "join the dots" across either side of the break. Consider the graph shown in Figure 1.43.

These data were collected in the Mojave Desert one hot and dusty afternoon. There is a continuous record lasting about 90 minutes. In fact, it is most unlikely that the temperature fluctuated this rapidly—the reading seems highly correlated with the reading from the anemometer, as shown in Figure 1.44, implying that the sun was heating the thermometer and the wind was cooling it.

Be that as it may, suppose there had been a break in the record, with no data collected for some of the period. It would certainly be incorrect to show the data as in Figure 1.45 to correct the omission. Far better to leave out the line for the period where data are missing, as in Figure 1.46. (The question of whether or not to "join the dots" is surprisingly difficult to answer. It is addressed in Chapter 3, where some generally applicable rules are given.)

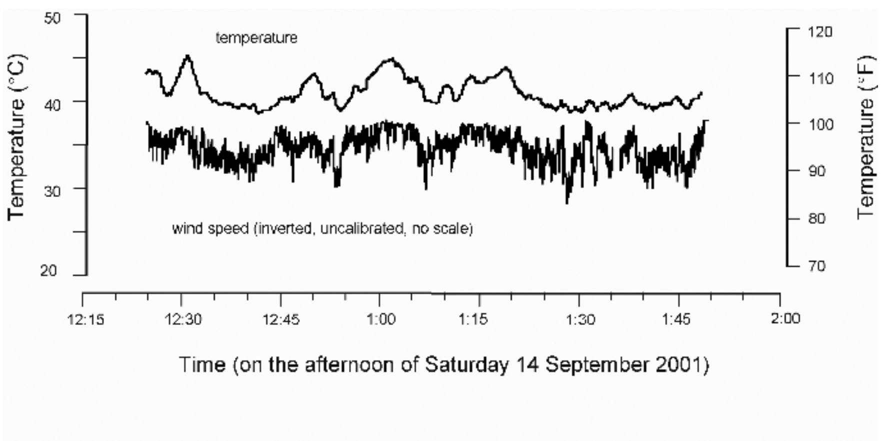


Figure 1.44

