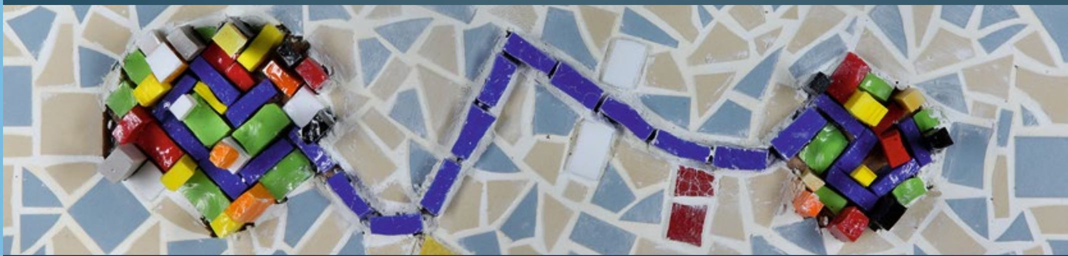
Robert Spence



Information Visualization

An Introduction

Third Edition

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An Introduction

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To Robert and Merin


for their love and support

Preface to Third Edition

Who Is the Book For?

Despite conventional – and misplaced – views about information visualization, this book is *not* targeted solely at computer science students: visualization basically has nothing to do with computer science[1] and is far too powerful and important to so many disciplines for it to be confined to such a small audience. Rather, the book is intended as an introduction to information visualization for first year (or later) students of *any* discipline, be it medicine, marketing, geology, security or demographics. Those students may be encountering the subject in their first university year or, following a Masters degree in any subject, they may be training to be visual and interaction designers. In fact, the book material has been extensively tested through presentation to many such students in the UK, The Netherlands, Portugal and elsewhere. For the same reason it does not attempt to bring you the latest results of research, though it remains topical and even looks ahead at what might be possible.

What's New?

In one sense, nothing. As in the second edition, the structure of the book can be represented by a 'Tube-like' model (Fig. P1) emphasizing three principal topics – representation, presentation and interaction – and reflecting the generally accepted 'reference model' of the information visualization process (Fig. P2). But the content of each of these principal chapters has undergone major revision.

[1]A provocative statement indeed, but one made (1) in full appreciation of the enormous benefits than can accrue from computation, and (2) to emphasise that visualization is essentially – and by definition – the formation of a mental model of something.

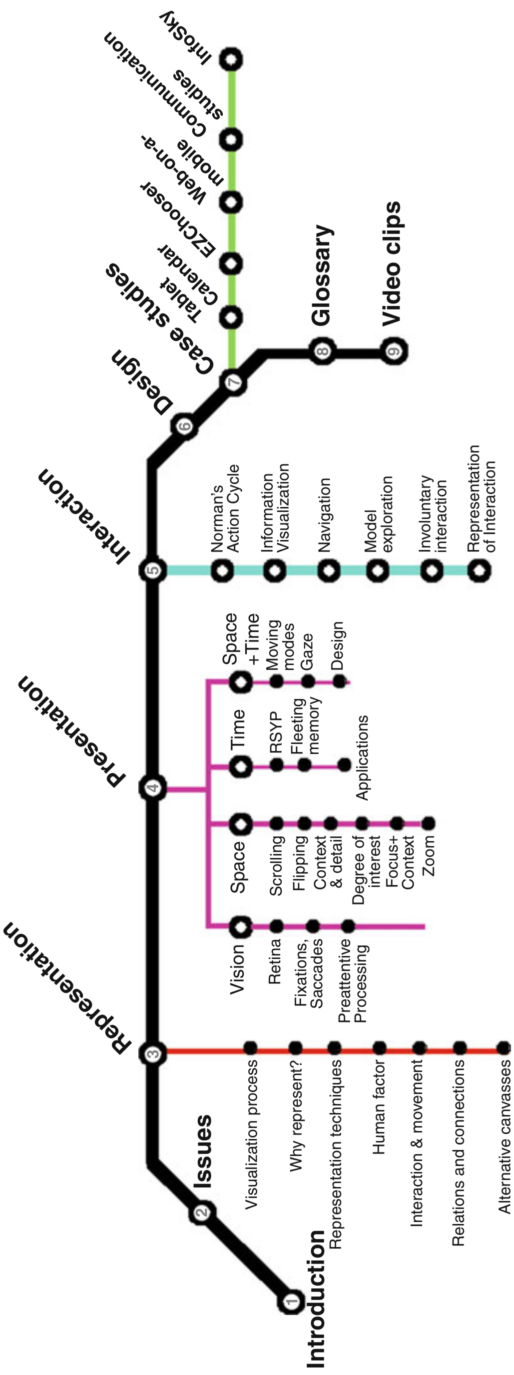

Fig. P1 The structure of the book

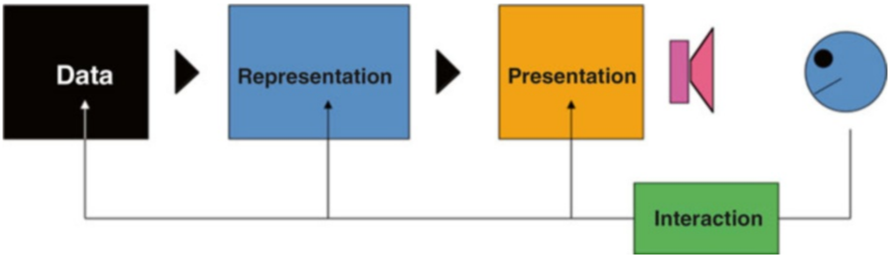

Fig. P2 The reference model of the information visualization process. The representation, presentation and interaction processes are the subjects of the principal Chaps. 3, 4 and 5 of the book. Consideration of the human user, pictured at *right*, proceeds throughout the book

The material on representation has been given a structure that will hopefully lead to better understanding. Presentation has been addressed by recognising three principal resources available to the designer: the human visual system, the constraints and freedoms associated with display space, and considerations of the time allocated to a task. The chapter on interaction has been completely rewritten. Although many researchers are seeking a science of interaction they have not yet found it, so I have adopted Norman's Cycle of Interaction for the powerful structure and guidance that it offers to those who have to design interactive systems.

Human Performance

Many visualization tools are proposed without much, if any, recognition of the fact that they are basically there to support a human activity – the formation of a mental model of something (i.e., visualization) or, put another way, making sense of data. What I have tried to do is distil, from the vast existing (and incomplete) knowledge of human perception and cognition, those aspects that are principally relevant to a user's attempts to form a mental model of some data. And I have tried to illustrate by practical examples *why* that distilled knowledge is relevant.

Creative Design

Two beliefs direct my teaching and are reflected in the book. First, I believe that the best way to gain an understanding of human-computer interaction, and information visualization in particular, is to *do it*. I decline to set end-of-term examination papers; I feel it is far more effective pedagogically to ask my students to undertake design exercises of varying complexity, ending with a substantial group project. Second, I focus on creative design, and certainly not on implementation: you will find no exercises beginning "Write a program for . . . ". Consistent with these ideals I try to place my design projects in a realistic setting. Thus, the group project that terminates a course treats each small group of students as a design consultancy working on a commission from a client, ending with an oral and written presentation to that client. The enthusiasm generated by this opportunity to be creative and imaginative is apparent from the feedback I receive.

Teaching Resources

For many years I have made the powerpoint files and other materials I employ in my teaching freely available to teachers, and will continue to do so (just contact me at r.spence@imperial.ac.uk).

Visual Analytics

Experts in information visualization will no doubt wonder how I have addressed the "new" topic of visual analytics. I haven't or, rather, I have briefly discussed the *context* of information visualization in Chap. 1 (Introduction) and provided two illustrative examples of what would be termed visual analytics. There is one principal reason: the book is intended as an *introduction* to information visualization, and there is plenty of material to absorb and experience, in a typical course, with just that single end in view. In any case, I am sure that a competent instructor will be able, if they wish, to introduce a flavour of visual analytics, perhaps without even mentioning it by name. Certainly, following an introductory course on information visualization there are many pedagogical paths that would introduce visual analytics, but it is certainly not for me to prescribe one that should be followed.

London, UK
June 2014

Bob Spence

Acknowledgements

The development of this third edition has, like that of the first two, benefited immensely from interaction with my students, and to them I am most grateful. They include those graduates of many disciplines (20 each year for 14 years) who chose to become professional interaction designers and attended my course at the Technical University of Eindhoven in The Netherlands. They also include my first-year students at Imperial College London. And they now include students studying for a number of postgraduate options at the University of Madeira, Portugal. I wish I could list you all by name – but then you know who you are.

I have also benefitted from careful reviews of parts of the book, reviews that have led to what I believe to be improvements. For this I am most grateful to Randy Goebel (Calgary, Canada), Harri Siirtola (Tampere, Finland), Mark Apperley (Hamilton, New Zealand) and Mark Witkowski (London, England).

There are many others who have made valuable contributions and have influenced my thinking about information visualization in many different ways. They include Dr. Brock Craft (who also took the photo of Jacques Bertin), Oscar de Bruijn, Jeremy Pitt, Kent Wittenberg, Par-Anders Andersson, Sheelagh Carpendale, Joost de Folter, Tim Cribbens, James Mardell, Ravinder Bhogal, Andrew Spence, Robert Michael Spence, Petr Kosnar and Ollie Ford.

Work on many aspects of the book was facilitated by the Award of a Leverhulme Emeritus Fellowship for which I am most grateful. It is also my great good fortune that my research and writing was carried out in the congenial and stimulating environment of the Department of Electrical and Electronic Engineering at Imperial College London.

I could not wish for a more supportive and efficient Editor than Beverley Ford who seemed to respond to queries within milliseconds. She and James Robinson guided me expertly through the process of getting this book published, and my grateful thanks goes to both of them.

Writing a book can lead to one becoming a somewhat unsociable character at times, and the forbearance of those around me is therefore much appreciated. Again, they know who they are!

London, UK Bob Spence
June 2014

Contents

Chapter 1
Introduction

A good way to introduce an unfamiliar discipline is to show how it can help you to perform a useful and familiar task.

1.1 Home Finding

Let's suppose that your job has been relocated to an unfamiliar city, and that you must find a home for yourself and your family. That is a formidable task, made especially demanding because you are looking for a *home*, not just a house. Traffic noise, school locations, average income, shopping facilities and the general environment can be just as important as the price of a house.

For a start you will probably drive (Fig. 1.1) around different areas of the city to get a first impression of its different sectors. You might also glance at specialist newspaper reports (Fig. 1.2) to get a feeling for where an acceptable home might be found; you will visit one or more estate agents (Fig. 1.3) to get some sense of property prices; and recommendations from friends might give you some awareness of desirable locations.

What are you doing? You are not yet buying a house. Rather, you are gaining impressions; you are getting feelings about desirable locations; you are acquiring some sense of prices and you are forming an awareness about desirable locations. You are, in fact, putting together a 'mental picture' of the city and its housing. But to avoid using so many different terms like '*impressions*', '*sense*', '*feelings*' and '*awareness*' we use a single term, *visualization*, because the dictionary defines visualization as:

visualization: the activity of forming a mental model of something

And that is what you are currently doing. Specifically you are indulging in **information visualization**, because what is relevant to your search is information in the form of images of houses, their prices and the multi-faceted nature of different parts

R. Spence, *Information Visualization*, DOI 10.1007/978-3-319-07341-5_1

Fig. 1.1 The view from a car can provide some impression of a section of a city

Fig. 1.2 Newspaper adverts are a source of house information

of the city. Indeed, you are visualizing information right up to the point when you finally choose a house to buy. What helps you to build your mental model is sight of the various items shown in Figs. 1.1, 1.2 and 1.3 together, perhaps, with recommendations from friends.

