CHAPTER 1

Issues

1.1 What is visualization?

Terminology is a problem in many fields of study. Familiar terms are often used very loosely, even though important concepts are being addressed. Does it matter? Yes, it does, because many useful insights can occur if we know precisely what we're talking about.

'Visualization' is a case in point. Is it something a computer does, as implied by a great many texts, or an activity carried out by a human being? Let's reach for one or two dictionaries?

> *visualize: (vb)* to *form* a mental image or vision *of* . . .
> *visualize: (vb)* to *imagine or* remember *as if actually seeing.*

Immediately we realize that visualization is an activity which a human being engages in, and that it is a *cognitive* activity (Ware, 2000; MacEachren, 1995): in other words, it goes on in the mind. Indeed, it results in something rather ephemeral (which we later call a mental model or internal model), something that cannot be printed out on paper or viewed through a microscope. The result is, as we say, *internal* to the human being. The potential value of visualization – that of gaining insight and understanding – follows from these definitions but so also, in view of the cognitive nature of visualization does the difficulty of its study.

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[1] The American Heritage and Concise Oxford dictionaries.

Intentionally, no mention has yet been made of the computer, of which the above definitions are independent (Spence, 1996). Indeed, they will remain so, though we shall certainly investigate how the computer can facilitate the visualization process with what we shall call visualization tools.

1.2 Information visualization

There are many situations in which data is available, sometimes in very large quantities, and where some human insight into that data is required. Two simple examples will suffice for the moment. One is associated with the familiar London Underground railway map (Figure 1.1). Sight of the map results in the viewer forming in his or her mind some understanding – though not a completely memorized image – of the underground railway routes and their regular and interchange stations. Typically, attention will focus on the planned journey, and hence on the intended departure and destination stations and a viable route between them. The route may well be memorized by the colour and the direction

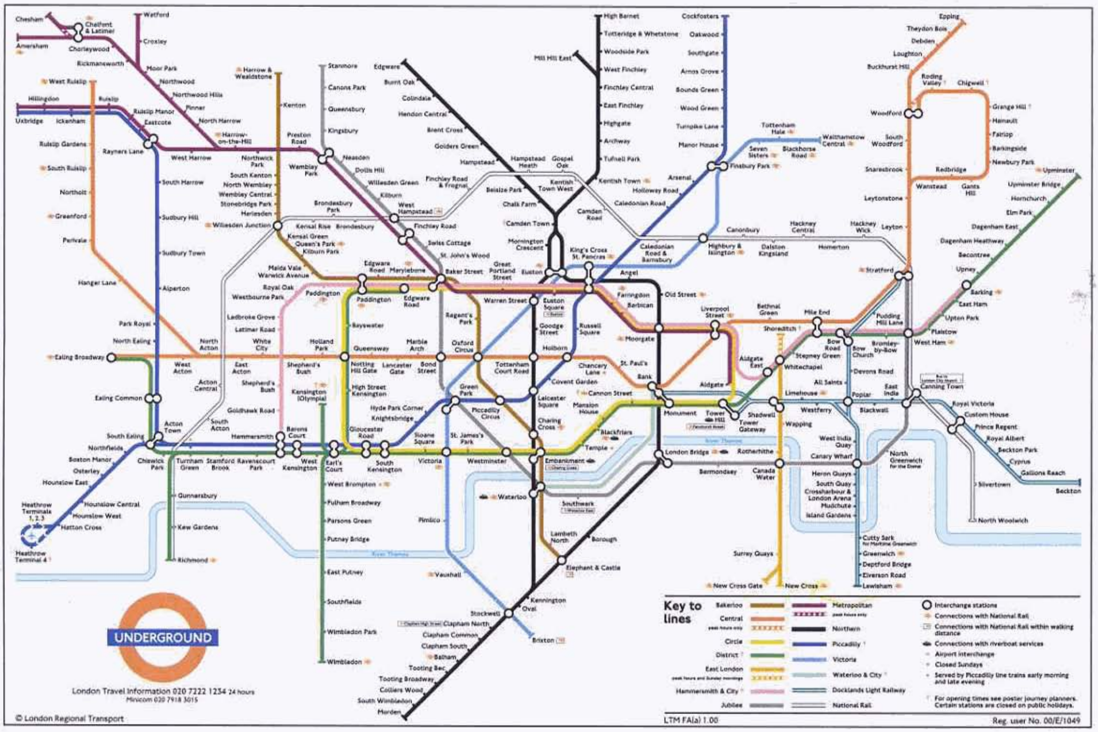

FIGURE 1.1

Contemporary map of the London Underground transportation system ('The Tube')

Source: *Reproduced by kind permission of London Transport Museum. Registered Exempt User No. 00/E/1049* of the line(s) involved and any interchange station, or it may be memorized verbally as 'east on the blue line then west on the red line'. In this way a relevant portion of the underground system has been visualized and the resulting internal model – whatever its form – can be accessed during the journey to ensure arrival at the correct destination.

Sometimes we refer to the internal model as a **cognitive map** to distinguish it from the map of Figure 1.1 which is real in the sense of being an object pasted to the wall of the underground station. As Tversky (1993) points out:[2]

> *As mental constructs available to mental inspection, cognitive maps are presumed to be like real maps available to real inspection.*

With the underground map the task facilitated by visualization is that of planning a journey. In a simple – but true – sense the printed underground map is a visualization tool.

The second example, also supportive of visualization, is somewhat different in its aim. Its purpose is to elicit, from the viewer, a response of the form 'Ah HA' (the 'HA' being emphasized, prolonged and probably of higher pitch!), indicating that sudden insight has been obtained into some effect, insight that might well lead to significantly enhanced understanding or a new idea. The concept is illustrated in Figure 1.2, the origin of which is almost 200 years old but redrawn here for clarity. Sir Edward Playfair, its author, wished to stress that, of the four great empires of his day, the British Empire was far too heavily taxed (Biderman, 1990). The left-hand uprights are proportional to gross national product and the right-hand uprights to tax income, so it is the slope of the connecting lines that draws attention to the point that Playfair was trying to make.

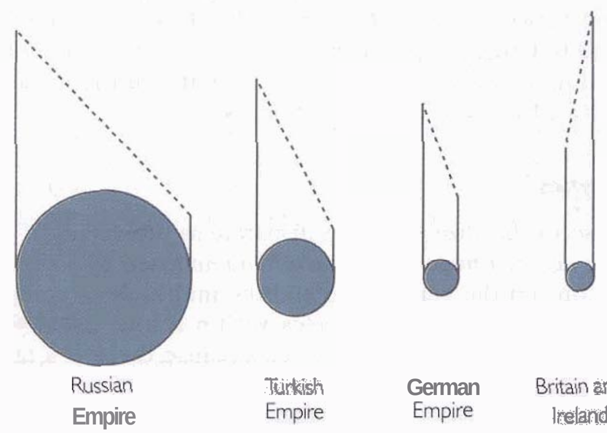

FIGURE 1.2 Sir Edward Playfair's circles, showing gross national product (left upright) and tax gathered (right upright)

[2] Tversky goes on to point out that the concept of a cognitive map may be too restrictive, and proceeds to discuss the interesting concept, to which we refer later, of Cognitive Collages.

1.3 Scientific visualization

There is a related, and somewhat overlapping field called 'scientific visualization' in which what is seen primarily relates to, and represents visually (usually in simulated 3D) a physical 'thing' such as a mountain range over which clouds are flowing or a girder in which the stress is of interest. Notwithstanding the fact that many of the techniques we discuss can usefully be applied in these situations, the need to display the physical 'thing' is not so important – and is often entirely irrelevant – in information visualization. In this hook we are more concerned with abstract concepts such as price, stress, baseball scores, currency fluctuations and 'nearness to optimum' which, while undoubtedly associated with real physical things, are far more important than the view of those things. A currency trader knows perfectly well what a dollar bill looks like, but does not need to see its image (unless used for encoding purposes – see Chapter 4) while trading. Similarly, a study of baseball statistics (see Chapter 2) does not require an image of a baseball, whereas flow in a pipe is usually best displayed in the immediate context of the pipe itself. This book does not address the subject of scientific visualization, though many of the techniques discussed are relevant to it.

1.4 Data and information

Broadly speaking, we are concerned in this hook with situations in which a body of data is available and a human being wishes to gain insight into that data: in other words, they wish to be *informed* by that data. It is important to make a clear distinction between data and information. The 'information explosion' so widely discussed is actually a data explosion: it is the derivation of information (or understanding, or insight) from the data that is difficult, and which we attempt to facilitate by means of visualization tools.

1.4.1 Data types

The data we wish to visualize can be as disparate as the details of houses in the files of an estate agent, a huge collection of data amassed by a supermarket, the network of stations on the Paris Metro and the multitude of complex relationships between the currents and voltages within a hifi. Usually, though not always, insight and knowledge are required because there is a task to be performed: buying a house, planning what brand of grapes to advertise as a special offer, getting to the Opera station, or designing a high-quality hifi.

The data will not always be *numerical*, though much of it is. It can be *ordinal*, as with things that are naturally ordered (such as the days of the week), or *categorical*, such as the names of animals where there is no order (for example, horse, zebra, antelope) (Figure 1.3).

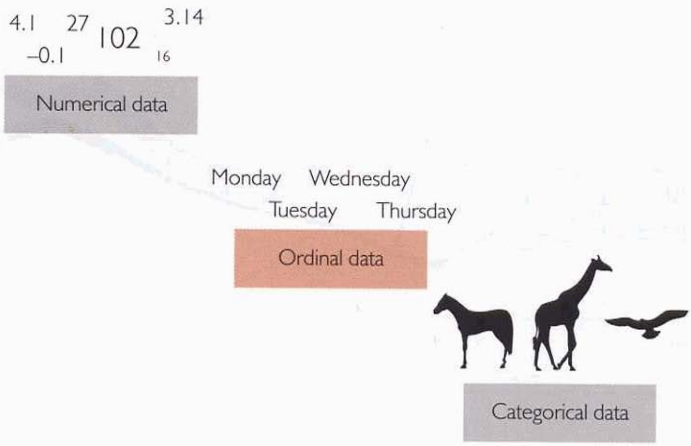

FIGURE 1.3
Numerical, ordinal and categorical **data**

1.5 Examples

We begin by examining six examples of visualization, four from the nineteenth century, one from the early twentieth century and one of recent origin. In each case we briefly reflect upon the issues raised and, in apparent contradiction to an earlier exhortation, begin to use, without formal definition, some of the terminology that will become commonplace later in the book.