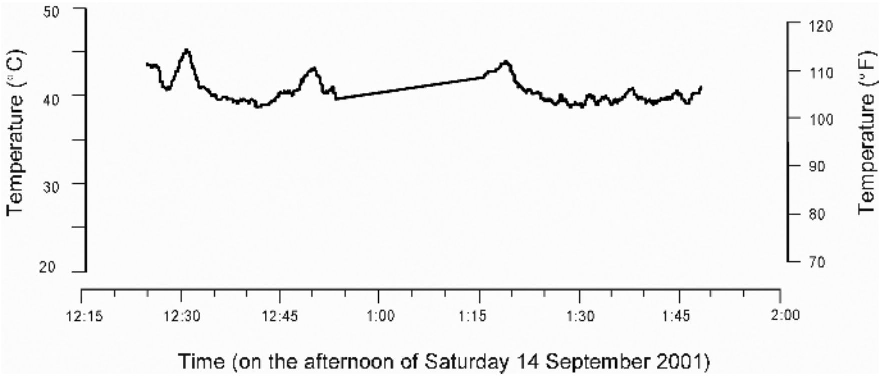


Figure 1.45

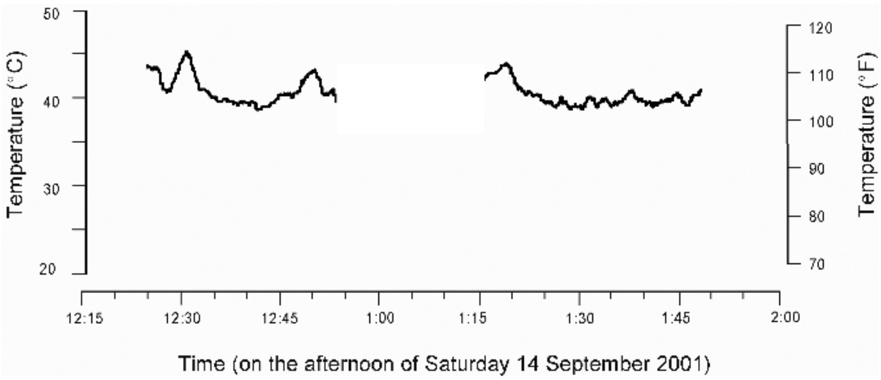


Figure 1.46

If the data gap were longer, you might be tempted to show the scale break as in Figure 1.47. Resist the temptation! It is too easy with this presentation to imagine that there is only a *small* period of missing data. If there must be a break, but you must save space, be sure that the reader has no doubt that data are missing. You might even consider the method of Figure 1.48.

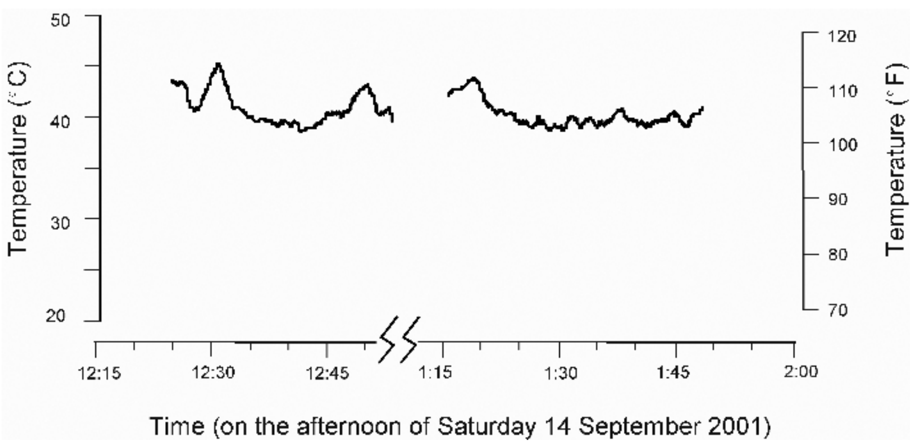


Figure 1.47

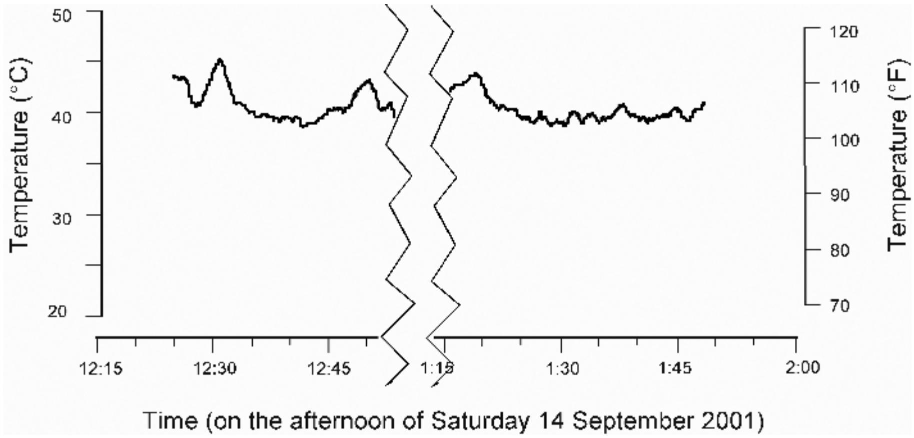


Figure 1.48

A scale break is sometimes a possibility in the vertical axis, too, again because of missing data, although the data may be missing in a sense other than that you stopped collecting data for a while. The only excuse for using a scale break is that it is essential to show two distinctly separate parts of a graph in similar detail. Instead, consider using a logarithmic axis, and consider using two separate graphs.