It is essential to note that, so far, the word 'computer' has not appeared. That is because visualization is, by definition (above), a *human* activity and, basically, *has nothing at all to do with computers*, notwithstanding the fact that visualization can be enhanced immensely through computational support. To emphasise that information visualization is basically a human activity let us briefly put aside your search for a house and look for a moment at some brief examples of information visualization dating back at least 100 years. But if you're not interested in history for the moment go immediately to Sect. 1.3.

Fig. 1.3 Displays in an estate agent's window provide some feel for house appearance and price

1.2 History

1.2.1 Florence Nightingale

Florence Nightingale (Fig. 1.4) is known for two achievements. What is well known is her introduction of very significant improvements in the performance of military hospitals in Scutari during the Crimean War of 1853–1856. The report (Nightingale

Fig. 1.4 Florence Nightingale

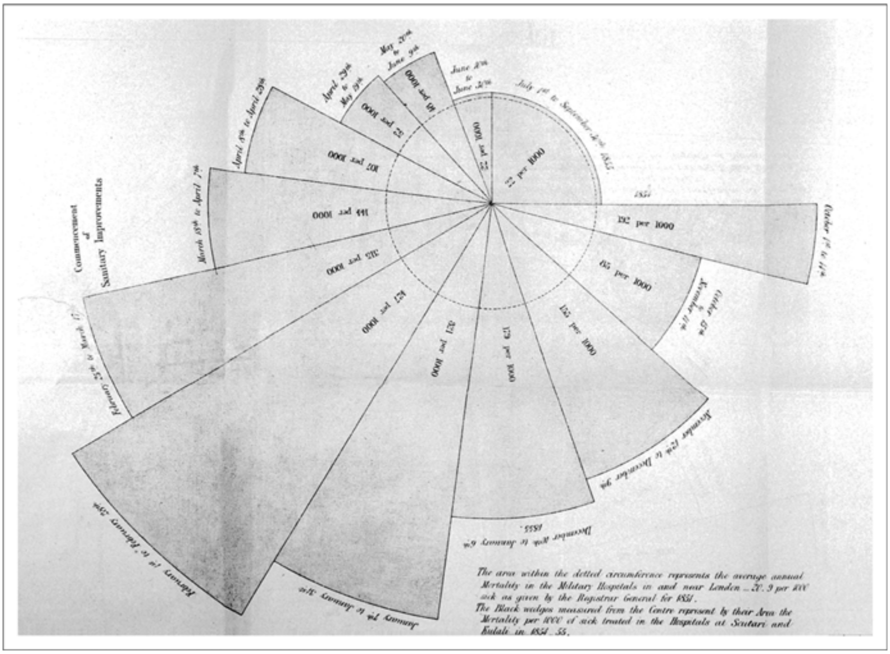

Fig. 1.5 Florence Nightingale's 'Rose diagram' showing the reduction in the number of deaths in military hospitals in Scutari arising from the changes she instituted

1858) she wrote for the British government is not so well known unless you are interested in information visualization. Why? Because, contained within that report is a remarkable figure (Fig. 1.5) whose essential feature is shown, for clarity, in the sketch of Fig. 1.6. If one is told that the number of deaths in the hospitals in a given month is proportional to the area of the segment associated with that month, the improvements that Nightingale achieved over time are immediately obvious and impressive. One look at that figure immediately creates a mental model; one,

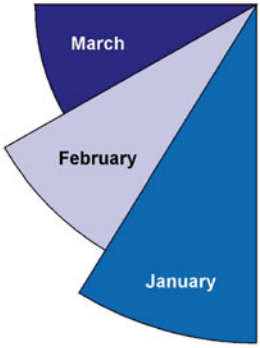

Fig. 1.6 The basis of Nightingale's 'rose diagram'. The area of each monthly segment is proportional to the number of hospital deaths

moreover, that you could access to produce a sketch during conversation with a friend. You have just engaged in information visualization even though you didn't perhaps plan to!

1.2.2 Travelling on the Tube

In 1931, after concluding that the then current map of the London Underground (Fig. 1.7) left something to be desired, Harry Beck (Garland 1994) created a new map (Fig. 1.8). It describes the same transportation network, but is laid out like an electrical circuit

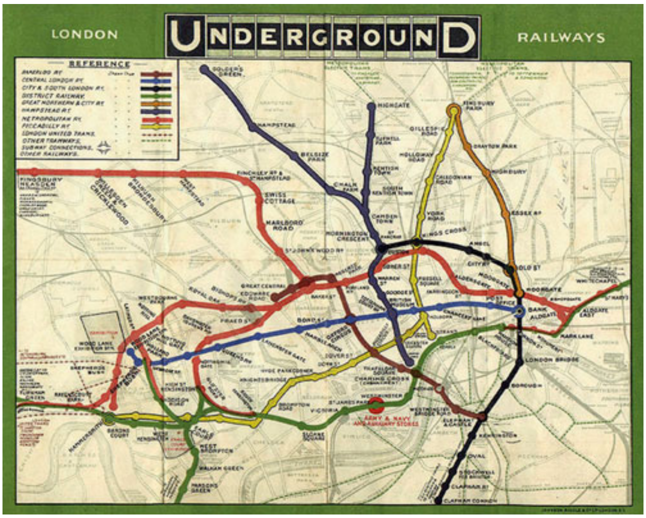

Fig. 1.7 The map of the London Underground in use before the introduction of Harry Beck's new map shown in Fig. 1.8

Fig. 1.8 Harry Beck's new (1931) map of the London Underground

Fig. 1.9 Accessing a mental model of the London Underground

diagram and does not try to retain geographic accuracy.[1] London Underground was at first very sceptical about the new map but the rest, as they say, is history: there has been no fundamental change in the 'Tube Map' for 80 years and most transportation authorities around the world adopt the same approach (Ovenden 2003). I have been working in London for some time, necessarily often encountering the Tube Map, and in that time have formed a reasonably accurate mental model of parts of it. So if a tourist asks "How do I get to Harrods?" I do not search for a map: I access my mental model (Fig. 1.9) and say "Go west on the red line, change to the blue line and go south to Knightsbridge". I do not need a map – I simply refer to the relevant part of my mental map.

[1]As Bill Bryson (1998) remarks, "Beck realized that when you are underground it doesn't matter where you are".

1.2.3 *Napoleon's March to Moscow*

Another classic in the field of information visualization is provided by Napoleon's mapmaker, a Monsieur Minard, who represented Napoleon's march East to Moscow, and his retreat West, in a diagram whose interpretation presents few if any problems (Fig. 1.10). One usually guesses –correctly – that the width of a line is proportional to the number of soldiers left in the army as the campaign progressed, a number that was probably affected more by disease than by bullets or swords, and not helped by the (indicated) very low temperatures experienced during the retreat. It is also not difficult to guess, correctly, that the brown line refers to the advance and the black line to the retreat. And like most useful representations, it poses new questions. "Did thin ice on the Berezina River cause the huge loss of soldiers, or did they just (understandably!) desert?"; "What caused a significant number to head North just after marching a few miles towards Moscow?".[2]

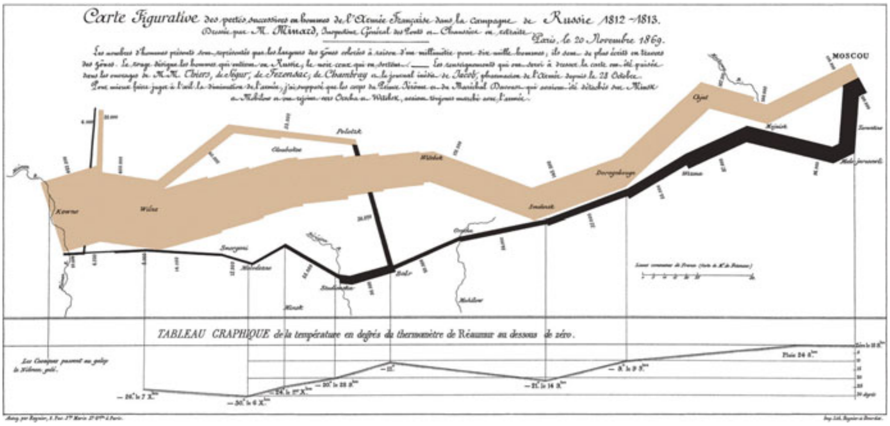

Fig. 1.10 Minard's map showing the march of Napoleon's army towards Moscow, and its retreat

1.2.4 *Cholera*

We briefly visit just one more historical example, but one that introduces techniques that, like those of Nightingale, Beck and Minard, are still extremely relevant today, whether or not computation is involved.

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[2] One hopes that Minard's map was not intended as a recruitment poster!

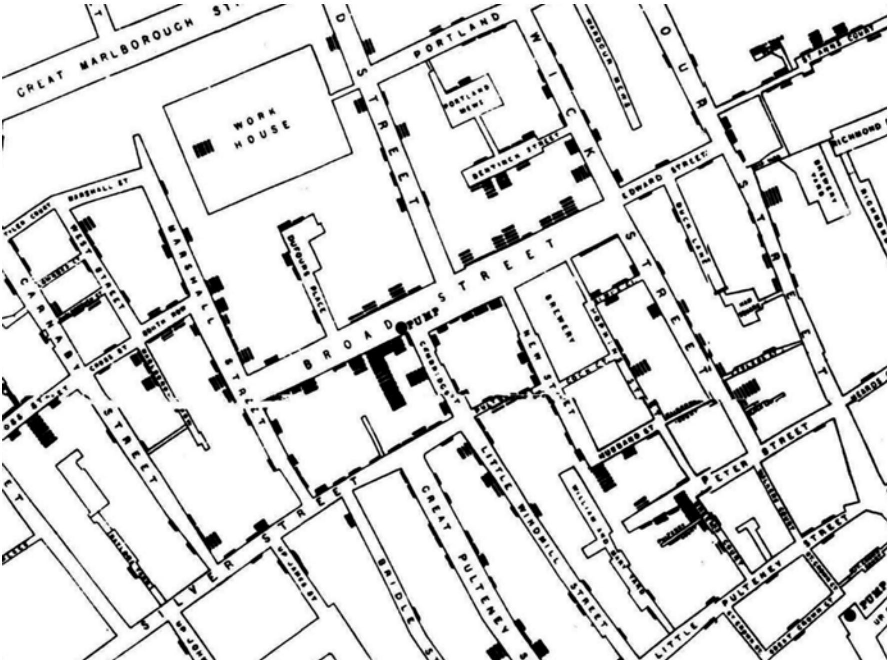

Fig. 1.11 An 1845 map of London's Soho district showing, by bars, deaths from cholera and, by points, the location of water pumps (*Drawn by Snow*)

John Snow was a very clever Medical Officer of London. And he had a theory - that the deadly disease called cholera was water borne (Snow 1852). But the medical establishment of the day disagreed. However, Snow got his opportunity to persuade the authorities otherwise during the cholera epidemic of 1854. He produced a map (Fig. 1.11) of the affected area (Soho, in London), on which each death from cholera is represented by a bar. He noticed that the deaths were clustered around the Broad Street pump from which many residents obtained their drinking water. After a lock was placed on the Broad Street pump the deaths from cholera diminished.[3] If more persuasion was needed that cholera was water-borne, Snow also produced the map shown in Fig. 1.12 in which he drew a dotted loop: if you lived within that loop your nearest water pump was the Broad Street pump, whereas if you lived outside it some other water pump was nearest. Most of the deaths from cholera occurred within the loop, supporting Snow's theory. Although cholera has disappeared from Soho (at least at the time of writing), Snow is celebrated by a pub (Fig. 1.13) located in what has inexplicably been renamed Broadwick Street.

[3] Low death rates in the area containing a brewery have led to speculation about the liquids consumed in that region.