1.5.1 Taxation

The first example has already been introduced (Figure 1.2) and was created as long ago as 1801 by Sir Edward Playfair. Here we have four objects, each with two *attributes* (gross national product and tax income), and the presentation is chosen to make one statement. It is the slope associated with the British Empire that stands out as the 'odd one out' and thereby makes the point for Playfair.

Many questions emerge. Is slope the best way of drawing attention to something that is different? How could Sir Edward have handled more attributes such as population and the sources of income. Would colour offer a good encoding mechanism?

1.5.2 Napoleon

Monsieur Minard, Napoleon's mapmaker, produced an illustration (Figure 1.4) of the famous march to, and retreat from, Moscow by Napoleon's army. The thickness of the brown line is proportional to the number of soldiers at any one location during the advance, and black similarly encodes the retreat. The toll on life is immediately obvious: of the 422,000 soldiers who started out, only 10,000 returned. The loss of life which occurred during the crossing of the Berezina river during the retreat (when many soldiers fell through the ice) is particularly striking. A contributory factor overall was the weather conditions which can be imagined from the temperature plot at the bottom of the illustration. Hardly, you may reflect, a good recruitment poster!

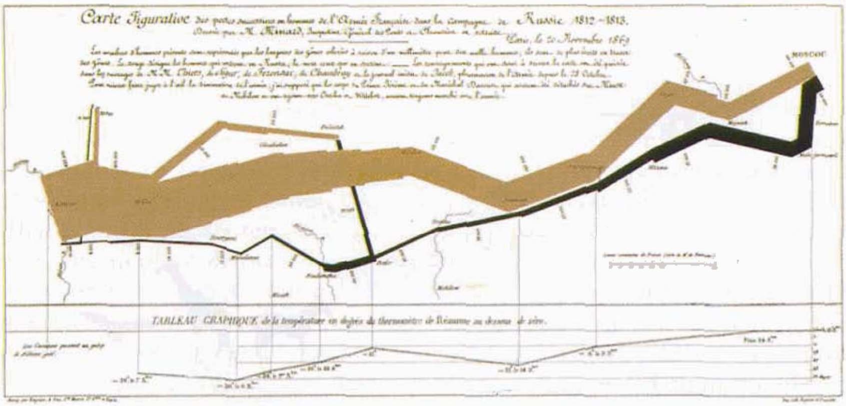

FIGURE 1.4 Minard's map of Napoleon's march to, and retreat from, Moscow

Source: *Tufte (1983)*

Minard's design triggers further questions. Why use the colours we see in Figure 1.4? Were they the only colours available? How does one strike a balance between simplicity and complexity – could additional interesting information have been included? Are there any locations where more detail might have been beneficial? If so, how could it have been included? Could temperature have been encoded differently? Anticipating later chapters, how could the illustration usefully be made interactive? Could Tchaikovsky's 1812 overture be effectively combined with the map?

1.5.3 Nightingale's roses

Florence Nightingale was the heroic nurse who went out to the front-line British Army hospitals in the Crimea in the mid-1850s, to tend the wounded and the sick (the latter were by far the majority). What is not widely known is that, as a result of her observations of the appalling conditions in those hospitals (and too graphic to repeat here), she persuaded a Sanitary Commission to undertake improvements and, furthermore, wrote a report (Nightingale, 1858)[3] to the British Government describing the unsatisfactory conditions and how they were improved.

The improvements she achieved are strikingly displayed in a rose-shaped diagram (Figure 1.5), which not only shows the number of deaths, month by month, in the British Army hospitals in the Crimea but also, to provide a basis of comparison (the dotted line), the number of deaths in Army hospitals in Manchester, England, during the same months. Each segment, whose subtended angle corresponds to elapsed time, has an area proportional to the number of deaths during that period. The effect of the new regime, begun in March 1855 ('Commencement of Sanitary Improvements' in Figure 1.5) is clearly displayed.

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[3] Nightingale's book contains a fascinating appendix containing recipes. However, it is strongly recommended that details of the Crimean hospitals are not perused before eating the results of Nightingale's – or anyone else's – recipes.

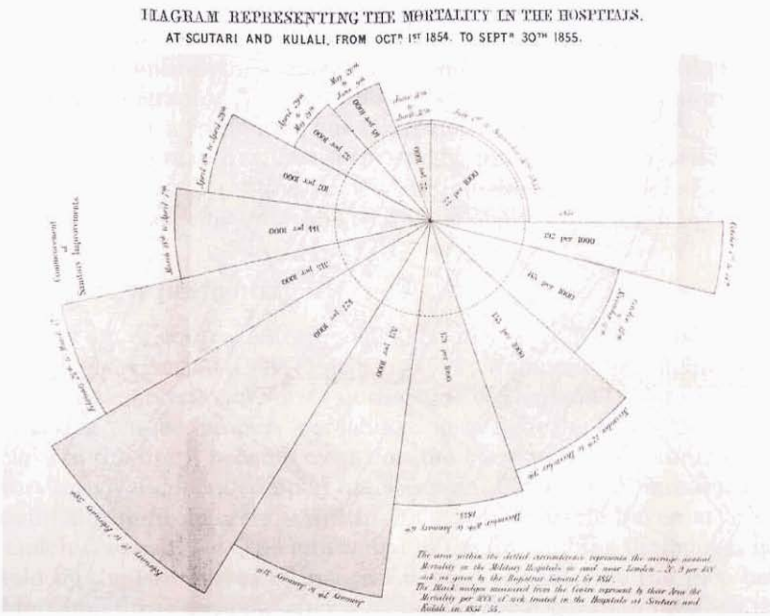


FIGURE 1.5 Florence Nightingale's diagram showing the dramatic reduction in the death rates

Source: *Nightingale (1858)*

1.5.4 An outbreak of cholera

There was an outbreak of cholera in London's Soho district in the year 1845. The medical officer for London at that time, Dr John Snow, had the task of bringing that outbreak under control. Although the detailed story behind John Snow's investigation makes fascinating reading (Tufte, 1997), the relevance to information visualization is clear from Figure 1.6. Here we see John Snow's map of the area: black dots represent individual deaths from cholera and × marks the positions of the water pumps. Snow observed that most of the deaths were concentrated around the Broad Street pump. His disablement of that pump was followed by a decrease in the number of deaths from cholera. Workers at the nearby brewery were noted to be relatively free from cholera, for reasons that can be left to the reader's imagination.

It is interesting to speculate what other representations would have assisted John Snow and how, with the availability of interactive computer graphics, a present-day John Snow[4] could be assisted in his detective work.

1.5.5 Harry Beck's map

More recently (Figure 1.1) we have the invention, in 1931, of the famous London Underground map by Harry Beck (Figure 1.7), an out-of-work draughtsman 'who realized that when you are underground it doesn't matter where you are. Beck saw – and what an intuitive stroke this was – that as long as the stations were presented in their correct sequence with their interchanges clearly

[4] A present-day John Snow would find, in Broad Street, neither pump nor (at the time of writing) a cholera epidemic, merely a rather pleasant pub. Its name? The *John Snow*.

FIGURE 1.6
An 1845 map of London's Soho district, showing deaths from cholera and the locations of water pumps

Source: *Tufte (1983)*

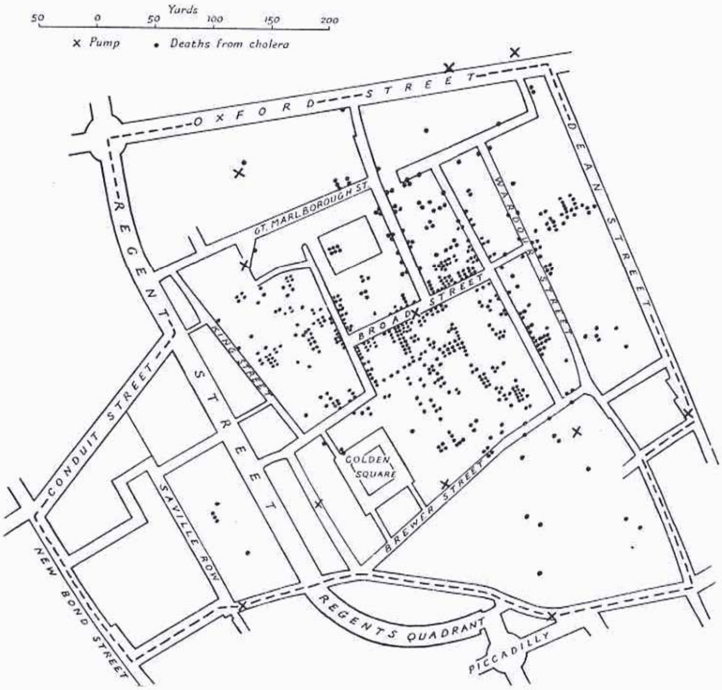
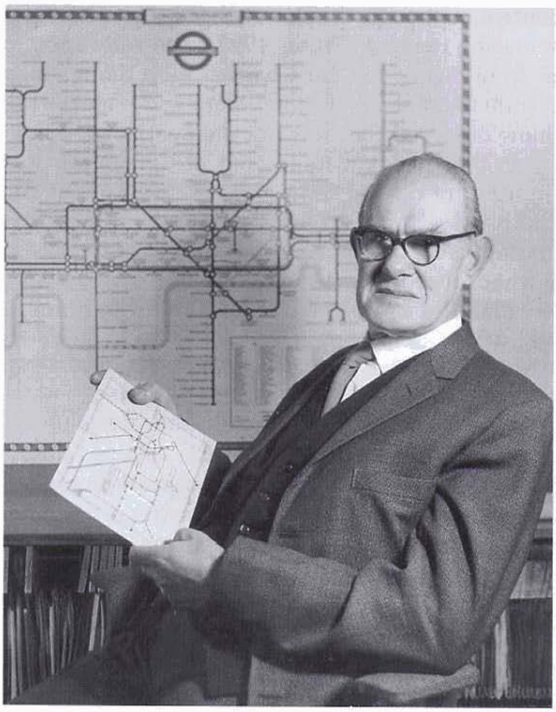


FIGURE 1.7
Harry Beck, creator of the familiar London Underground map

Source: *Ken Garland*



delineated, he could freely distort the wale and, indeed, abandon it altogether! He gave his map the orderly precision of an electrical wiring system, and in so doing created an entirely new, imaginary London that has very little to do with the disorderly geography of the city above' (Bryson, 1998). The story of Harry Beck and his map is a fascinating one (Garland, 1994).