The same argument applies to bar graphs, too. A bar graph was used by *The Economist* to show the effect of the Chinese astrological calendar on birth rates, in particular, that in certain years, viewed as auspicious, there were more births.[6] The actual number of births in Huludao, a port city in northeastern China, were plotted. The obvious way to plot the data would have been as in Figure 1.49.

However, the idea was to show the dramatic increase in the Year of the Dragon, and so the axis was changed as in Figure 1.50. Note that the left end of the bars has a very pronounced raggedness, so that even the casual reader must see that the bars were "torn" at this end.

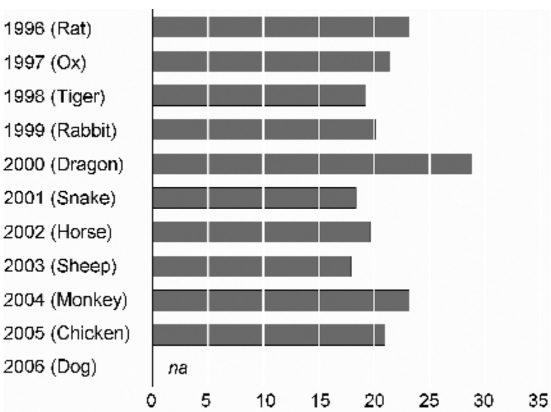


Figure 1.49

[6]The Golden Pig cohort, *The Economist*, page 44 (February 10, 2007).

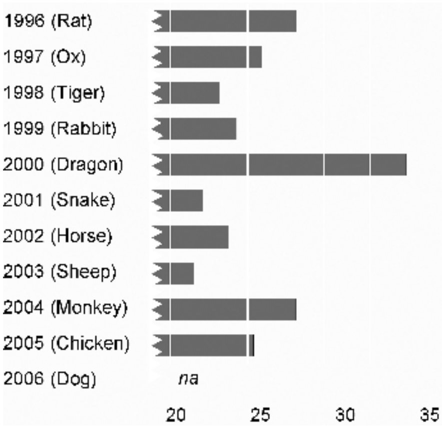


Figure 1.50

You Don't Have to Put Lines at the Top or Right. Since you are not cutting the graph out of a printed page, and you are not drawing it on actual graph paper, there is no need to put the graph area inside a four-sided box. A line at the bottom and one on the left will do.

This is just a matter of style, and that topic is addressed in Chapter 13. The modern style of things is for a clean, uncluttered appearance, and an approach that says, in essence, "justify every bit of ink on the graph" is in keeping with that.

If you have multiple parameters that require multiple ordinates, you can put them all on the left, or (for the special case of two axes) put one each side (like we did above with the Fahrenheit and Celsius scales). If you follow this rule, the scale on the right will be different from the one on the left, and so a line joining them at the top will not intersect at a tick mark. Ugly, very ugly! Remember Figure 1.14? It is reproduced here as Figure 1.51 for convenience.

Close examination reveals that the right scale was adjusted so that the two curves lay on top of one another. Neither horizontal line intersects the right axis at a tick mark.

You Don't Have to Put Lines Across the Graph Area. Except for lines of longitude and latitude, it is no longer considered good practice to put lines across the graph area. (Longitude and latitude are different, because it may be that on flat paper they are not straight lines, depending on the projection being used.) Several examples of graphs with lines on them have already been presented in this chapter, so no more will be added here.

It seems that the default appearance of graphs produced by spreadsheets includes lines. However, these can usually be removed, either by the spreadsheet software or in your graphics package. More on this in the chapters on spreadsheets.

Look Out for Step Functions. Another almost accidental feature of spreadsheet graphs is the joining of adjacent data points by straight lines. Usually the result is acceptable, though the question of joining data dots is actually far from simple, and we have devoted a fair amount of space to it in Chapter 3.