Fig. 1.12 The *dotted boundary* in one of Snow's maps includes those households whose nearest source of water is the Broad street pump (*Drawn by Snow*)

Fig. 1.13 A London pub named after John Snow

1.3 Back to Home Finding

The examples of the previous section have been presented for two major reasons: first, to emphasise the fact that information visualization is something carried out by a human being. Second, to show that a view of an appropriate representation of data (e.g., house appearance, house price) is crucial to the formation of one's mental model.

Intentionally, the introduction has so far considered only static representations of data – present-day examples in Figs. 1.1, 1.2 and 1.3 as well as the historical illustrations provided by Nightingale, Beck, Minard and Snow – and for very good reason: the content one encounters in newspapers, magazines, books and official documents employs static representations of data, and usually to very good effect.

Nevertheless, computational power can immensely enhance the activity of information visualization, and in many ways. To provide an illustration of the ability of digital representations of data to support the formation of a mental model we now return briefly to the home-finding task.

A family with children might understandably be interested in identifying those parts of a city where a high percentage of houses are home to children. If that family is relocating to Rotterdam in The Netherlands the display of Fig. 1.14 would be particularly helpful since, following a menu selection, the city map has colour-coding superimposed to show the relevant percentages. Another attribute that may be of interest, and can be selected from a menu, is the monthly salary per person, resulting in the display of Fig. 1.15.

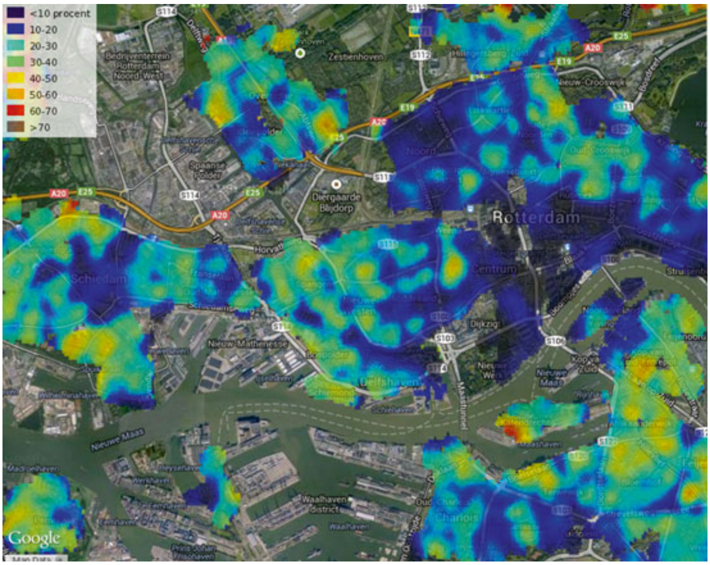

Fig. 1.14 A map of the city of Rotterdam with superimposed colour-coding showing the percentage of houses that are home to children (*Source:* http://www.nrc.nl/nieuws/2012/02/14/statistiek-saai-cbs-cijfers-komen-tot-leven-op-een-kaart/)

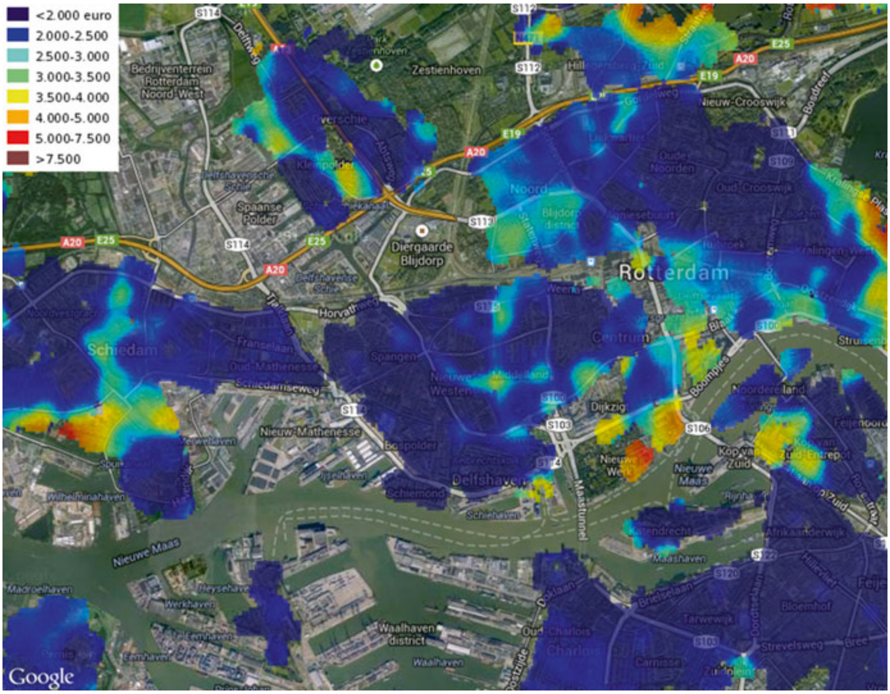

Fig. 1.15 Monthly income distribution in the city of Rotterdam (*Source:* http://www.nrc.nl/nieuws/2012/02/14/statistiek-saai-cbs-cijfers-komen-tot-leven-op-een-kaart/)

Reference to the illustrations of Figs. 1.14 and 1.15 provides an opportunity to discuss two terms related to information visualization. What is provided by the interfaces shown in those figures is a *visualization tool*, a term we shall use frequently in the book. But what is *seen* in those two figures are not 'visualizations' – they are not mental models – even though that term is in common use. We prefer to use the term 'representations' since their *raison d'etre* is support of the act of visualization *in the mind of a user*.

There are many other ways in which computational support can be helpful. For this introduction just one will suffice. Figure 1.16a shows the result of an experiment in which ten crops all received seven different treatments (e.g., spraying, fertilizers): a black square indicates that the treatment was beneficial, and a white square that it was not. It is difficult if not impossible to gain any understanding from that representation. However, if the rows and columns are automatically rearranged as in Fig. 1.16b the situation is transformed: it is immediately obvious that certain groups of crops benefit from certain groups of treatments. And it would almost certainly have done what many successful representations do, and that is to trigger questions: "What do the crops 2, 6 and 10 have in common?" and "Are treatments C, E, G and B similar in any respect?" (Siirtola and Makinen 2005).

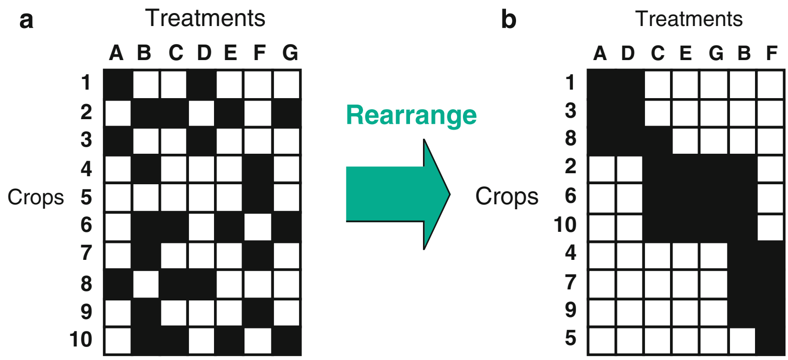

Fig. 1.16 An example of a simple rearrangement of the representation of data that can lead to insight (*Courtesy Bob Waddington*)

There are, of course, a countless number of examples where computational support has benefitted the process of visualization, and many are discussed later in this book.

1.4 Is Information Visualization Worthwhile?

Although the examples illustrated above may appear fascinating, it is nevertheless useful to have some hard evidence of the benefits that can accrue from information visualization. We provide three such examples.

1.4.1 Mortgage Fraud

The Serious Fraud Office of the United Kingdom spent eight person-years examining 48 file drawers of paper-based data in order to identify the perpetrator of a suspected building society fraud (Davidson 1993). As a result an alleged perpetrator was identified, sent for trial and judged guilty. The same task was then set to a single investigator who was provided with a visualization tool with which to access and view the same data. The same perpetrator was identified within 4 weeks, a time improvement of about 100 times. But that was not all: within the same time frame the master criminal behind the perpetrator was additionally identified. The fascinating aspect of this story is that the manner in which the data was displayed (Fig. 1.17) was extremely simple and based on straight lines (see Chap. 3, Sect. 3.6.1).

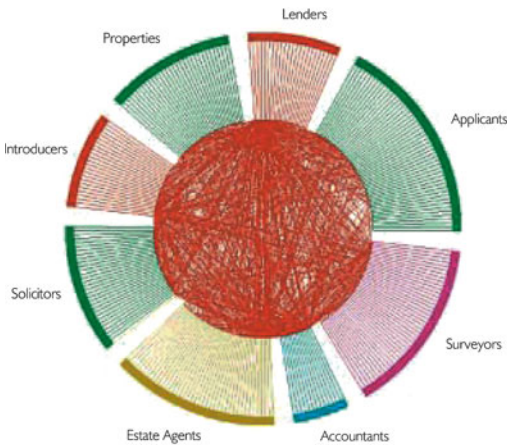

Fig. 1.17 Initial appearance of the visualization tool involved in a mortgage fraud investigation. More detail is given in Chap. 3, Sect. 3.6.1

1.4.2 *Drug Design*

Speaking to Fortune magazine, Sheldon Ort remarked that:

> Eli Lilley has 1500 Scientists using an advanced information visualization tool (Spotfire) for decision making. With its ability to represent multiple sources of information and interactively change your view, it's helpful for homing in on specific molecules and deciding whether we should be doing further testing on them.

An illustration taken from the Spotfire visualization tool is shown in Fig. 1.18.

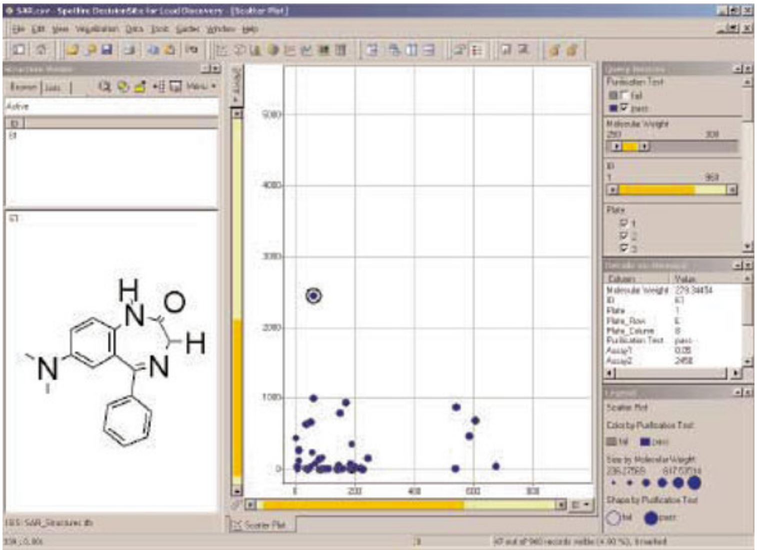

Fig. 1.18 A view of data provided by the Spotfire visualization tool. A property 'ID' is plotted against 'Assay 1'. Colour and shape both encode the passing or failure of a purification test, and size encodes molecular weight. The identification of one compound reveals its molecular structure (© *Tibco Software Inc. Used by permission*)

1.4.3 Silicon Chips

For a major company involved in the manufacture of silicon chips an article in Fortune magazine commented upon the benefits of information visualization[4]:

> Texas Instruments manufactures microprocessors on silicon wafers that are routed through 400 steps in many weeks. This process is monitored, gathering 140,000 pieces of information about each wafer. Somewhere in that heap of data can be warnings about things going wrong. Detect a bug early before bad chips are made.

1.5 Why Do We Need a Book About Information Visualization?

The need for a book about information visualization arises from the fact that many of us – professionals as well as amateurs[5] – must at times act as a visual designer. You have already met four visual designers – Nightingale, Minard, Snow and Beck – and a glance inside your morning newspaper will almost certainly reveal a contemporary designer who is taking data and transforming it into a picture in order to enhance your understanding of a topical news item.