Since 1931 the map has, not surprisingly, undergone many additions and modifications, but still retains Beck's brilliant idea; it is copied worldwide. Interestingly, we shall encounter the technique of distortion again in Chapter 7.

1.5.6 Tragically firefighting

A fire that is out of control is terrifying, and forest fires are especially awesome. On the night of 5 August 1949 (Maclean, 1992; Wainer, 1997), lightning struck trees in the Helena National Forest in the state of Montana (Figure 1.8). Sixteen Forest Service 'smoke jumpers' parachuted in to fight the blaze. But when they were close to the fire it became clear that the blaze was out of control and that their very survival depended upon quick action. But the fire moved faster, and eventually all the firefighters – within 200 yards of a safe haven at the top of Mann Gulch – were killed. The movement of the fire and the firefighters is tragically told by the two curves of Figure 1.9. One can imagine the race between firefighters and fire, especially after 5.52 pm, as the separation between the two curves becomes inexorably smaller, only 200 yards from safety. If only we could separate those two curves by 5 minutes or 200 yards . . . .

1.6 Computation

Although no computers were involved in any of the above examples (Spence, 1996), the simplicity of the illustrations nevertheless allows us to identify significant issues associated with information visualization, issues which are all the more pertinent when the power of the computer is available. The issues are many, and in most cases identify a chapter in which they are addressed in some detail.

1.6.1 Selection

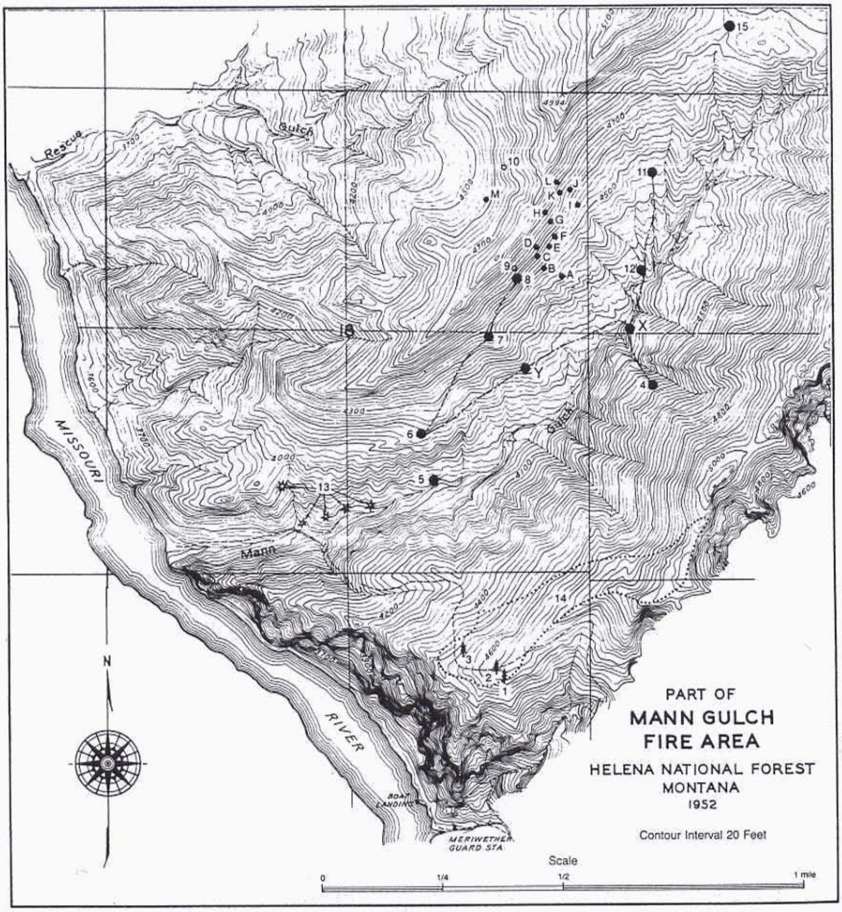
From all the data available, each author selected that which was thought to be relevant to an envisaged task. A single message from Playfair, an historical record from Minard, a diagnostic tool from John Snow, and so on. What do we need to know about selection? Can it take place automatically? Is it useful sometimes to suppress information? Is selection very fundamental to information visualization? Some answers are provided in Chapter 2.

1.6.2 Representation

The author of a visualization tool must represent abstract things in some way. Playfair used contrasting slopes, Minard used colors, Nightingale invented 'roses' and Beck used colour and connectivity. Many other methods of encoding are

FIGURE #&
Map of part of the Helena National Forest in Montana, USA

Source: *Reprinted from MacLean (1992), which in turn reprinted it from a 1952 U.S. Department of Agriculture report*



LEGEND

1,2,3 Lightning struck trees.
4 Dodge met Harrison.
X Dodge ordered crew to north side of Gulch.
Y Dodge and Harrison rejoined crews; beginning of crew's race.
5 Jansson turned back.
6 Dodge and crew turned back.
7 Dodge ordered heavy tools dropped.
8 Dodge set escape fire.
9 Dodge survived here.
10 Rumsey and Sallee survived here.
11 Jumping area (chutes assembled, burned).
12 Cargo assembly spot (burned).
13 Spot fires.
14 Approximate fire perimeter at time of jumping and cargo dropping (3:10–4:10 P.M.).
15 Helecopter landing spot.

BODIES FOUND

A Stanley J. Reba
B Silas R. Thompson
C Joseph B. Sylvia
D James O. Harrison
E Robert J. Bennett
F Newton T. Thompson
G Leonard L. Piper
H Eldon E. Diettert
I Marvin L. Sherman
J David R. Navon
K Phillip R. McVey
L Henry J. Thol, Jr.
M William J. Hellman

possible, but which are useful? Can they be combined? What happens if an object has twenty attributes rather than two? Some answers are provided in Chapters 3 and 4, and by many examples throughout the text.

1.6.3 Presentation

Each author had to 'lay out' their data in some way. Harry Beck distorted the geography of the underground transportation network to make effective use of

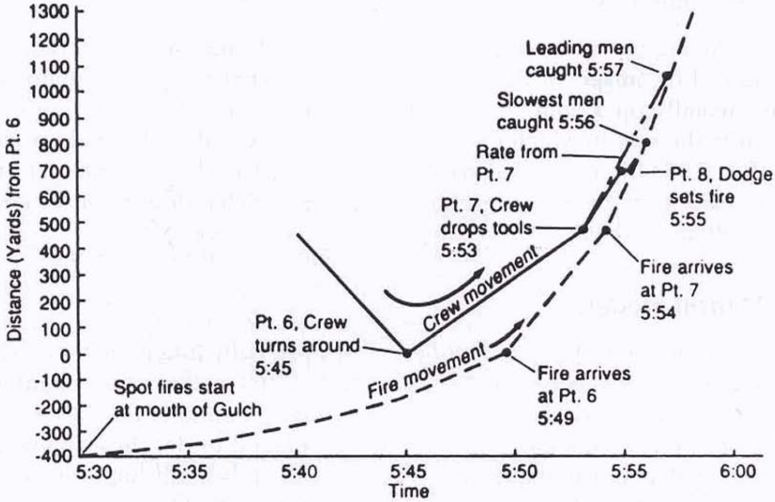


FIGURE 1.9 Movement of fire and firefighters towards Mann Gulch

Source: MacLean (1992)

space and make the result more memorable, and Playfair lined up his empires so that the differences in slope were obvious. Often, we find we have more data than can easily be displayed at once in the limited area of the screen, especially with the emergence of Personal Digital Assistants and other hand-held devices such as mobile telephones. What can we do about this presentation problem? Some answers are provided in Chapter 7.

1.6.4 Scale and dimensionality

The illustrative examples examined so far involved very little data, whereas in many realistic situations in commerce and industry the volume of data into which insight is desirable can be huge. We must therefore be aware of ways in which scale influences the way in which visualization tools are designed. Chapters 5 and 7, in particular, address this issue. We must also consider the dimensionality of displayed data: how many features can be incorporated? Playfair considered two (national product and tax), and Minard more (location, temperature, size of army, direction, etc.): what techniques are available for handling high dimensionality?

1.6.5 Rearrangement, interaction and exploration

For someone viewing the examples presented in this chapter, the opportunity to explore the underlying data is either non-existent or rather limited, partly due to the relatively small amount of data involved and partly because there is no means of rearranging the data to provide a new and possibly much more valuable view of it. The ability to explore data by rearranging it interactively is so valuable that a great deal of effort has been invested in the invention and implementation of interactive visualization tools that harness this potential, as Chapters 2 and 5 in particular will emphasize.

1.6.6 Externalization

When introducing the concept of visualization we referred to the creation of an internal model or 'image' in the mind of the user. What the user actually sees, nowadays usually on a computer display, is called the externalization of the data. Clearly, the way in which data is externalized – usually by visual presentation (Tufte, 1983) – is crucial to the success with which visualization is achieved, a fact particularly emphasized in Chapter 4 but continuously underlined throughout the book.

1.6.7 Mental models

It has been pointed out that visualization is an essentially human activity, albeit supported most effectively by the computer, and we have referred to the internal model which the act of visualization creates within the mind of the viewer. If we can understand how this happens we are well placed to design visualization tools. Unfortunately our understanding is very limited, but in Chapter 6 we present a framework, broadly based upon models in human memory, that offers a useful tool for organized thought about information visualization.

1.6.8 Invention, experience and skill

All the visualization tools discussed in this book had to be invented or designed: they were not generated automatically. Nothing much has changed in this respect, and this is not surprising in view of the complexity and unpredictability of typical tasks, the fast changing 'palette' of interaction techniques available to the designer, and our lack of understanding of human-computer interaction in general. As Donald Norman remarked not too long ago, 'our lack of knowledge about Human Computer Interaction is appalling'. Nevertheless, inventions are usually followed by attempts to provide theoretical underpinnings which lead to a deeper understanding and pointers to possible future developments, and some of these underpinnings are presented in this book. But in the great majority of situations the design of a new visualization tool is a craft activity, the success of which depends upon the designer's understanding of the task for which the tool is intended, as well as the designer's possession of many and varied skills ranging from visual design to algorithm design.