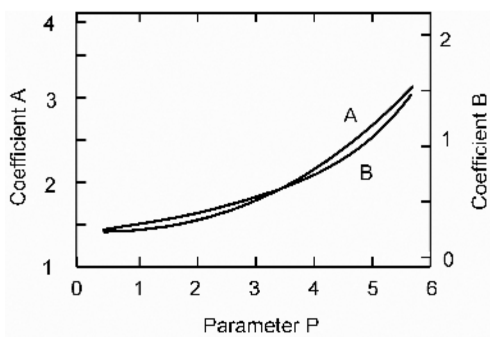


Figure 1.51

One particular aspect of this feature of spreadsheet graphics is apparent in graphs of funding and expenditures, exactly the kind of thing spreadsheets were originally designed for. For example, suppose we have a project that is spending money at a reasonably constant rate, and receiving funding on an annual basis. One way to present to the manager her financial information is to plot the accumulated expenditures and the funding received as a function of time. The result might look like the graph in Figure 1.52. The light gray line is the available funds.

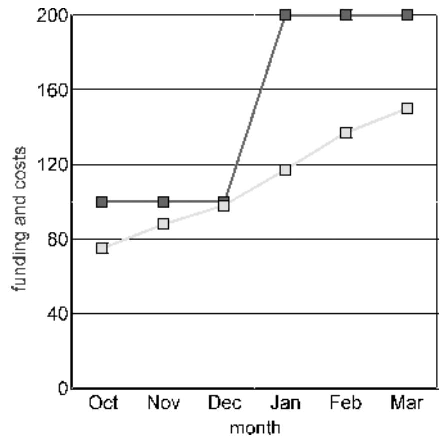


Figure 1.52

This is the sort of thing the default graph from a spreadsheet would give you. New funding is expected in January, so the manager may glance at this graph and conclude all is well. It isn't. By joining the adjacent data points by a straight line, the spreadsheet obscures the fact that the project will run out of money late in December. Happy Christmas, indeed!

The problem lies in the way the available funding line appears to ramp up from one value to another. It would be a more accurate representation if it looked like a step function.

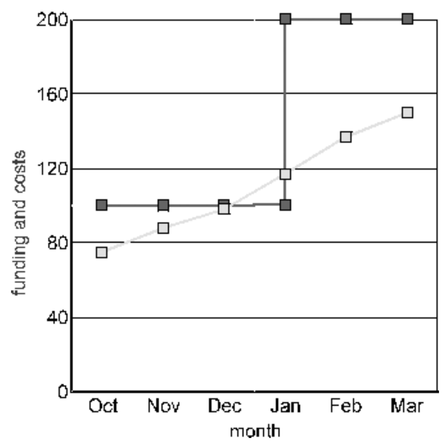


Figure 1.53

One way to achieve the right effect is to add another data point, just before the value changes. It may be possible to do this in the spreadsheet, or it may be necessary to import the graph into your graphics package. The desired result is shown in Figure 1.53.

This is closer to what you might want.

Actually, some spreadsheets offer a step-function graph, but only if you make it three-dimensional, at which point it looks like the diagram for the air-conditioner ducts above the office. See Figure 1.54.

More on peculiar defaults in Chapters 8 and 9 on Spreadsheets.