1.5.1 Variables

In the home-finding illustration of Sect. 1.1 it was the *sight* of house images, prices and map locations that helped a user to form and gradually refine a mental model. The ease with which a mental model can be formed is therefore heavily influenced by how data is encoded in an image: and that choice is made, for better or worse, by a visual designer. Sometimes there is a single and vital piece of data that must be communicated, as with Florence Nightingale's hospital improvements which she wisely did not obscure with other data. But usually the data consists of many variables, each of different (and possibly time-varying) importance, as when choosing a car to buy: it would be unusual for the purchaser of a car not to be concerned with horse-power, miles per gallon, acceleration, price and other attributes (including colour!). So there is often a *multi-dimensional* challenge to be faced when deciding

[4] The letters v-i-s-u-a-l in visualization can be misleading. Data can be encoded in sound, touch and smell as well as images with a view to leading to a mental model.

[5] The task of encoding data in a picture is not only faced, for example, in the design of a web page, but in many other activities such as the production of a church newsletter or a school pamphlet.

how to encode data in pictures, almost always calling for a creative act on the part of a visual designer.

1.5.2 Canvasses

But the number of dimensions is about to grow! The choice of a data-to-image transformation is further complicated by the fact that different technologies can provide different 'canvasses'; paper and LCD displays are familiar examples. Some may constrain the visual designer in view of limited display area (e.g., tablets) while others, such as a wall display, may provide valuable degrees of freedom. And because the final chosen representation could be static, animated or interactive the visual designer may have to additionally adopt the mantle of interaction designer. Again, creativity will play a large part in the success with which the underlying data is understood by a user.

1.5.3 Tasks

If a further challenge to the creativity of a visual/interaction designer must be identified a major one is provided by the variety of tasks that a mental model may be called upon to support. A single task might be easy to address, but usually the achievement of a goal requires a number of subtasks to be performed, sometimes in unpredictable order. When searching for a home, for example, the activities of exploration, search, attention to detail, and the suppression of unwanted data will each be influenced by the manner in which data is transformed into pictures.

1.5.4 Perception and Cognition

Because visualization is a human activity, our designer must also be aware of those characteristics of a human being that are relevant. Especially when data is transformed into images, the human visual system becomes of paramount importance. Therefore, at appropriate points in the remainder of this book relevant aspects of the human visual system will be discussed. Some are beneficial, some are surprising and non-intuitive, and many present limitations for which the designer must find a solution.

Whereas our understanding of visual perception is far from complete, that of human cognition is even less so. Some aspects of memory, for example, have received experimental investigation, sufficiently so for the results to be directly applicable to the design of a visualization tool, but other cognitive processes such as the formation of a mental model remain the subject of research.

1.5.5 The Design Challenge

As pointed out above, the issues requiring attention by the visual/interaction designer are many. Unfortunately, as Goebel (2014) has pointed out, *there is no existing theory of visualization* which can be used to guide the decisions about how to compress large data sets and transform them into pictures. That is why a book on information visualization is needed: first to identify issues (Chap. 2), then to illustrate possible data representations (Chap. 3) and their presentation in space and time (Chap. 4) and, finally, to provide a framework to support the design of interactive tools (Chap. 5). Hopefully this material will begin, with practice, to encourage the design of effective systems to support visualization. Bear in mind, however, that what follows is not a "How to" prescription but rather a "Why should I?" explanation.

If the tasks of visual and interaction design appear daunting, take encouragement and inspiration as well as caution from the remarks of Stu Card (2012):

> The purpose of information visualization is to amplify cognitive performance, not just create interesting pictures. *Information visualization should do for the mind what automobiles do for the feet*.

1.5.6 Context

Information visualization is usually not the only activity carried out by the user of an interactive system. Even in applications where it is a major concern, other key activities will invariably take place. And for this reason the *context* of information visualization is of great importance and will almost certainly affect the design of representation, presentation and interaction. Although design for information visualization *in context* is not the primary focus of this book it is appropriate here to provide, by illustrative examples, some idea of the inherent challenges. We select two examples, one from bank fraud and the other from silicon chip design.

The WireVis system (Chang et al. 2007) was designed to support investigation into bank fraud and related matters. With the 'wire transfer' of money occurring at the rate of millions of transactions per day, the challenge for investigators is huge, not least because fraudsters change their tactics to avoid detection.

In a brief summary appropriate to a discussion of context some idea of the essential ingredients of the WireVis system might best be gained from a view of its user

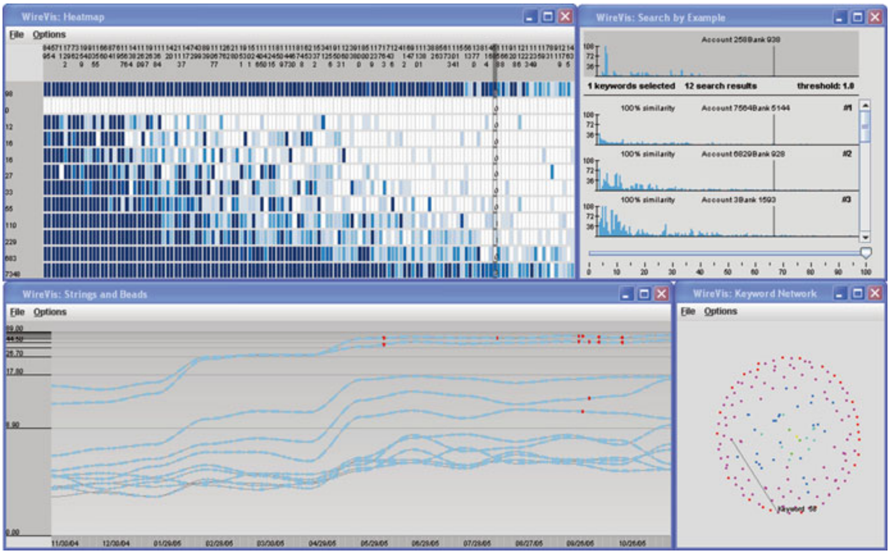

Fig. 1.19 The interface of the WireVis system showing heatmap (*top left*), search by example (*top right*), keyword graph (*lower right*) and strings and beads (*lower left*) (©2007 IEEE Reprinted, with permission, from Chang et al. (2007))

interface (Fig. 1.19). A fundamental feature is the creation of 'keywords' that may be indicative of high risk. At bottom right is a 'keyword graph' showing the relationship between keywords: if a transaction contains two keywords that should not be related it needs to be quickly identified. At top left is a 'heatmap' indicating the number of keywords for each account. The 'strings and beads' representation (lower left) supports the visualization of wire activity over time: 'strings' refer to accounts and 'beads' to specific transactions on a given day. At upper right a 'search by example' facility is provided to allow transactions showing activities similar to a defined prototype to be discovered, thereby providing the user with some feeling for a space to be explored. Even this extremely brief overview demonstrates the variety of disciplines involved in a powerful tool, and that information visualization, while a crucial component, is not the only one involved. The example also suggests the frequent need for coordinated multiple views of data, the need for both overview and detail and the enormous benefit that can accrue through interaction.

The CoCo system (Colgan et al. 1995) was invented to help designers of silicon chips, products that often contain thousands, and sometimes millions, of individual components. The value of each component must be chosen to achieve satisfactory chip performance. Not surprisingly an important feature of the CoCo system is a visual representation of the (hierarchical) properties of the chip being designed (Fig. 1.20-A). But an additional novel aspect of CoCo is an automated

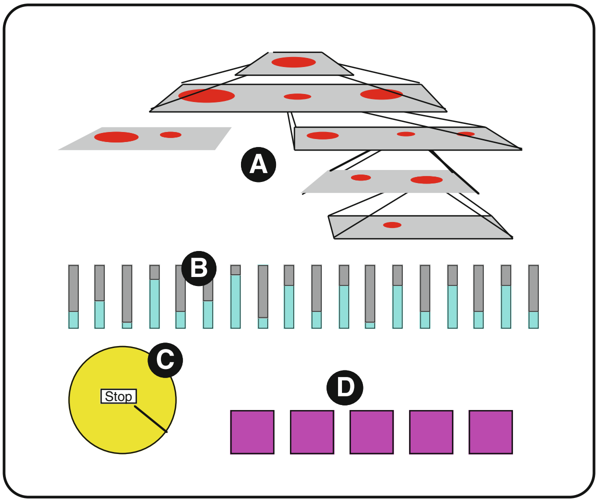

Fig. 1.20 A simplified diagrammatic representation of the CoCo interface, emphasising some principal components: *A* is a representation enabling a chip designer to view the extent to which performance specifications are being met. *B* shows individual component values. *C* is an interactive count-down clock indicating the (controllable) process of optimization. *D* represents advice to the chip designer generated by artificial intelligence

design ('optimisation') facility[6] that will accept a designer's initial – and often sub-optimal – design and adjust the component values (Fig. 1.20-B) in such a way as to move chip performance closer to an ideal. However, since autonomous optimization procedures leave much to be desired[7] provision was made for the designer to interactively 'guide' the optimization (Fig. 1.20-C). Yet another novel component of CoCo involves an artificial intelligence facility acting as a surrogate 'experienced designer' who, in human form, 'looks over the shoulder' of a chip designer and offers comments about the design as it progresses (Fig. 1.20-D). Thus, while the architects of the Coco system drew upon knowledge of information visualization, an understanding of automated design, artificial intelligence, the guidance of autonomous processes and the manner in which chip designers go about their task was essential.

The two systems described above are examples of the recently identified and now energetically and beneficially pursued discipline called Visual Analytics which combines automated analysis techniques with interactive visualization tools for effective understanding, reasoning and decision making, usually in the context of large and complex data sets.

[6] An optimization algorithm is designed to enhance some property of a system by making appropriate adjustments to the values of that system's components.

[7] A problem with autonomous optimization is that the reason why its outcome is better, and what limiting relationships (e.g., trade-offs) might have been encountered during the process, is not visible to a user. Readers of Douglas Adams' *Hitchhiker's Guide to the Galaxy* will recall the answer '42' provided by the computer when asked "what is the secret of Life, the Universe and Everything?"

Exercises

Exercise 1.1

Without consulting the chapter you have just read, sketch what you can remember of Minard's record, Nightingale's diagram and Snow's Soho map. In other words, externalize your mental models of those representations.

Exercise 1.2

In the course of a normal day, make notes of examples in which data is represented visually, aurally or by tactile means. Afterwards, identify whether, for each example, the data has value (numeric, ordinal or categorical) or is a relation.

Exercise 1.3

By means of sketches explore alternative ways of representing the data encoded in the representations of Minard, Nightingale, Snow and Beck.

Exercise 1.4

Select a physical object (e.g., a car, yourself, a house) and identify some of its attributes that can usefully be represented visually. Sketch a possible visual representation of that object.

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Chapter 2
Issues

What are the principal issues that need to be addressed by a book about information visualization? To answer this question we examine how and why an information visualization tool is typically employed. It can be employed in many ways for very different purposes. In one situation we may be concerned with a single – possibly printed – image that is intended for viewing by many people: a railway time table, and Minard's map come to mind. In these examples interaction between user and image may be described as 'passive'. In a very different situation a user seeking information or a product may interact intensively with what is seen on a display. The approach adopted in this brief chapter is to select a few representative tasks to see what important issues they identify. Those issues are presented in **boldface**.

But first, a reminder of what information visualization is. It is *not* what a user sees on a computer display. To repeat the earlier definition,

Visualization is the formation of a mental model of something.

This definition must be kept in mind as we identify important issues associated with information visualization.