1.7 A model

In the pre-computer age (Figure 1.10) the author of an image had to perform selection, representation and presentation according to his or her understanding of the task to be performed or the message to be conveyed: author and viewer were two different people. Now, with the availability of powerful computers (Figure 1.11), interactive control by a user – who is thereby to some extent the author of externalizations – can influence all these activities within a freedom defined by the architect of the visualization tool. It is the architect who has to design this interaction to constructively handle the range of interests that a user

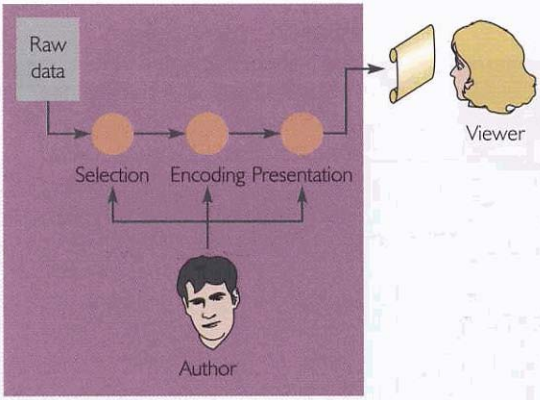


FIGURE 1.10
Pre-computer creation of a visualization tool

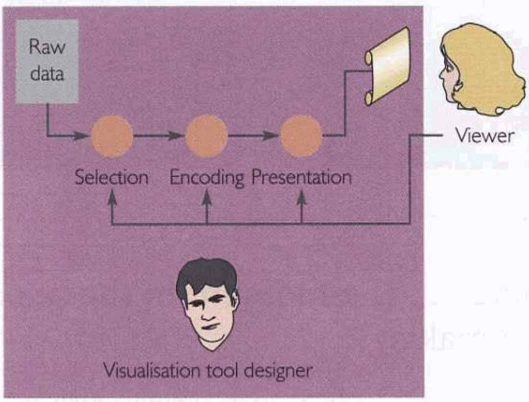


FIGURE 1.11
The creation and use of a computer-based visualization tool

may have. It is, in fact, that architect to whom this book is especially addressed, and whose motivation is reflected in the words of Proust:

> *The real voyage of discovery consists not in seeking new landscapes but in having new eyes.*

CHAPTER 2

Rearrangement and Interaction

2.1 'A graphic . . . is a moment in the process of decision making'

Anyone who has seen, and especially used, a highly responsive interactive visualization tool will be struck by two features. First, that a mere rearrangement of how the data is displayed can lead to a surprising degree of additional insight into that data. Second, that the very property of interactivity can considerably enhance that tool's effectiveness, especially if the computer's response follows a user's action virtually immediately, say within a fraction of a second.

To illustrate the concept of rearrangement we begin with a simple example in which ten crops (for example, wheat, rice, beans . . .) have been subjected to seven treatments (for example, insecticide, . . .), and the improvement or otherwise noted. If improvement is coded black and degradation white, the result of the experiments might appear as in Figure 2.1(a), where crops are numbered from 1 to 10 and treatments designated by A to G. Note that we are here concerned with categorical data: the ordering has been imposed merely for convenience of reference.

It is probably fair to say that the likelihood of anyone gaining immediate insight from Figure 2.1(a) is negligible. Now, however, imagine the diagram to be cut into rows as shown in Figure 2.1(b) and for these rows to be rearranged in an order which assigns priority to placing black squares as high as possible, first in column A, then in column B, and so on (Figure 2.1(c)). In other words, rows with a black entry in column *A* are ordered first, followed by rows with such an entry in column *B*, and so on. In Figure 2.1(c) we see some sort of pattern beginning to emerge.

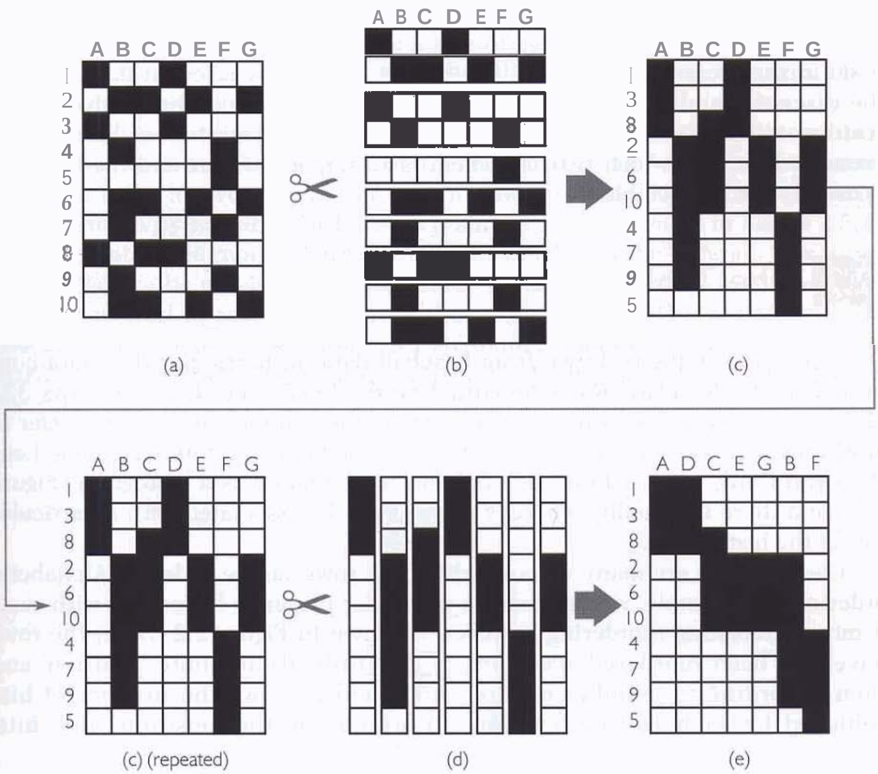


FIGURE 2.1 Rearrangement of data concerning the treatment of crops

If the same process is now repeated, starting with Figure 2.1(c) but with cuts (Figure 2.1(d)) to allow *columns* to be similarly rearranged, the result has the appearance of Figure 2.1(e). The same data is involved, but its presentation has changed: one can clearly perceive a pattern, showing that certain groups of treatments are appropriate to certain groupings of crops.'

It is at this point that the question 'OK, but what now?' may be asked. The most useful – as well as the most perceptive – answer was provided by Bertin (1981) who commented that:

> *A graphic* is no longer *'drawn' once and for all: it* is *'constructed' and reconstructed (manipulated) until all* the *relationships which* lie *within it have been perceived . . . a graphic is never an end in itself: it is a moment in the* process *of decision making.*

We have just seen, in Figure 2.1, one such 'reconstruction'. That there will typically be more is confirmed by Cleveland's (1985) comment that:

> *Graphing* data needs *to* be *iterative* because *we often* do *not know what to expect of the data; a graph can help* discover *unknown aspects* of the data, *and once* the unknown is *known, we frequently find ourselves formulating new questions about the data.*

I am most grateful to Bob Waddington for permission to use the material shown in Figure 2.1.

Thus, following inspection of Figure 2.1(e), a user – and especially a user in possession of domain knowledge (for example, a crop geneticist) – may decide upon further rearrangement or the addition of possibly relevant data. Here is the essence – and certainly quite often the excitement – of interactive visualization: a lively, iterative examination and interpretation of graphically presented data, in which rearrangement is an important part and the outcome is usually not predictable.[2]

2.2 The Table Lens

Our second example is drawn from baseball data, in particular that data contained in the Baseball Encyclopedia Update 1997. The data concerns 323 players, each associated with a row in a table; the columns of that table refer to attributes such as salary, position (in the baseball Field) and hits. The Table Lens (Rao and Card, 1994) allows each column to be viewed as a histogram (Figure 2.2), and there is a facility whereby a name can be associated with a particular row of the histograms.

Clearly there are many ways in which the rows can be ordered. Alphabetic ordering, for example, would enable a particular player to be located with ease. A more interesting reordering however, is shown in Figure 2.2. Here, the rows have first been reordered according to the (ordinal) attribute 'position' and then according to 'number of hits'. It therefore shows the number of hits achieved by each batting position. By examining the 'position' and 'hits'

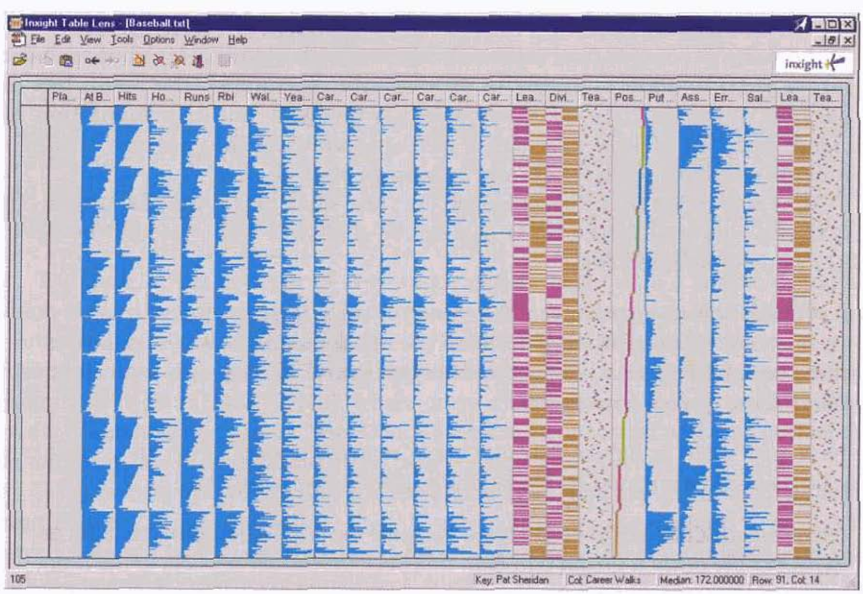


FIGURE 2.2 A Table Lens displaying baseball data

Source: *Inxight Software, Inc.*

2 Rearrangement, of course, is not always beneficial, as when a well-intentioned cleaner 'tidies up' one's desk (Malone, 1983)!

columns one can see that different batsmen in the same position are characterized by a range of batting skills. The Table Lens possesses the advantage, as far as ease of use is concerned, that it is based on a table, a concept with which most people are familiar.

We shall revisit the Table Lens again in Chapter 7 to identify additional beneficial features; in the context of rearrangement, however, an important question to be answered now is *how* the rows are reordered. The reordering action chosen by Rao and Card (1994) is simple, and illustrated in Figure 2.3(a): a movement of the mouse down the column which is to be ordered. The movement need not be precisely vertical. Another example of how a gesture with the mouse can lead to rearrangement is shown in Figure 2.3(b): a 'tick' with the mouse in the column associated with attribute B followed by a similar tick for attribute A triggers the generation of a new column containing a histogram of the values of *B/A*.