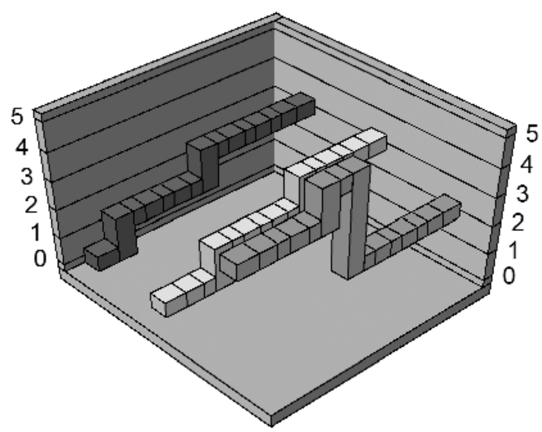


Figure 1.54

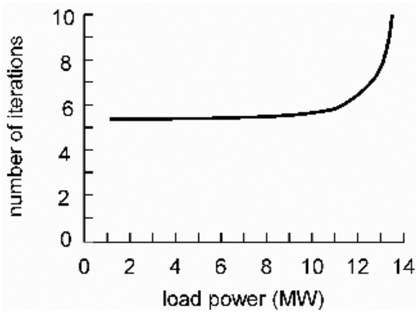


Figure 1.55

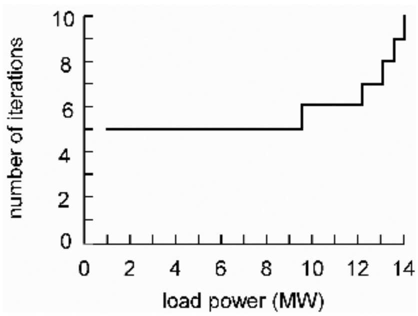


Figure 1.56

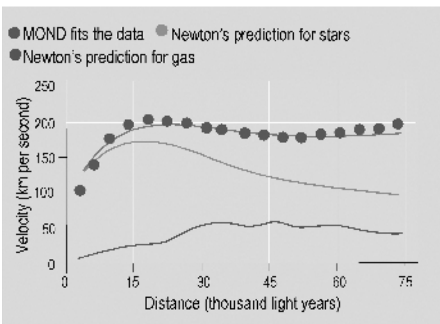


Figure 1-57 See insert for color representation of this figure.

Step-function graphs like the one in Figure 1.53 are reasonably common. For example, when interest rates and exchange rates are changed, they change abruptly from one value to another. If your data produce something that looks almost like a step on your graph, it might be wise to think about whether it actually *should be* a step.

For example, suppose the power system load flow that we showed at the beginning of the chapter was made much more efficient, so that only a few iterations were needed instead of a few thousand. The graph of Figure 1.55 would certainly not be correct. The number of iterations must be an integer, so Figure 1.56 shows what you might expect.

The Key. The *key* used to be a common part of a graphic. It was the little box in the corner that explained what the various colors signified on a map, for example, or explained the meaning of the solid and dotted lines on a graph. This way you could tell the difference between the route of the treacherous Pizarro and the way to Piglet's house.

In the latter part of the 20th century, the key fell out of favor, and other ways were found to get the information across. Now the key seems to be making a comeback, largely because of the increasingly gratuitous use of color in graphics. Resist the trend. Avoid using a key, if possible. *The key is an obstacle the reader has to get past before he can understand the graph.*

In the graph in Figure 1.57, which is similar to one that appeared in *New Scientist* (January 25, 2003), conventional Newtonian gravity is compared with an altered version (MOND—modified Newtonian dynamics). MOND is a possible alternative to postulating large amounts of cold dark matter in the universe as a way to explain the motion of stars in the outer reaches of galaxies. The text makes it clear that the distance referred to in the graph is the distance of a star from the galactic core, though the galaxy whose data are being presented is not identified.

The *key* in the graph of Figure 1.57 consists of the top two lines.

Well, actually, it's more of an intelligence test than a key. Remember intelligence tests? They were used to find out whether twins or tall people were smarter. "Find two symbols that have something in common in the following set":

See how the MOND graph fits this pattern? There are four colors in the graph (not counting background colors), and only three in the key. There is one set of round blobs in the graph, but there are three in the key. After a moment of study, you see that the round blobness of the items in the key is irrelevant. The key applies to the color of the *lines*. The round blobs on the graph are not described anywhere, but it seems likely they represent data.

The graph highlights some of the problems with producing a key. If the purpose of the key is to explain color, then the colored part of the key must have a shape. If the shape of the object in the key is different from the object in the graph, the reader is faced with an intelligence test: Is the important part of the key the shape of the objects or the color?