2.1 A Task

The first task we address is that of finding a car to buy, a specific but representative example of the generic and widespread task of selecting one **object** from among a collection of objects on the basis of its **attributes**. A variant would be the 'whittling down' of a large number of objects to identify a few worthy of further consideration. An associated and vital subtask, that of **gaining insight** into – that is, forming a mental model of – a collection of data, is widely relevant and also an essential component of activities such as data mining and decision support.

R. Spence, *Information Visualization*, DOI 10.1007/978-3-319-07341-5_2

Although we shall first address the task of selecting a car to buy using a digital information space we shall note useful parallels with the physical world of car showrooms.

2.2 Fuzzy Goals

Typically, someone looking for a car to buy will not express their needs with precision: “nice looking”, “sporty”, “around £3,000” are examples of articulated requirements. Other requirements of which the buyer is aware but which may not initially be articulated could well include shape and colour. Not surprisingly then, and as happens with many tasks, it is frequently the case that **problem formulation** at first takes place only in general terms: more precision may be introduced as the task proceeds (Schon 1983). We often do not know what we do not know.

2.3 The Data

Despite a general preference for choosing a car by visiting a showroom, data describing a collection of cars usually originates in the form of a table and is frequently presented to a car buyer in this way (Fig. 2.1). Each row corresponds to a single car (in general, an **object**), while each column is associated with an **attribute** of that object. Not all attributes are of the same type: some are numeric (e.g., price), some are categorical (e.g., make), some are ordinal (e.g., rating) and one may be an image (e.g., the appearance of a car). A photograph of a car can often exert considerable influence on choice.

Make	Price (£)	MPG	Rating	Age (yrs)	Photo
Ford	8000	42	*****	5	
Renault	6500	37	***	3	

Fig. 2.1 Example of the tabular representation of car attributes

2.4 Table Presentation

Notwithstanding the public's widespread familiarity with them, tables are often of limited help especially if there are many rows (cars) and ten or more columns (attributes). In the very unusual situation in which a buyer knows *precisely* what they want the table can certainly be searched, by eye or some automatic search mechanism, until a car satisfying those requirements is found (or, more likely, not found!). Nevertheless, even if a precise match is found, the purchaser may still wonder what else may have been acceptable and, on further reflection, perhaps more desirable. Even if a precise match fails to be found it is unlikely that a line-by-line search of the table will contribute much to the buyer's **mental model** of the data. Nevertheless, a table is not without its attractions. As we shall see later when discussing the Table Lens, an **interactive rearrangement** of table rows according to some attribute (e.g., Price) can be immensely helpful.

2.5 Derived Data

There are alternatives to the table representation. For example, the price of a car can be **represented** by a dot on a scale (Fig. 2.2) and the actual value estimated to within an accuracy acceptable during the early stages of a search. Using this same representation the price of each of a collection of cars can be presented to a buyer in the manner shown in Fig. 2.3a. With regard to Price, what is shown in Fig. 2.3a can be called **raw data**. But if the prospective car buyer is simply trying to get some rough idea – an **overview** – of car prices an alternative representation may be more effective. One (and only one of many) such representation of what we call **derived data** is shown in the Tukey Box Plot of Fig. 2.3b. We see there (1) the *median* price (which simply divides the number of data items into halves – it is *not* the mean),[1] (2) the bottom end of the box representing the 25 percentile (i.e., below which one quarter of the cars are to be found) and the top end representing the 75 percentile, (3) the separate horizontal bars representing the 5 and 95 percentiles and (4) 'outliers' represented as points. What the Tukey Box Plot does not fully show, however, is the distribution of the data points, but this information is easily added by a

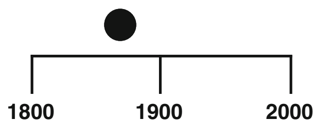
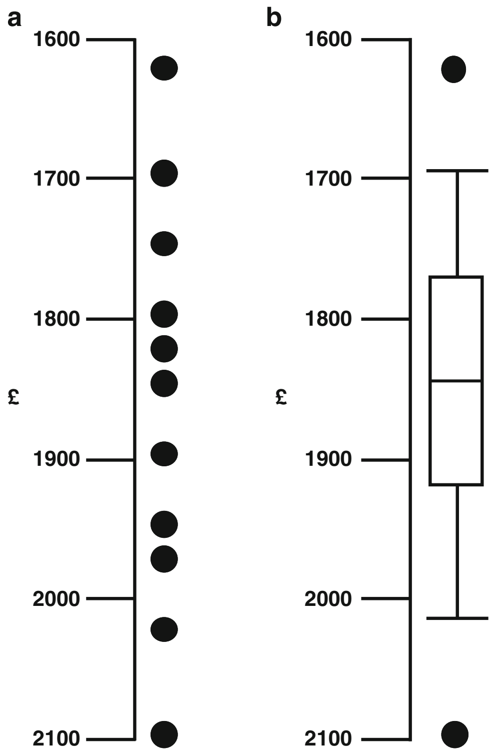


Fig. 2.2 One representation of the price of a car

[1] The median is much more useful than the mean, because one false data observation can seriously throw off the mean, whereas the median is not affected until half the data observations are false. In other words, the median is a much more robust measure.

Fig. 2.3 (**a**) Raw data – a representation of the prices of a collection of cars (**b**) a 'Tukey Box Plot' representation of raw data



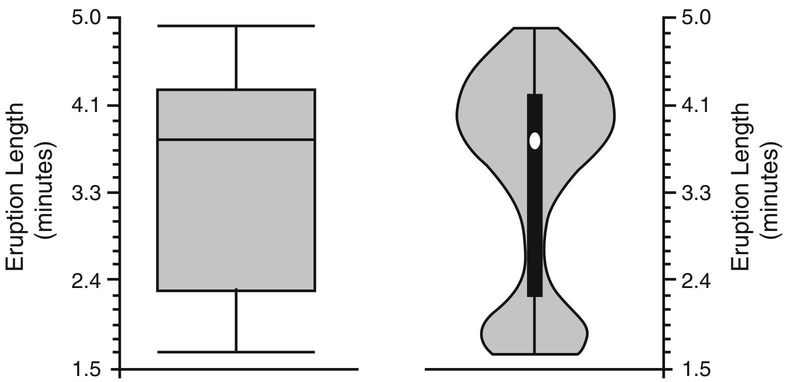


Fig. 2.4 A Tukey box plot and a violin plot for the eruption length of the geyser Old Faithful (*From* Hintze and Nelson (1998) *reprinted by permission of the American Statistical Association)*

representation known as a Violin Plot (Hintze and Nelson 1998), as illustrated by data relevant to the eruption length of Old Faithful, the geyser in Yellowstone Park (Fig. 2.4).

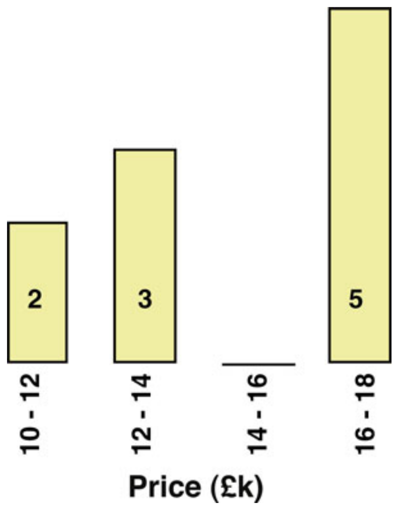


Fig. 2.5 A histogram of car prices

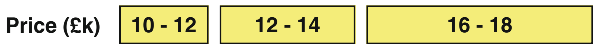


Fig. 2.6 A bargram representation of the data represented by the histogram of Fig. 2.5

Another familiar representation of derived data is the histogram (Fig. 2.5): again, an **overview** of prices is facilitated. One advantage of these representations of derived data is that rapid judgments can be made (e.g., "cars are cheap or expensive – nothing in between" or "there are too few cars – let's not bother"). In other words, a **qualitative awareness** of some aspect of data can be achieved and, as we shall see later in the book, sometimes within about 100 ms.

2.6 Alternative Representations

The representations of Price data shown above are only three of many that are possible. A useful variant of the histogram (Fig. 2.5) is achieved by 'pushing over' its columns and then abutting them as shown in Fig. 2.6, a **representation** known as a **bargram**. But why should a bargram be of any interest, especially as it omits the information that no cars are available in the £14k–£16k range? As well as offering an overview of car prices it provides a convenient framework for adding more information, as shown in Fig. 2.7. Here, individual cars are represented by small circles (icons). The advantage of this is that we can **encode**, quite compactly in the circles, additional information about each car. For example (Fig. 2.8) the appearance of a car can be clearly associated with its price by the use of colour. The car can be selected for identification by **interaction**, either with its image or its icon. Clicking on an icon to change its colour and result in the framing of the corresponding image

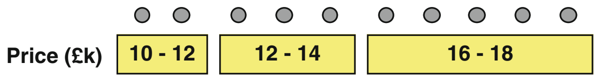


Fig. 2.7 Icons positioned above price ranges represent individual cars

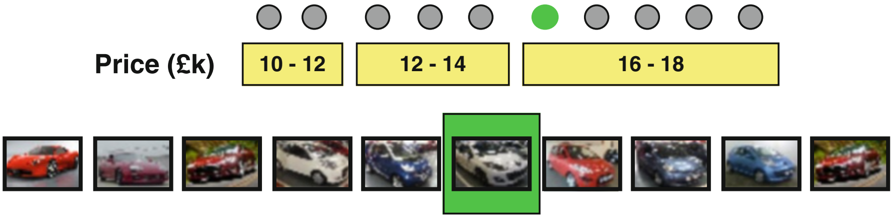


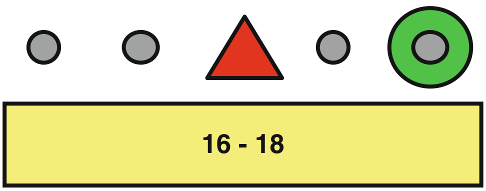
Fig. 2.8 Colour coding can be used to associate a car with its appearance. Either the image or the icon could be selected interactively

is called **brushing**, and is an extremely powerful technique (Cleveland et al. 1988). Since it will often be the case that a purchaser notices an attractive car and wants some idea of its price, **brushing** in the opposite direction can provide an immediate answer. The price could, of course, be displayed in a label just below its image, but there is no reason why Price – just one of maybe ten important car attributes – should be chosen for that label. Similarly, clicking on a price range bar could cause brushing into the corresponding car images as we shall soon see in Fig. 2.11.

2.7 Adding a Representation

A buyer will usually have in their mind the attributes of their **ideal** car. Although that car may not – and probably will not – be part of the available collection, it can be useful to **represent** it amongst the available ones (Fig. 2.9) to permit comparison with what is available. Similarly if, in the course of exploring available cars, one is considered to be a ‘possible’ and worth remembering, it can be **tagged** as shown in Fig. 2.9.

Fig. 2.9 The positioning of an ideal (and possibly non-existent) car (*red triangle*) and the tagging of an existing car that may be worth remembering



2.8 Multiple Attributes

Price is not usually the sole criterion on which the selection of a car is based. If the miles-per-gallon (MPG) performance is also of interest another bargram can be positioned above the Price bargram (Fig. 2.10). If object icons representing cars are also positioned above this new bargram then, because they represent the same cars, the two bargrams will be of the same length in terms of numbers of cars. But because, in general, there will be no correlation between the positions of the two sets of icons, a particular car will not necessarily be represented at the same position on each bargram. Indeed, Fig. 2.10 shows that one particular car has been selected (perhaps through interaction with its image) and that selection has been brushed into the two rows of icons: reverse brushing would have the identical result.