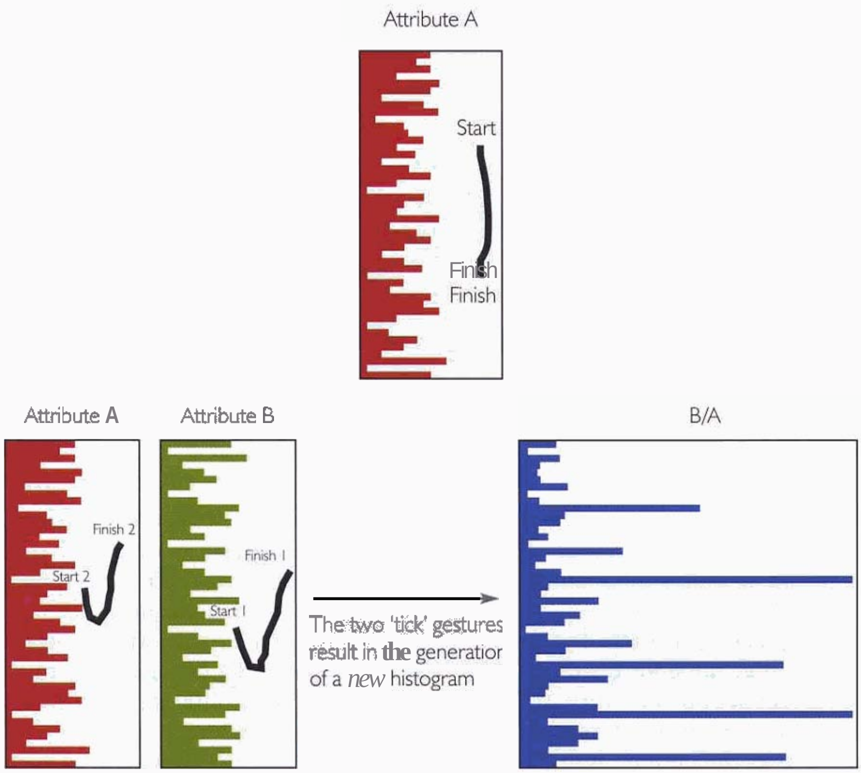


FIGURE 2.3
(a) Reordering of the entries in the Table Lens
(b) Calculation of a new column in the Table Lens

2.3 Affordances

The example of the Table Lens illustrates an important aspect of rearrangement to which the designer of an information visualization tool must give attention: it is called affordance. The concept is perhaps most effectively introduced by a physical example taken from Norman (1988) You are approaching a door through which you eventually want to pass. The door, and the manner in which it is secured to the wall, permits opening by pushing it from its 'closed' position. We say that the door affords (or allows, or is for) opening by pushing. On approaching that door (Figure 2.4) you observe a flat plate fixed to it at waist height on the 'non-hinge' side, and possibly some sticky fingermarks on its otherwise polished surface. You deduce – correctly in this case – that the door is meant to be pushed open: you therefore push on the plate, whereupon the door opens and you pass through. Here, there is a perceived affordance, triggered by the sight of the plate and the fingermarks, that is identical with the *actual* affordance. Note that the affordance we discuss is neither the door nor the plate: it is a *property* of the door ('the door affords opening by pushing').

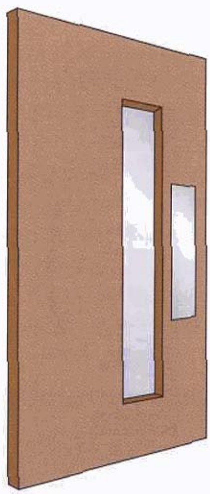


FIGURE 2.4 The door is perceived, correctly, to afford opening by pushing

You now have to proceed through a second door, and observe (Figure 2.5) that it has a handle, again at about waist height. Your interpretation is that you are meant to pull the handle towards you, thereby opening the door. Though a reasonable interpretation, it happens to be incorrect – the door does not move. You try pushing it instead, again to no avail. After some exploration you then discover that the door opens by sliding (it *affords* opening by sliding), and that the correct action is to 'turn' the handle and apply a horizontal force. In this situation the *perceived* affordance (that the door affords opening by pulling) is not the same as the *actual* affordance (the door affords opening by sliding). Clearly, designers of doors, and particularly their mechanisms and associated devices such as handles, will try to ensure that perceived and actual affordances are identical.[3] It is important to note from these simple examples that experience and convention influence one's perception of affordance.

[3] Those who are required quite frequently to stay in hotels may well wonder whether designers of shower controls are familiar with the difference between perceived and actual affordances.

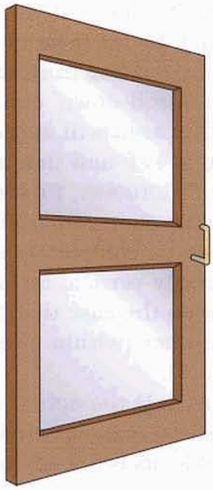


FIGURE 2.5
The door is perceived, incorrectly, to afford opening by pulling

In designing interactive displays to facilitate a beneficial rearrangement of the visual presentation of data, the same design objective is present: the designer should ensure, as far as possible, that perceived and actual affordances are identical. But that is not always easy to achieve. As an illustration we choose (Figure 2.6) the familiar scroll controls associated with a word-processing application. A 'mouse-down' on the control **A** (that is, anywhere within the rectangle containing the triangular arrow) will, for example, cause the contents of the display to scroll downwards until 'mouse-up' occurs. Thus, the *actual* affordance of scrolling must be deduced by the user. In this case the sensitive control icon **A** is chosen by the interaction designer with the expectation that the perceived affordance of scrolling will be identical to the actual affordance of scrolling. Nevertheless, the interaction designer will be aware that an understanding of the icon's function depends upon many factors including convention and how suggestive the icon is.

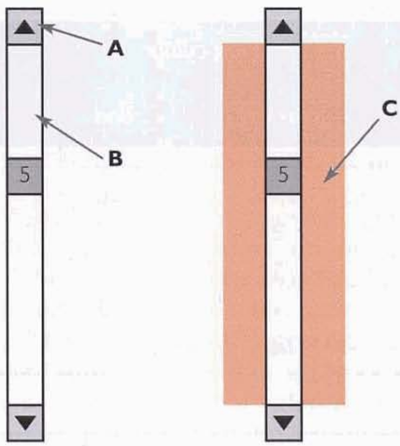


FIGURE 2.6
Scroll controls familiar from a word-processing application

In some cases a perceived affordance is difficult to formulate, sometimes because the relevant control may be far from obvious. An example is provided by area **B**, the rectangular area extending from the upper edge of the page indicator to the lower edge of the 'scroll-down' control. At a first glance it is not obvious if a mouse-click on this area will achieve anything at all. However, through exploration or training it is found that a mouse-click in B causes flipping to the extent of one page.[4] Moreover, prolonged mouse-down in B causes page flipping to continue at a convenient rate until terminated by a mouse-up.

Other controls may not even be completely externalized: to ease the user's task and avoid demanding precisely vertical movement of the cursor within the relatively thin scroll-bar, it is often the case that the mouse-down drag can deviate considerably from the scroll-bar (within area C) and yet be interpreted as being at the scroll-bar (Figure 2.6).

With the Table Lens (Figure **2.2**) the actual affordance is far from obvious and must be learned. Nevertheless, once learned, considerable insight into the underlying table of data is possible, as is fluency of use.

2.4 Hair and eyes: the Mosaic Display

The two illustrative rearrangements presented above – the crop treatments and the Table Lens – were intentionally simple, even though the Table Lens offers other useful functions which are discussed in Chapter 7. We now examine another example of rearrangement called the Mosaic Display (Hartigan and Kleiner, 1981, 1984; Unwin *et al.*, 1996; Unwin, 1999).

Once upon a time, as all interesting stories seem to begin, a lecturer in statistics (Snee, 1974) recorded, far each of his 592 students, the colour of the student's eyes and hair. The result is shown in Table **2.1**, from which little insight can immediately be gained. Instead, we consider (Figure **2.7**) a diagram

TABLE 2.1 Data concerning the hair and eye colour of 592 students

Eye colour	Hoir colour: Black	Brown	Red	Blond	Total
Brown	68	119	26	7	220
Blue	20	84	17	94	215
Hazel	15	54	14	10	93
Green	5	29	14	16	64
Total	108	286	71	127	592