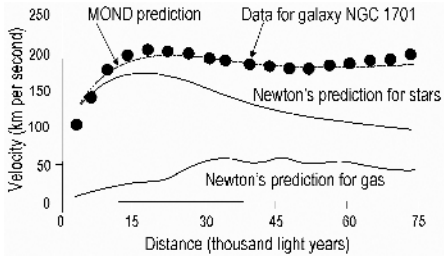


Figure 1.58

This conundrum is exacerbated by the fact that lines act somehow to make color difficult to see, and colors appear to change when surrounded by other colors. Since the key and the graph have different background colors, there is a potential problem.

The MOND graph could just as well have been presented in black and white, as in Figure 1.58, with the dots and curves identified conventionally.

Note that there are now four things identified in the graph, instead of the three of the original. Perhaps the presentation is not quite as spiffy as the colored version, but the point is made much more clearly. The MOND prediction is a reasonable fit to observation, Newtonian dynamics for stars is not. (It is to be noted, however, that the "observations" shown in this graph are just a shade suspicious. The spacing between dots is remarkably regular where the curve is flat—above a distance of 5 kparsec, say—and this spacing decreases where the curve is steeper. Although we have no basis in evidence, we suspect that the dots are merely an artist's impression of how data might look superimposed on a curve.)

Here's a similar example from *Science News*. Under the heading "Our big fat cancer statistics" (November 19, 2005, Vol. 168, page 334), the argument was made that obesity was the second largest cause of cancer in the United States (responsible for 10% of all cancers, compared to smoking's 30%). The data were presented in a graph like the one reproduced in Figure 1.59 (in which the background color of the original has been removed).

In this example, the key seems to be entirely unnecessary, and is again more of an annoyance than an added value. Suppose you are curious which is the most common type of cancer attributed to obesity. You look at the chart, and decide it is the blue one (although you are not sure what the percentage is, since the bar is taller than the axis). You search through the colors in the key area below the chart, and you find "endometrial."

Why should "endometrial" be blue and "colon" beige? No reason. Why should the types be written in the order Colon, Breast, Endometrial, Kidney, and so forth? No reason. The order is not the order of occurrence or the order of the alphabet. Nor do the initial letters spell anything pronounceable: C-B-E-K-E-P-L-M.

Compare the graph of Figure 1.59 with the one in Figure 1.60, which contains all the same information.

In directly labeling the bars of the bar chart, we have avoided the need to use a key. This means that one step has been removed from the process of reading the graph. As a result, the presentation is simpler to understand. As a side benefit,

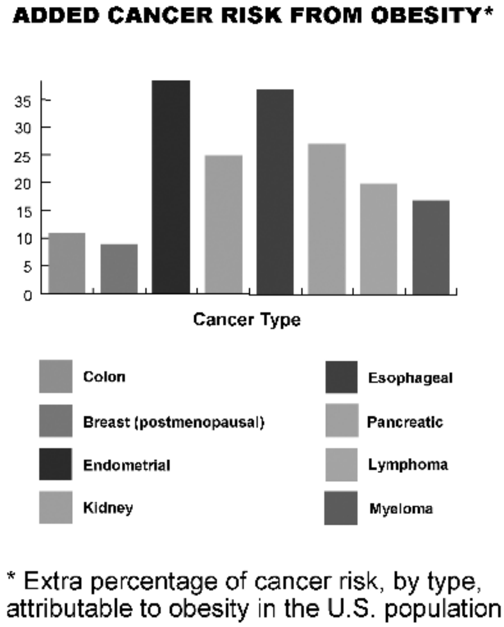


Figure 1-59 See insert for color representation of this figure.