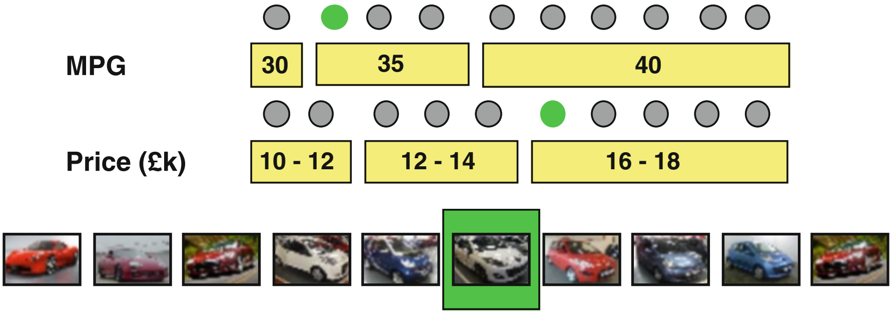


Fig. 2.10 By the use of multiple bargrams a number of car attributes can be represented, and brushing used to link different attributes for a selected car

2.9 Attribute Specification

Usually, the prospective car buyer will **explore** the available cars by specifying acceptable ranges of attributes, achieving this by interacting with – perhaps by clicking on – the appropriate ranges in the bargrams, whereupon the identified range is highlighted to provide confirmatory feedback. In Fig. 2.11 the buyer has expressed an interest in cars costing between £12,000 and £14,000 and having an MPG performance of around 40. Colour-coded icons and images then represent the two cars that satisfy both selected attribute ranges. Figure 2.11 illustrates the important action of filtering out items considered, at least temporarily, to be irrelevant. It would, of course, be impossible to know which car icon corresponds to which car image, so the technique of **brushing** is again employed. Identification (by mouseover, for example) of *any* of the three representations of a single car will highlight the other two.

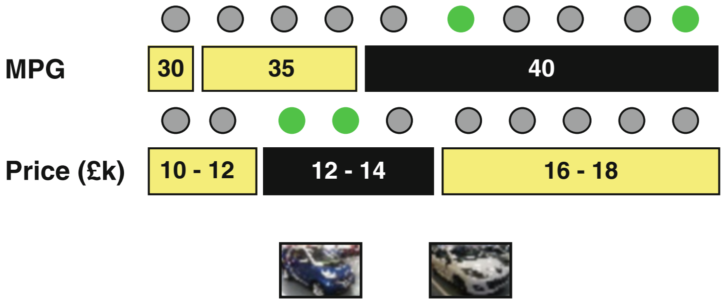


Fig. 2.11 The interactive selection of a Price range and an MPG range, resulting in the colour coding of icons and the presentation of images representing the two cars that satisfy both of the specified ranges

In the course of a search for an acceptable car the buyer will undoubtedly **explore** – by selection and deselection – the effect of different range selections. As this process proceeds the buyer will hopefully build up some understanding – i.e., create a **mental model** – of what is available. Eventually the buyer may decide to concentrate on only one Price range and only one MPG range, in which case a facility to remove from view – i.e., **filter out** – all other (distracting) ranges (as in Fig. 2.11) may reduce the **cognitive effort** involved in a search.

2.10 Display Space Limitations

As many as ten attributes of a car may be examined before a final decision is made as to which one to buy. Unfortunately there may be no room on a display to contain so many bargrams, as well as the image collection, in the form and detail shown in Fig. 2.8. It is of course always possible to implement a scrolling function, but the disadvantages of hiding a majority of bargrams at any one time will be familiar to anyone who has encountered situations in which only a fraction of available data can be seen.

An alternative and advantageous **presentation** of those bargrams is shown in Fig. 2.12. The vertical size of all but a few bargrams is reduced, allowing them *all* to appear on the display, but necessarily requiring range values to be suppressed and car icons to be superimposed on the bargrams. However, if the buyer is exploring Price and MPG, any significant change on the other bargrams would immediately be apparent and could be investigated. When necessary, a stretching action brings other bargrams into full view so that range values can be discerned.

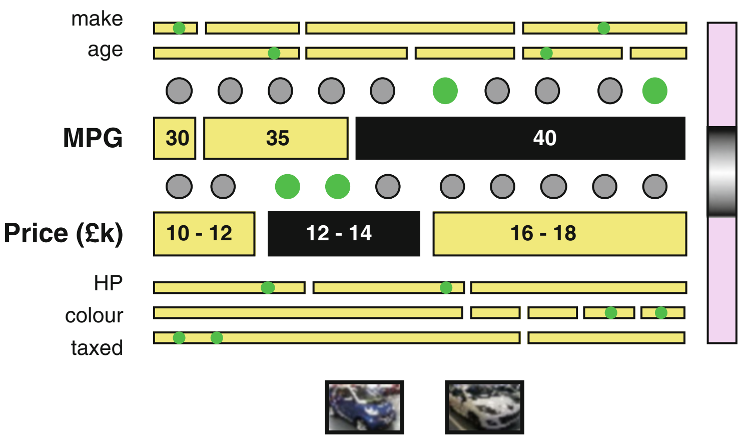


Fig. 2.12 If display space is too limited to accommodate all attribute bargrams, many can be reduced in size vertically, albeit with a loss of the range values but with the advantage of a better overview

2.11 Mental Models

It has been stressed that **visualization** means 'the formation of a **mental model**[2] of something'. A mental model has been described as an internal representation of external reality. We don't know very much about mental models, but we can be sure about some of their features. For example, we do not usually form a single model about some data, but rather (Tversky 1993) a collection ('collage') of sub-models associated with each other either tentatively, confidently or perhaps not at all. And the collage varies with time: it may be enhanced as we accumulate new insight but also pruned as we conclude that some content is no longer relevant (perhaps because of a decision to concentrate on inexpensive cars). Enhancement of a mental model will result from both overview and detailed information. The model will not always be quantitative: a qualitative overview may sit alongside quantitative detail ("the sporty looking car for less than £12,000").

2.12 Near Misses

It is quite common, after finding a car whose attributes are judged to be satisfactory, to wonder "what would happen if we had another £400 to spend? Perhaps a very much better car would be available" An answer to this question could, of course, be obtained by selecting the next higher price range and observing the result. But such

[2] Also referred to as a cognitive map (Tversky 1993).

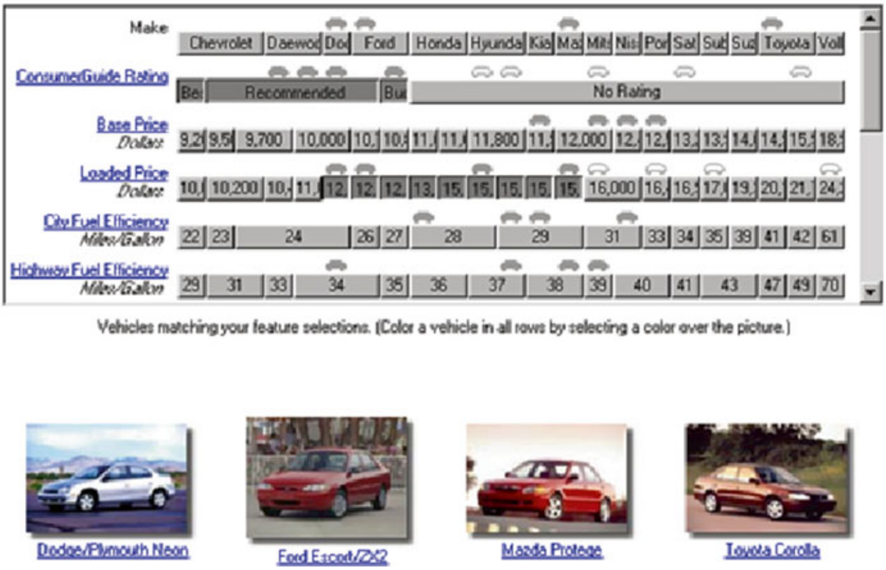


Fig. 2.13 A view of the EZChooser, showing sensitivity information in the form of outline cars (*Courtesy of Kent Wittenburg*)

a step would then have to be reversed in order to ask a similar but different question about another attribute: “what would happen if we weren’t concerned about MPG?” A much more effective way to answer such “what if?” questions is to encode ‘near miss’ features in an icon. In the (real) example (Wittenburg et al. 2001) of the EZChooser (Fig. 2.13) the icons above the bargrams take two forms: a ‘filled’ car shape and an ‘outline’ car shape. The former indicates a car that satisfies all the specifications, whereas an outline car indicates that the bargram range below it must be selected for that car to satisfy the new set of needs. What this encoding is doing is providing **sensitivity information**[3] which can be extremely useful in supporting a user’s **exploration** and **search**.

2.13 Time

The simple example of car purchase has identified many of the issues discussed in this book. Nevertheless, to identify other important facets of information visualization we now focus a little more on **the human user** and especially the processes of **perception** and **cognition** (Fig. 2.14).

Users don’t just want to gain insight into data – they usually want to do so as quickly as possible. Fortunately, computation can be extremely fast, and this leads to many opportunities, some familiar from the real world. For example, imagine that you

[3] The concept of sensitivity has very wide relevance, and will be a recurring theme of this book.

Fig. 2.14 By riffling the pages at a fast rate (e.g., ten per second) an illustration can quickly be found

want to show a friend a particularly nice painting in a book. Rather than look up the index you might instead **search** for the item by rapidly riffling the pages – say at a rate of about 10 per second – in which case you would probably find that painting very rapidly. This is because you are able to recognise the painting in around 100 ms through a process known as **preattentive vision** (Ware 2012). Equally, you may riffle through a car magazine to see what attractive cars are featured. You often employ the same ability to handle rapid change in the images on a display when you fast-forward and rewind recorded programmes on your television. This remarkable property of the **human visual system** has many applications. Imagine a search for a Christmas present. One approach, of course, is to wander through a department store and see what's available. But that takes time – why not stand still and arrange for the department store to move past you? Impossible in the physical world, but not in the digital one: Fig. 2.15 illustrates the **presentation** of products by 'floating' them towards you and allowing them to disappear 'over your shoulders', much as the signs on motorways 'move' past you. The ability to reverse and stop such a presentation facilitates **browsing** and offers many advantages over the familiar interface in which you are interrogated about what you are looking for before you are allowed to see any products.

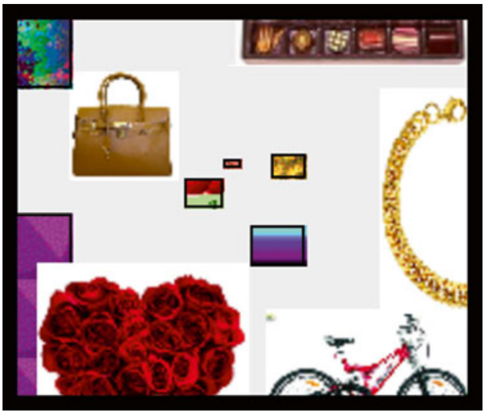


Fig. 2.15 Representations of products 'float' towards you as if you were moving quite quickly through a department store. If you see something of interest you can slow the movement down, reverse it or stop it to interactively gain more detail

Time is also a key feature of exploration when trying to learn how things are related. Suppose you need a financial loan. A typical website might appear as in Fig. 2.16, implicitly making the assumption that you (a) know how much money you need, and (b) know the period over which you will repay the loan. Since the relation between Term, Amount (of loan) and Monthly Payment is known to the Lender, why not provide the user with a **fluid interactive interface** such as the one in Fig. 2.17? It allows you to vary *any* of the three important quantities and see its effect on the others. If that is possible the user can not only explore, but – most effectively – explore *dynamically*. As they smoothly move the sliders up and down and see the resulting effect they are building up a **mental model of** – in other words they are **visualizing** – the relations between variables that are of interest to them.