[4] Except for the last line, to provide continuity

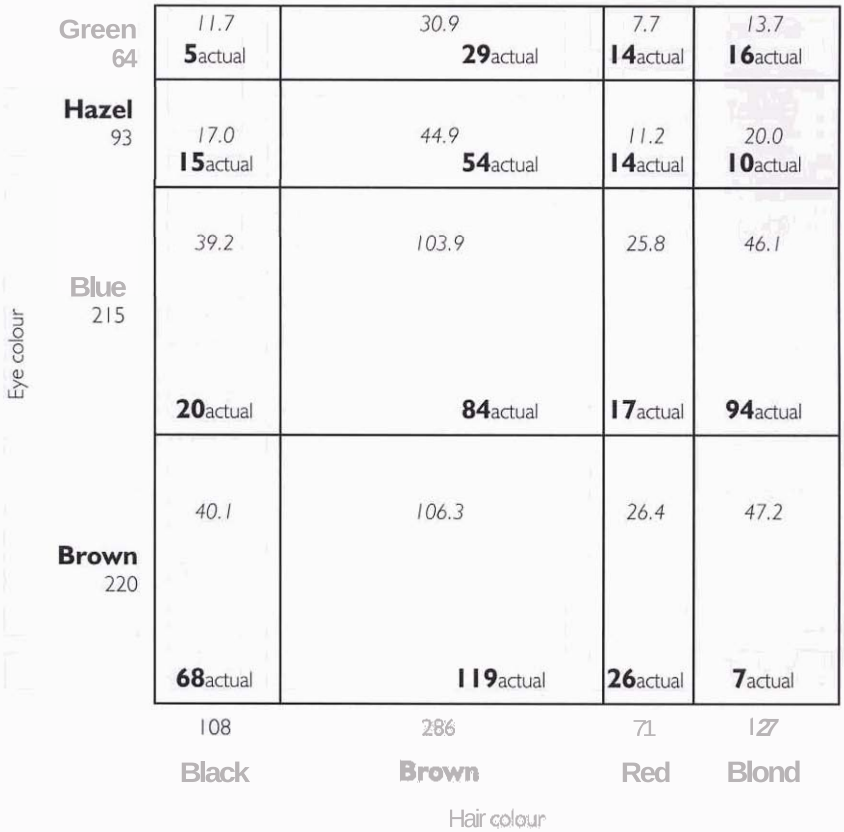
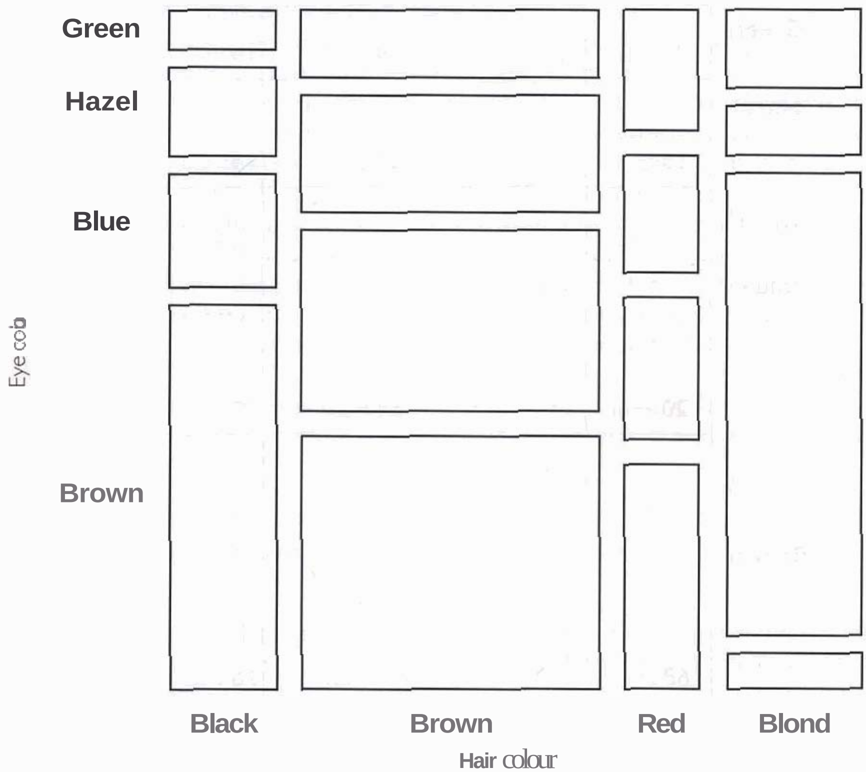


FIGURE 2.7 Diagram showing all combinations of eye and hair colouring

to be constructed so that each rectangle, of which there are 16 corresponding to all oombinations of eye and hair colour, has a height proportional to the number of students having a given eye colour, and a width proportional to the number of students having a given hair colour. Now suppose – incorrectly, as we shall see – that a person's eye color is independent of hair colour: the area of each of the 16 rectangles in Figure 2.7 (and indioated by the small *italic* Inscribed values) would then be a measure of the probability of occurrence of all combinations of eye and hair colour. In fact, these values are those probabilities multiplied by the total number of students, so that the total is 592, the number of students.

The inscribed numbers, however, do not correspond to the data in Table 2.1, because it transpires that eye and hair colour are not independent. The actual numbers, taken from Table 2.1, are shown bold and labeled **'actual'** in Figure 2.7, and are seen to be different and in many oases very different, from the 'independent' numbers. The areas of the 16 rectangles are therefore misleading. A simple modification of Figure 2.7 is all that is required to provide a far more informative presentation: in the absence of independence the so-called Mosaic Display of Figure 2.8, which is similar to a divided bar chart, can provide more insight (Hartigan and Kleiner, 1981, 1984; Friendly, 1994). Here, the width of

FIGURE 2.8
A Mosaic Display, with areas proportional to the actual numbers possessing various combinations of eye and hair colour



each 'tile' is still proportional to the relative occurrence of the four hair colours, but now the height is governed by the actual number of students with the appropriate eye colour. Unlike Figure 2.7, where equal heights indicate an assumed independence, the mosaic display of Figure 2.8 reflects the actual dependence and provides more insight. Certain tiles stand out: there are, for example, more blue-eyed blonds and brown-eyed black-haired people than would occur under independence. With the exception of the first and last rows, the rows are not aligned, which makes it harder to make comparisons within eye-colour groups. This drawback can be remedied by generating a new mosaic plot with the eye colours determining the widths and hair colours determining the heights.

Further rearrangement can be helpful. Figure 2.9 recognizes the deviation from independence between eye and hair colour Shades of red and green indicate the extent of the deviation from independence, and the ordering of the eye and hair colours (which, of course, are categorical and not ordinal variables) has been chosen to ensure that deviations from independence have an 'opposite-comer' pattern. Extensions of the mosaic display are treated in Chapter 3: the underlying concept is first introduced here to provide yet another example of the value of rearrangement.

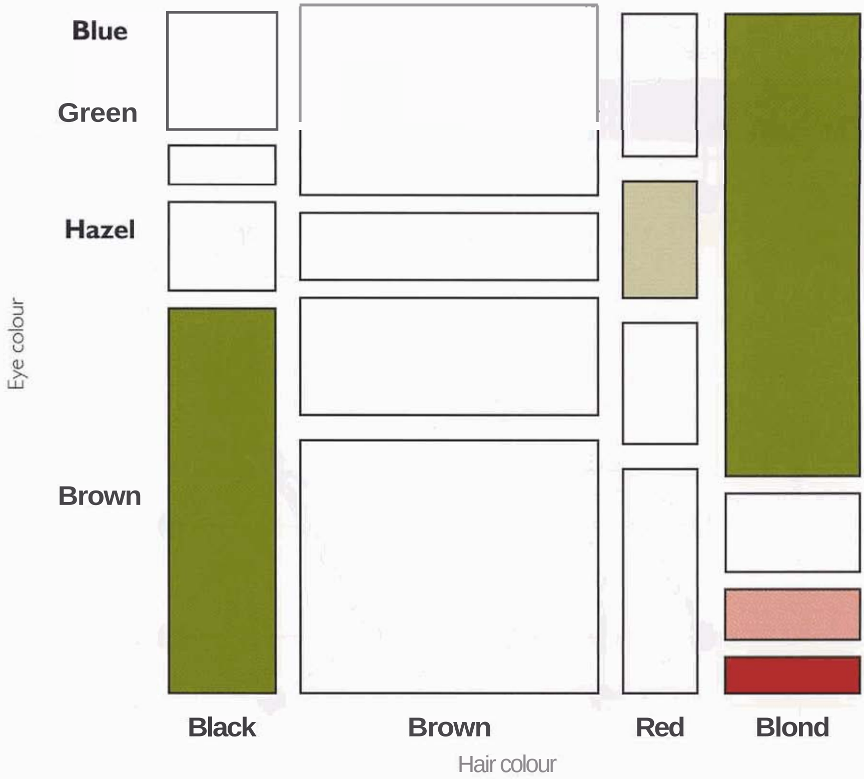


FIGURE 2.9 In the Mosaic Display, colour indicates the deviation from Independence

2.5 Network data

A dramatic benefit arising from the rearrangement of data can also be associated with 'network' or 'connectivity' data. Suppose that the telephone calls made and received by 13 people (labeled '*A*' to '*M*') during a specific period are recorded and presented in a table (Table 2.2). Even a careful study of Table 2.2 will typically fail to disclose any interesting pattern or features of interest. Even when represented in the form of a node-link graph (Figure 2.10) it is still not easy to discern a pattern in the same data.

However, if the data is processed in a very simple way to identify unconnected subgraphs, and represented by a node-link diagram (Figure 2.11), we begin to see interesting features. While their interpretation cannot at this stage be deduced it is clear that there are three distinct groups of telephone users between which no telephonic communication took place during the time period of the recording. If the duration and/or frequency of each call was additionally recorded, then the encoding of this information, for example by line width, could provide additional insight (Figure 2.12(a)); so also could colour-coding to represent the proportion of outgoing and incoming calls (Figure 2.12(b)).

TABLE 2.2 Telephone communication between 13 people

Originator	Receiver
A	H
C	L
I	M
B	E
F	H
G	I
I	B
B	M
K	B
G	B
K	E
C	J
D	C
F	A
J	L

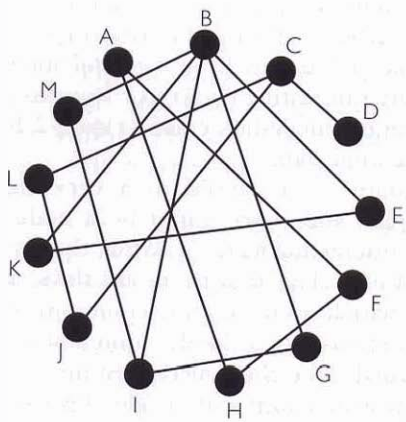


FIGURE 2.10 A node-link graph representing telephone communication between people

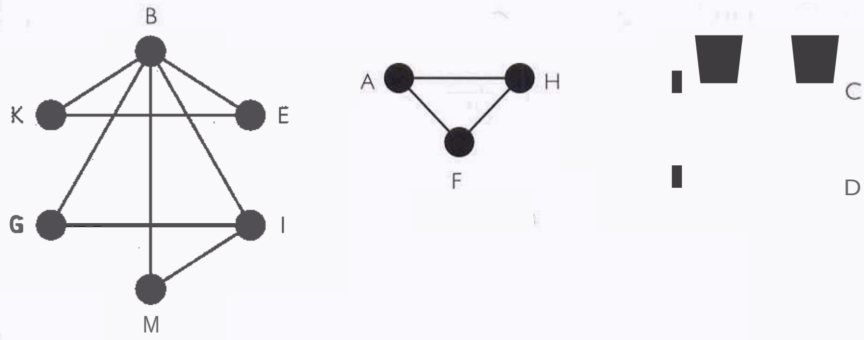


FIGURE 2.11 A rearrangement of the graph of Figure 2.10, identifying an interesting feature