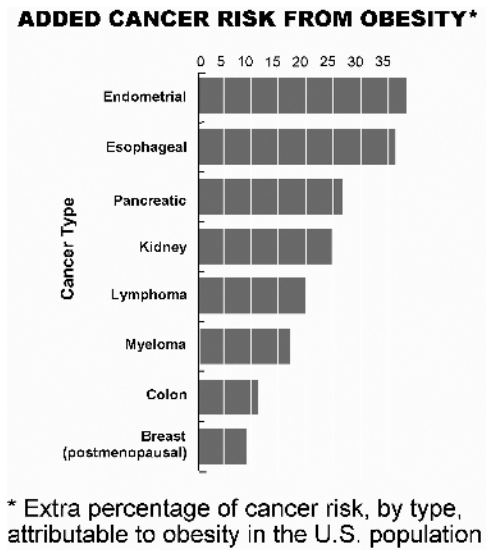


Figure 1.60

it takes up slightly less space. If *Science News* had done this, they could have retained the use of color simply by coloring the bars—but they could all have been the same color.

The presentation is also improved by ordering the types by their relative contribution, in the manner of the graph from *The Economist* presented earlier in the chapter.

Finally, comparison of the types is aided by running the lines for the percentages over the top of the bars.

Sometimes a key makes sense, however. In the graph shown in Figure 1.61, based on one in *The Economist* of February 1, 1986, the key is a good way to explain the difference between the light and dark shaded parts of the bar chart. Really, this is two charts combined, one showing the performance of Singapore, the other that of South Korea, between 1979 and 1984. There is a lot of information in this graph!

Note that the key contains objects that are the same shape as the objects they explain in the graph: rectangles. Note also that the graph would copy well. It may not be as visually appealing as a graph done in color, but from the point of view of usefulness, it is hard to beat. Usefulness is surely a primary goal in works of science and engineering, with visual appeal coming second.

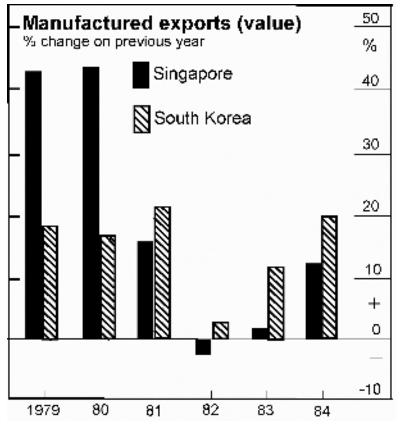


Figure 1.61

SUMMARY

We have looked at several kinds of graph and examined some of their peculiarities. The next chapter will look at the applications of various graphs in more detail. For all graphs, the basic rule for the author is to strive for clarity and avoid ambiguity.

- Think about what it is you want your graphic to say (and even whether a graph is the best way to go), and how best to arrange things to that end. (This question is addressed further in the next chapter.)
- Let the data make the case. Don't distort the graph to make your point. Don't use areas or volumes in simple numerical comparisons.
- Aim for a neat, clean appearance, with balance and good proportions. Varying line widths, making the graph line heavier than the axes, is a good way to improve appearance.
- Minimize the size of the graph, resizing the words if necessary.
- Control the amount of clutter in the graph. For example, use tick marks sparingly, and don't feel obliged to label all of them.
- Don't feel obliged to have lines around the graph on all sides, or all the way across the area.
- Clutter control is a matter of judgment and style, so the details are up to you.
- Think about what happens when the graph is copied or converted to microfiche.
- If there are two axes, label them both.
- Keep the graph within an imaginary rectangle, but don't feel you have to draw the rectangle.
- More or less fill the rectangle range with data, unless you have several similar data sets to compare.
- It is not essential to join axes—but avoid midscale breaks.
- Look out for step functions.
- If you can avoid using a key, do so. If you must use a key, make sure it is clear.

EXERCISES

1.1. The most important thing before you start making a graph is to figure out your objective, and choose a way of presenting the information. Something like the graph shown in Figure 1.62 appeared in *New Scientist* (May 31, 2008). Would this be appropriate, assuming you could guess the writer's purpose? What changes would you make for a technical paper?