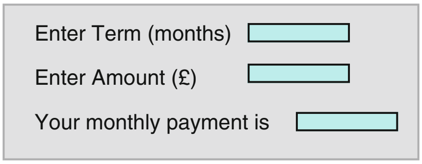


Fig. 2.16 An interface that shows the monthly payments required for a specified loan amount over a given term

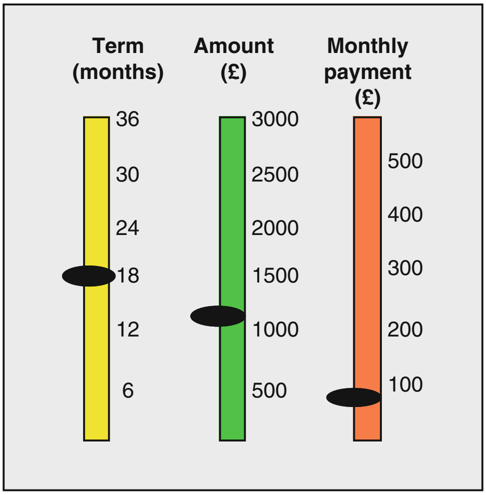


Fig. 2.17 An interface that allows a user to dynamically explore the relation between loan amount, term and monthly payments

2.14 Archives

'**Archival time**' is fundamental to a great deal of data. News stories accumulate over time and provide a rich source of archival material for both historians and the general public to interpret and understand. Similarly, measurements of physiological data must be **represented** and **presented** in such a way as to facilitate interpretation. There are many ways of representing such data: an attractive one is called ThemeRiver (Havre et al. 2002) and is illustrated in Fig. 2.18. Here, coloured 'currents' represent changing content in a document collection.

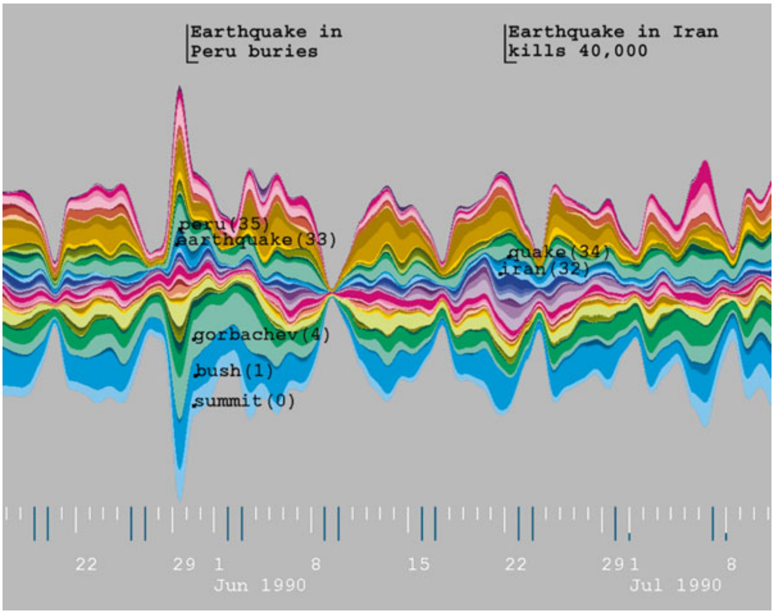


Fig. 2.18 The ThemeRiver representation of time-based data (*©2002 IEEE Reprinted*, *with permission*, *from* Havre et al. 2002)

2.15 Unwanted Information

I'm driving north from Huddersfield to Halifax and my navigator is using the map shown in Fig. 2.19. We've successfully driven north through Huddersfield and simply wish to get to Halifax without undue difficulty. One problem is that the map contains far more information than we need. We do not, for example, plan to visit

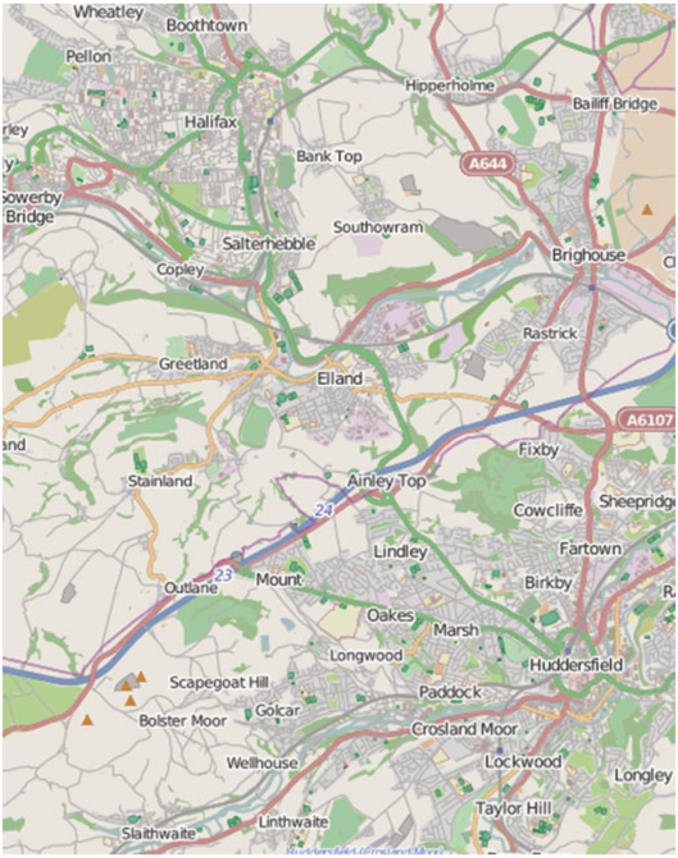


Fig. 2.19 A conventional map of the region between Huddersfield and Halifax (© *OpenStreetMap contributors*)

the undoubtedly charming village of Woodhouse. In fact, it would help enormously if a new map was available that took account of my **degree of interest** in the various features contained within the conventional map of Fig. 2.19. Such a map is shown in Fig. 2.20. All the driver needs to know is that, once through Huddersfield, he must travel along the A629 and then the A6025 to get to Halifax. Purely for reassurance a landmark (the motorway over which the driver will pass) is shown. There are many other situations where documentation is complex and can be simplified by the removal of items of little or no interest.

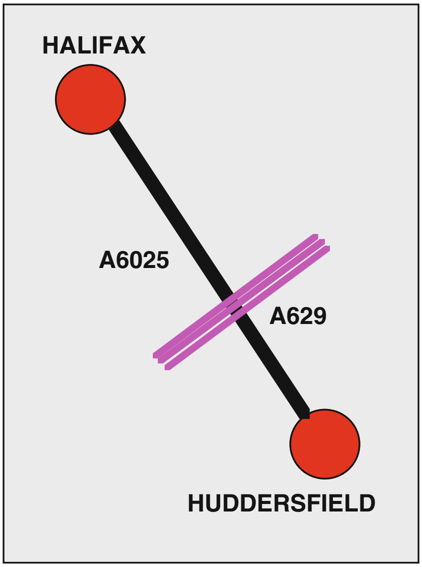


Fig. 2.20 A map reflecting a driver's degree of interest in the journey between Huddersfield and Halifax

2.16 Movement

Anyone who has **searched** the internet for information will be aware that they are 'moving', step-by-step, through **discrete information space** from one web page to another, partly to **explore** that space (and form a mental model of it) and partly to progress towards the page that contains the required information. Such movement is often made difficult by poor interface design: either the **interaction** required to move from one web page to another is not obvious or the available **destinations** (web pages) are themselves not obvious. Figure 2.21 illustrates the confusion that

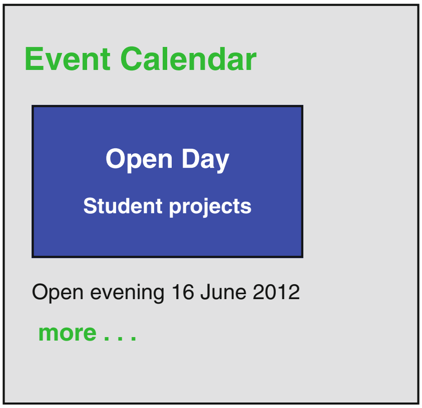


Fig. 2.21 An example chosen to illustrate the difficulties of navigating discrete information spaces (see text)

can arise from a poorly designed web page, confusion that impedes the formation of a **mental model** of the immediate region of information space. The small part of a College's web page appears to emphasise the Open Day that I want to attend in order to see this year's student projects. So I click somewhere on the large blue area that advertises the Open Day. Nothing happens. So I try to click on the text giving the date. Again, nothing happens. I then notice the word 'more', with dots to indicate it might lead to something, so I click on it. Success! – I get transferred to a page with illustrations of the exhibits and details of how to register. But wait! – I noticed that the sensitive 'more . . . ' is in a particular shade of green. The same shade of green was used for 'Event Calendar', so perhaps I can see a list of events, one of which is the Open Day. So I click on Event Calendar. Nothing happens.

There are many lessons to be learned from just this small part of a home page (Nielsen and Tahir 2002), and all are associated with the **navigation** of discrete information spaces. In particular, it is essential to make it obvious which items are **sensitive** to **interaction**.

2.17 Conclusion

We have identified a number of important concepts in the field of information visualization, and in general we have noted that there are many applications in which data is first **represented** (e.g., by bargrams – Fig. 2.13) and then **presented** (e.g., by a simplified map – Fig. 2.20). An interpretation of that presentation of represented data by a **human user** engaged in a variety of tasks can then usefully lead to **interaction** (e.g., to navigate to a new web page). That sequence is illustrated by the Reference Model of Fig. 2.22.

Let us examine the Reference Model in more detail. On the left we have raw **data**, the content into which a user wishes to gain insight. Usually that data is vast in size, but purely for illustration we take an example (a) of a 5×5 numerical array. (We also saw that a view of **derived data** can sometimes be preferable, but for the moment we implicitly include that within the box marked 'data'). There are many ways in which numerical data can be **represented**: in Fig. 2.22 (b) we have chosen to represent each number by the size of a circle to convey, more easily, the location of large numbers. However, it may well be that, while keeping all the circles in view, the user wishes to examine, in more detail, some aspect of the value in the centre, in which case (c) the centre of the display is 'stretched' to provide more room for that detail. This is only one of many ways in which represented data can be **presented** for viewing and comprehension. Additionally, as pointed out, the **human user** may well wish at some point to **interact** to change either the data that is selected for representation, the manner in which it is represented or the way in which it is presented. At the right of Fig. 2.22 two examples are illustrated. In the uppermost example (d) colour coding is employed to represent some feature of each of the numerical entries shown below the Data box, while below it (e) is a sketch suggesting an interactively driven animation showing, for example, how a patient's blood pressure changes with time.

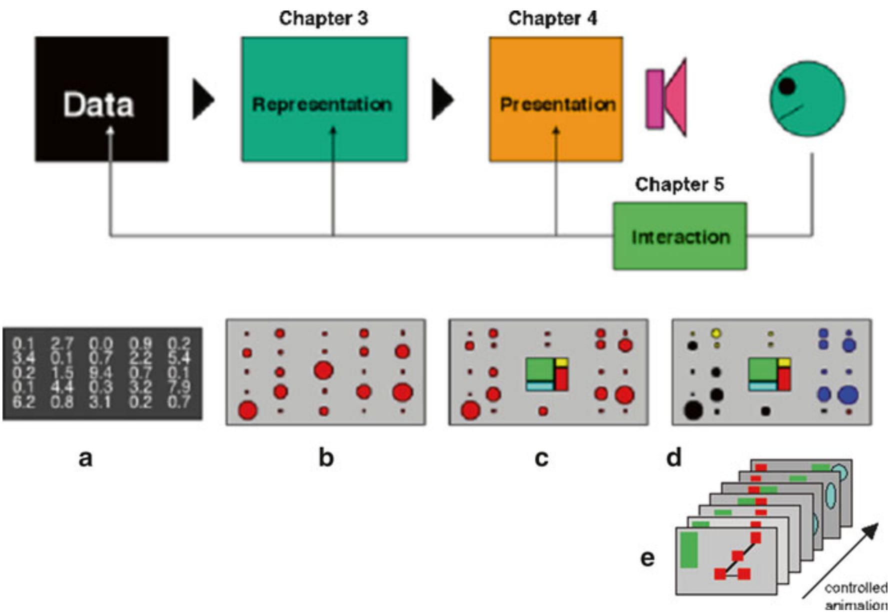


Fig. 2.22 A model of a system supporting information visualization (often called the Reference Model) and very simple examples to illustrate the function of each component

2.18 Remainder of the Book

The model of Fig. 2.22 defines the theme of the following chapters. Chapter 3 addresses the topic of Representation, Chap. 4 that of Presentation and Chap. 5 the topic of Interaction. What is *not* considered in a separate chapter are the issues associated with the capabilities and limitations of the **human user**, for one simple reason: those issues are intimately associated with how we represent, present and interact with data in order to form a mental model of that data – in other words, to **visualize** it. Therefore, aspects of human perception and cognition are introduced as and when appropriate.