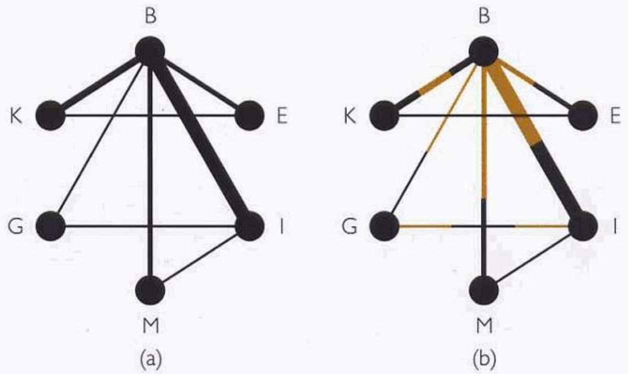


FIGURE 2.12 Methods of encoding parameters characterizing a link

2.6 Selective manipulation

The display of Figure 2.13 shows the geographic location of a supply distribution network for a relief effort in a large-scale crisis, as presented by the Selective Display and Manipulation (SDM) system (Chuah *et al.*, 1995). Supply centres are represented by cylinders, main routes between them by dark lines on the 'floor plane' and shelters where supplies are needed by rectangular bars. Heights indicate material quantities. Figure 2.13 might be regarded as a very 'busy' and cluttered display, attracting the comment that perhaps too much data is being presented concurrently, with the attendant danger of occlusion. On the other hand, it could be argued that one's interpretation of (say) the green items depends at times on the layout of the purple items, and that the display of only one type of item would lead to an impoverished display. A useful technique under these circumstances (Figure 2.14) is that of 'raising' the reference level for one class of item so that it can be examined in a clutter-free manner, though still within context. Shrinking the width of irrelevant bars is also possible, and can be helpful. A typical drawback of a three-dimensional presentation – the difficulty of comparing patterns, widths and heights that are at different 'distances' from the user – is overcome by allowing selected bars associated with a user-drawn reference line to be projected onto a two-dimensional presentation that allows comparisons to be made (Figure 2.15).

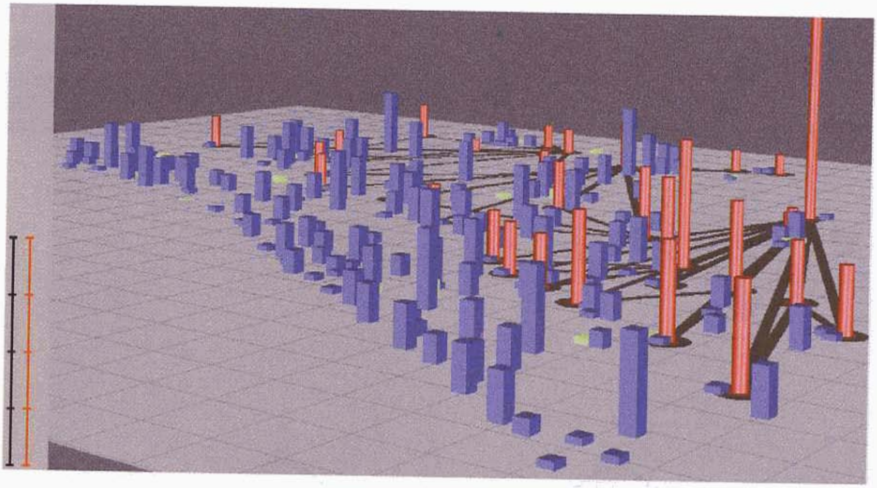


FIGURE 2.13 Display of the geographic location of a supply distribution network for a relief effort in a large-scale crisis

Source: *Chuah (1995), Chuah et al.* *© 1995 Association for Computing Machinery, Inc Reprinted by permission*

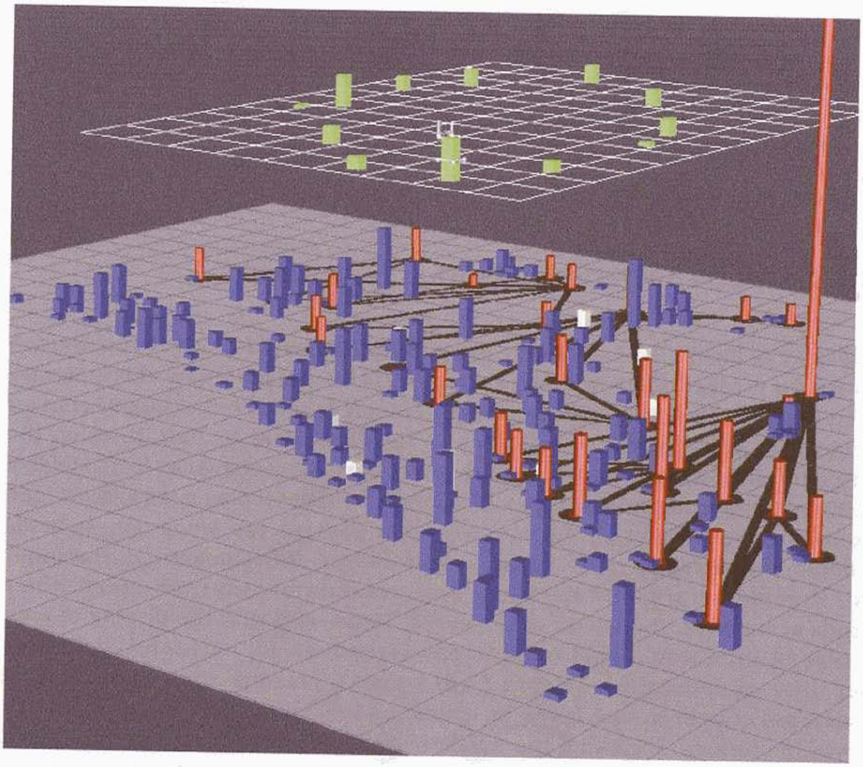


FIGURE 2.14 Raising a reference for one class of item allows that class to be examined more easily

Source: *Chuah (1995), Chuah et al.* *© 1995 Association for Computing Machinery, Inc Reprinted by permission*

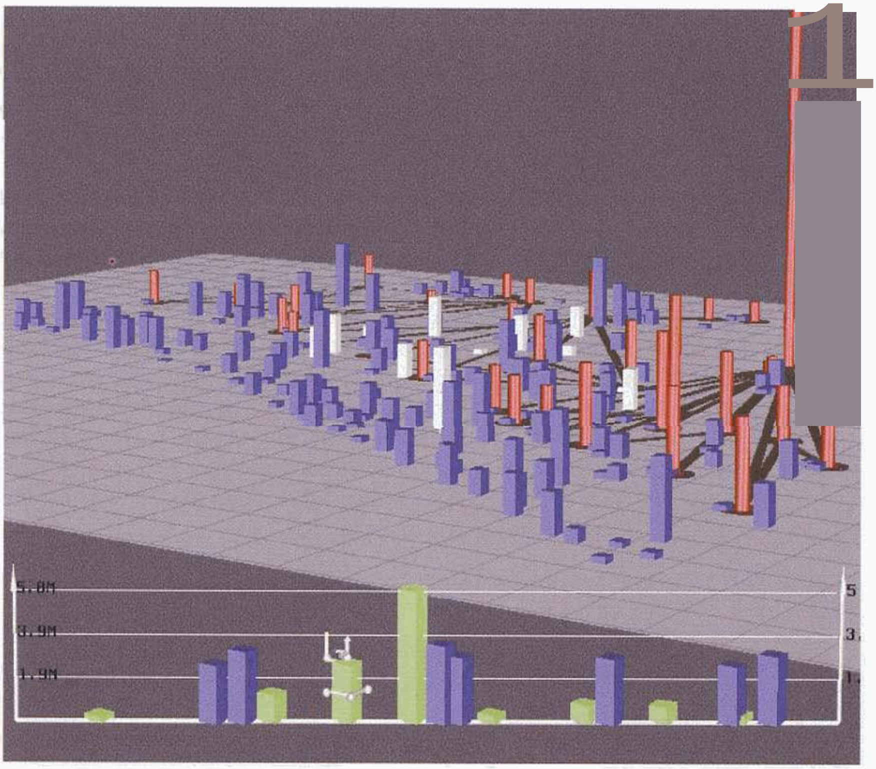


FIGURE 2.15 A reference line enables comparisons to be made

Source: *Chuah (1995), Chuah et al © 1995 Association for Computing Machinery, Inc Reprinted by permission*

2.7 Algorithms

Many visualization techniques are only made possible by algorithms of considerable complexity which operate upon available data. We choose for illustration an example that relates to a user's search among a collection of documents to identify one (or a group) which is partioularly appropriate to that user's interest.[5] Obviously the user does not want to have to read through a large number of documents – and especially those which are of little or no interest – to find the most interesting one; rather, they might be happy instead to supply either some keywords or an existing document known to characterize their interest to some degree and then, via an effective visualization tool, either discover a suitable document or be guided towards a revision of their query. Thus, as with other examples in this chapter, the same data is available but is selected, and its presentation rearranged, to suit the task being undertaken.

An underlying problem with searches for interesting documents is the huge amount of data required to characterize the word content of a single document. Words within a document will typically be examined to determine the frequency

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[5] A more detailed discussion of thii task is the subject of Chapter 10.

of their occurrence, often resulting in a collection (a 'vector') of thousands of numbers, each denoting the frequency of occurrence of a particular word. Comparison of that vector with keywords supplied by a user will enable the relevance of that document w be estimated. Fortunately, not only are algorithms available for carrying out such characterizations and comparisons, but others – also of considerable complexity – are available which can represent the documents in two-dimensional space on a conventional display. Frequently, this representation is so arranged that 'similar' documents are represented by points which are close together, whereas those with little in common are positioned far apart, and for these points w be displayed (Chalmers, 1993) in a landscape' presentation (Figure 2.16) which permits interactive interrogation. Chalmers *et al.* (1996) have proposed two features of a landscape presentation to aid search (Figure 2.17). One is w colour the area bounding those documents which are of interest, and the other, shown at the top of the display in the form of miniatures. is w display previous results and associated keywords; a visible trace of recent landscapes can be valuable in suggesting new or modified queries. In many visualization tools a visible record of earlier steps has often been found to be useful when a step-by-step approach to some goal is involved.