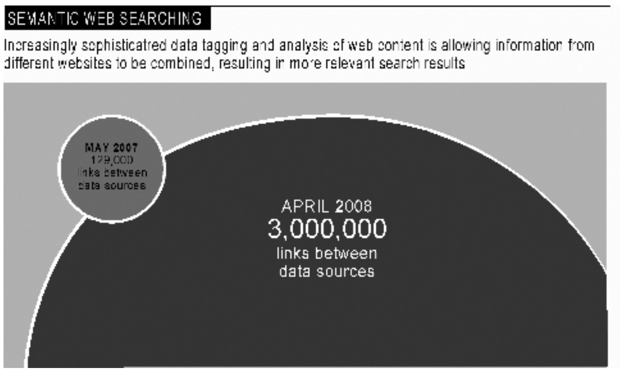


Figure 1.62

1.2. The following are some ranges of data. For each range, generate a sample scale for a vertical axis. Consider carefully how many tick marks, and how many labels there should be.

	Range 1	Range 2	Range 3	Range 4
Start	5:48 am	−3.1	0.1	1979
End	6:17 pm	17.6	100	2008
Comment			Logarithmic	Years

Would the scale be different if the data were used for the horizontal axis?

1.3. What is wrong with the graph of Figure 1.63, which is similar to a graph in *Science News* (May 24, 2008), that was aimed at showing that buying local produce would not have much impact on one's carbon footprint?

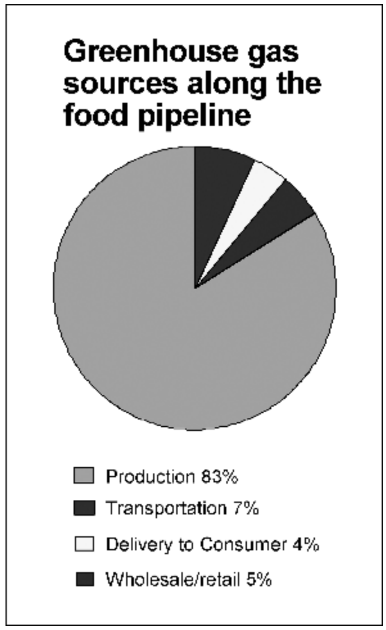


Figure 1-63 See insert for color representation of this figure.

1.4. What changes would you make to the graph seen in Figure 1.64, which is similar to a graph that was in an *IEEE Transactions* paper?

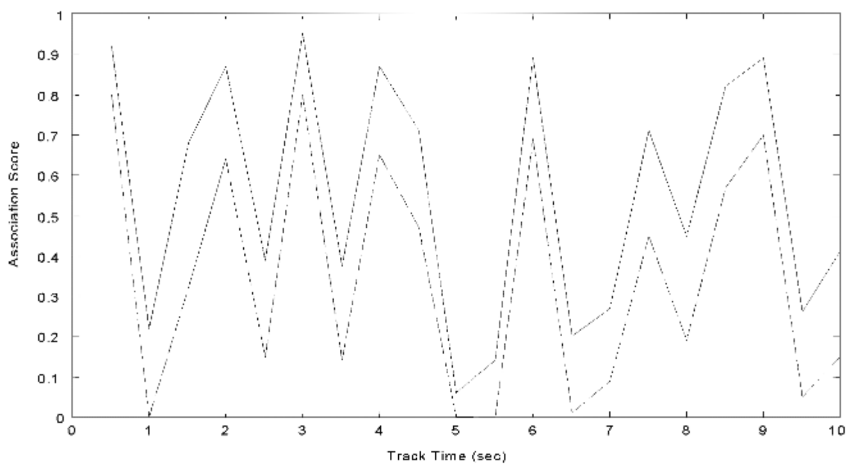


Figure 1.64