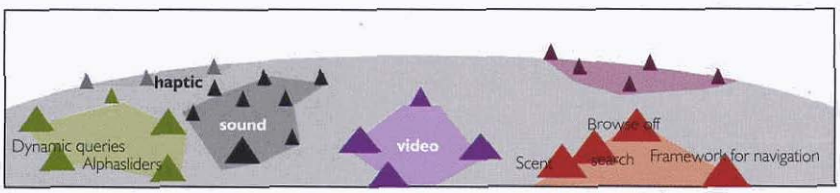

FIGURE 2.16
A landscape presentation of data about documents
Source: *After Matthew Chalmers*

2.8 The nature of rearrangement

Rearrangement can occur in different ways. In the Table Lens and other examples a new presentation appeared following a discrete command of some sort. But there is another class of useful rearrangement in which the display of data is dynamically rearranged. Two modes are of interest. In one, a smooth manually controlled rearrangement enables cause and effect to be displayed simultaneously, often to good effect. In the other mode, rearrangement is automated, leaving the user free to concentrate upon interpretation. We briefly examine these two modes of dynamic rearrangement.

2.8.1 Dynamic manual rearrangement

Insight into the relation between two or more quantities is often sought by the manual variation of one variable and concurrent observation of the consequent variation of one or more remaining variables. An example is provided by the activity of engineering design.

The design of a physical object, whether it be a radio or a kettle, is not a straightforward process but, as Chapter 9 will demonstrate in detail, is one that can benefit considerably from information visualization. Figure 2.18 shows part

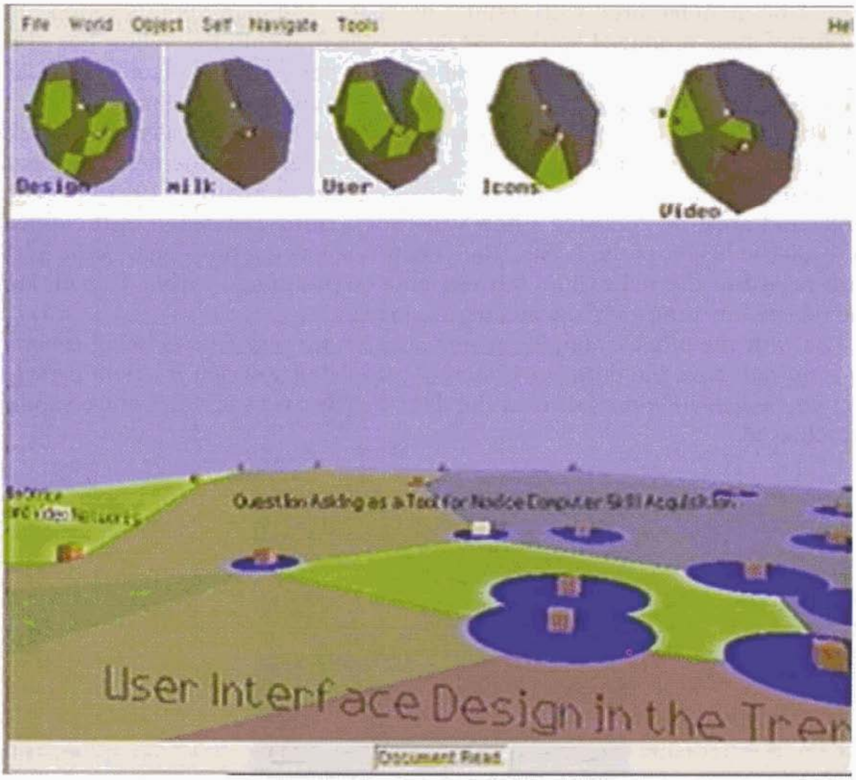

FIGURE 2.17
A visible trace of earlier steps in the examination of colour-coded landscapes

Source: *Matthew Chalmers*

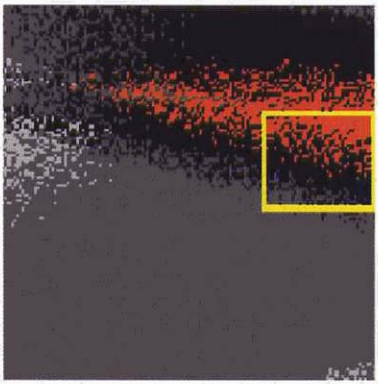

FIGURE 2.18
The red area of this display contains all acceptable designs of an artefact and the yellow box contains all the manufactured samples

of a display that can be of value to a designer. A point within the display area represents a design, since its projection onto the horizontal axis is one dimension of the object being designed (the base area of a kettle, for example), and its projection on the vertical axis is another – perhaps the thickness of the kettle. The red part of the display contains points (that is, designs) that satisfy the customer: one of the boundaries of the red region might correspond to the cost of manufacturing the kettle. But because a mass-produced object such as a kettle cannot be manufactured with infinite precision, the many points representing the many mass-produced kettles will lie *anywhere* within the yellow box. There is therefore much to be gained (especially 100 per cent manufacturing yield) if the yellow box can be made to lie completely within the red region.

The designer can easily move the box (in this case vertically) so that more designs lie within the red region. However, by exploration, the designer has discovered that the picture can be changed to that of Figure 2.19, to provide a larger red area, by choosing a new value for a third dimension of the object – perhaps the height of the kettle. The yellow box has not *only* been better placed with regard to the red region, but can now be positioned within a much larger red region, ensuring a high manufacturing yield.

As with the other examples in this chapter. no new data is being generated or acquired: here the designer is simply exercising a design freedom by selecting, for view, a different subset of the data, in this case such that more yield can be achieved.

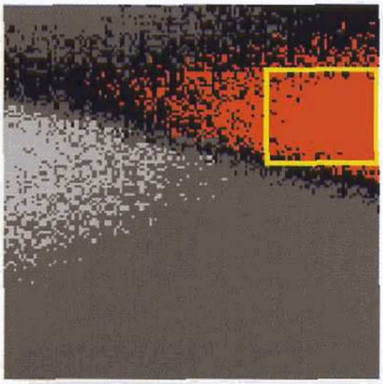

FIGURE 2.19
Alteration of the design leads to a greater area (red) in which acceptable designs can lie enabling the yellow box to be positioned to lead to a greater manufacturing yield

2.8.2 Dynamic automated rearrangement

Figure 2.20 is a display which shows the designer of an electronic circuit the extent to which each component within it affects the circuit's overall performance. Following the designer's sketch of the circuit diagram on a computer display (Figure 2.20(a)), the area of the circle superimposed[6] on a component's symbol (Figure 2.20(b)) provides an indication of the change in circuit performance that would result from a 1 per cent change in component value. This effect is termed 'sensitivity' and the circles are known as 'sensitivity circles' (Spence and Drew, 1971; Spence and Apperley, 1977). Such an indication of sensitivity can be immensely valuable to the designer.

However, if the circuit is a hifi, the designer is interested in the sensitivity to each component *over a range of frequencies* reaching from bass to treble, so that a static display, as in Figure 2.20(b), is of limited value. A simple solution to

[6] In the actual presentation the shape of the symbol can be discerned through the circle, thereby removing any doubt in the designer's mind about the nature of the component to which a circle refers.

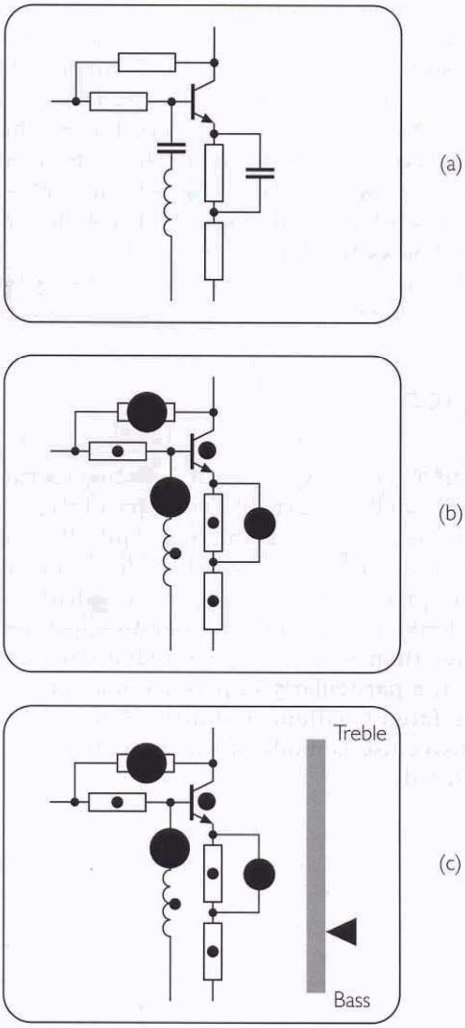

FIGURE 2.20
(a) Part of an electronic circuit diagram drawn on a computer display
(b) Circles provide a qualitative indication of the sensitivity of the circuit's performance to a change in

(c) A frequency indicator allows animation to display sensitivity as a function of frequency

the accommodation of an additional variable (frequency) is to employ animation: to change the size of the circles as the frequency is automatically varied over a range of interest (Figure 2.20(c)). As the frequency indicator on the right moves smoothly up and down the frequency scale between bass and treble limits, the circle sizes vary accordingly. A designer's observation of which circles are large or small at which parts of the frequency range can immensely enhance their understanding of the circuit. The scanning rate – in other words, the speed of animation – requires careful choice: if circle sizes change too rapidly the designer may fail to comprehend the meaning of the changing circles: too slow and the designer has difficulty in integrating what is seen on the display into a useful mental model. An animation period of about eight seconds was found by experience to be optimum.

For a particular electronic circuit the visualization tool shown in Figure 2.20 displayed a sudden, substantial but temporary increase in the size of two circles. This unexpected result was noticed with some surprise by the designer, but quickly recognized as an indication of 'resonance'. This phenomenon is perhaps more familiar from the example of the destructive oscillation of the Tacoma Narrows bridge, and is **equally** undesirable in an electronic amplifier: a hifi emitting a constant whistle does not lead to customer satisfaction! Here is an example of an animated rearrangement of data leading to *discovery*. Fortunately for the designer, the frequency on the **bass-to-treble** scale could also be adjusted *manually*, and the precise frequency of resonance read directly from a numerical display beside the frequency scale.

2.9 Conclusion

We have seen, from many examples, how interactive rearrangement of the way in which data is presented can provide an opportunity for additional insight into that data. We have examined **categorical** data (crops and treatments, eye and hair colour), numerical data (baseball statistics), topological data (telephone connections), **symbolic** representations (sensitivity circles and complex geographical operations) and **textual** data (landscapes), merely as representative examples rather than to establish an exhaustive categorization. Many other examples exist, a particularly impressive one having to do with the 'O'-ring disaster in the fated **Challenger** shuttle (Tufte, 1997). In the **chapters** which follow, extensive use is made of this potential, and many other examples will be encountered.