Following the three main chapters identified above we conclude with a chapter on design, for one simple reason. An introductory course in information visualization is enhanced immensely by carrying out a design, preferably in collaboration with two or three other students. Therefore, Chap. 6 (**Design**) offers advice to project groups undertaking a short (e.g., 5 day) commission of the sort that might be provided by industry. And an appendix contains brief descriptions of the short **videos** that illustrate many of the concepts and techniques introduced in this book.

Exercises

Exercise 2.1

What are the drawbacks and advantages of the bargram representation of data?

Exercise 2.2

A car is described by a number of attributes: price, appearance, make, recommendations, horse-power, year of manufacture and age. Say which of these attributes are numerical, ordinal or categorical.

Exercise 2.3

Based on your experience of buying a mobile phone, washing machine, bicycle, car or other multi-attribute object, express your view as to the meaning of the term 'overview' and 'detail' and give some examples.

Exercise 2.4

For which of the attributes mentioned in Exercise 2.2 would it be possible to order the objects above the corresponding bar of a bargram?

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Chapter 3
Representation

3.1 The Information Visualization Process

In the previous chapter we developed a Reference Model identifying the principal components of the information visualization process. It is repeated in Fig. 3.1. In this chapter we focus on the Representation stage by presenting and then critically examining a number of techniques, examples being selected from some of the many fields for which information visualization can be beneficial.

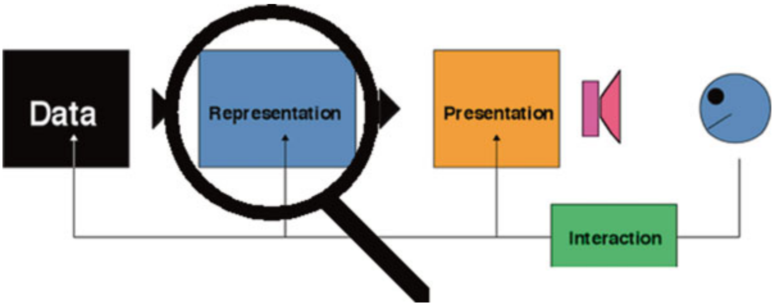


Fig. 3.1 The information visualization reference model, identifying the focus of this chapter

There are so many techniques available for the representation of values and relations that an exhaustive 'handbook' treatment would be bulky, inappropriate to an introduction and, frankly, potentially exhausting for the reader seeking an introduction. Rather, the aim is to introduce a selection of techniques and, at the same time, identify underlying concepts of value in design. The approach taken in this chapter is therefore as follows:

R. Spence, *Information Visualization*, DOI 10.1007/978-3-319-07341-5_3

- A brief reminder of the purpose of representation (Sect. 3.2);
- A relatively uncritical discussion of a variety of techniques for the static representation of data, mainly to convey a flavour of what is available as well as the extremely wide range of application fields (Sect. 3.3);
- By adopting a critical view of the already visited examples, as well as others, we now identify fundamental problems associated with what might appear to be acceptable representation techniques but whose potential is limited by the human visual system (Sect. 3.4). Because human perception and cognition is extremely complex, (and still not completely understood), the treatment will be brief but hopefully adequate to permit an appreciation of consequences for the design of representations;
- The power of the (mainly static) techniques visited in Sect. 3.3 can frequently be enhanced considerably by making the representation sensitive to interaction. Some illustrative examples of the interactive representation of data are presented here (Sect. 3.5), and followed up later by a detailed consideration of interaction in Chap. 5;
- The penultimate Sect. (3.6) looks at and assesses a number of techniques – both static and interactive – appropriate to the representation of relations;
- In a final brief Sect. (3.7) it is pointed out, with supporting examples, that information visualization is not restricted to computer displays or paper: representations made of wood, concrete and metal are equally possible, as a few examples will show.

3.2 Why Do We Represent?

A dictionary definition of the verb to represent:

represent: to present clearly to the mind

is consistent with our definition of visualization as the creation of a mental model of something. It is also compatible with many quotable statements about the benefits of representation, of which we choose just one, due to Simon (1996):

> … solving a problem simply means representing it so as to make the solution transparent.

The need to consider representation arises from the fact that the ‘raw data’ into which people want to gain insight generally originates in a form unsuited to that purpose. That data may, for example, be in the form of numbers, rankings from questionnaires and geological samples.

Before we look at techniques we identify three principal concerns:

- The **type** of data: it can be *numeric* (e.g., the price of a car), *categorical* (e.g., a dwelling type: house, apartment, cottage) or ordinal (e.g., Napoleon’s march towards Moscow and the retreat). It can also characterize a relationship (e.g., marriage). Text or music often warrant representation in unconventional forms.

- The **dimension** of the data. The difficulty of designing and interpreting a representation is strongly influenced by its dimension. As we saw in Chap. 2, the choice of a car to buy is much more difficult if about ten of its attributes must be considered than if only price is of concern.
- The **user** who has to interpret a representation is an exceedingly complex organism whose characteristics exert considerable influence over the design and effectiveness of a representation. Although they can be enhanced by training, the perceptual and cognitive abilities of the human being are basically invariant.

3.3 A Brief Introduction to Some Representation Techniques

As remarked earlier, there are so many representation techniques that it is appropriate here to visit just a small number in order both to provide some familiarity with available techniques and, most importantly, to establish concepts that will enable us to discover whether a particular technique is appropriate to a specific application. Such a discussion is essential if we have to design a representation. With each representation technique we briefly suggest why it should not be used uncritically.

3.3.1 Dials

A single number of crucial importance to the pilot of an airplane is its height above sea level. In the early days of aviation height was represented by an aircraft altimeter, as illustrated in Fig. 3.2. The small hand indicates tens of thousands of feet, the middle-size hand indicates thousands of feet while the large hand indicates hundreds of feet, all on the circular numeric scale.

Later, in Sect. 3.3, we shall see why this altimeter was the cause of many aircraft accidents, and examine a modern altimeter to see how the task of representing altitude data is now supported.

Fig. 3.2 The original aircraft altimeter

3.3.2 Point Representation

Still addressing univariate data, we consider the task of representing the price data for a collection of cars. Figure 3.3 is one possible representation in which each car is represented by a single dot on a price scale, a representation allowing quite a good estimation of the actual price of each car. But a car buyer will often be satisfied, at first, with some ‘overview’ of the car prices, in which case the Tukey Box Plot of Fig. 3.4 may help, its various components having been explained in Chap. 2. With the exception of outliers this latter plot mainly displays derived data. Derived data will be treated in the same way as raw data in our discussion of representation.

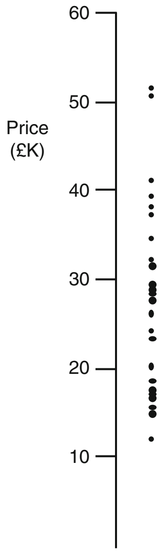


Fig. 3.3 Representation of raw price data

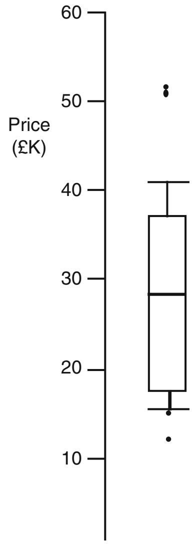


Fig. 3.4 A Tukey Box Plot of the data from Fig. 3.3

3.3.3 Scatterplots

When attempting to gain insight into bivariate data, the scatterplot is often used. Figure 3.5 records the Price and Number of bedrooms of a collection of houses, and allows a user to form some idea of a correlation between the two, the occurrence of trade-offs (lower price, more bedrooms) as well as outliers. For example, the availability of a five-bedroom house for a very low price might well not have been requested in a conventional search, and awareness of it might lead to reflection upon the buyer’s objectives.

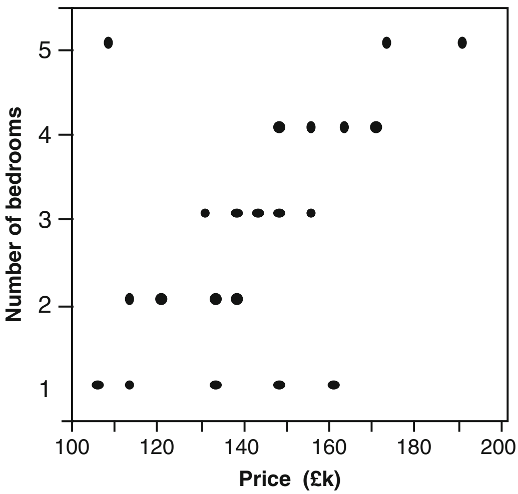


Fig. 3.5 A scatterplot recording the price and number of bedrooms of each of a collection of houses

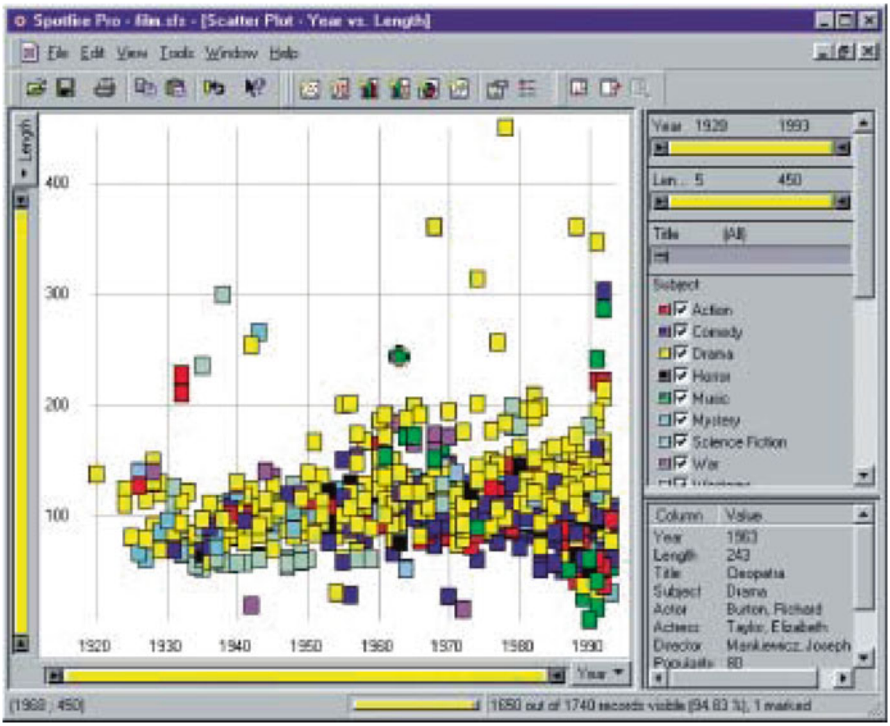


Fig. 3.6 A scatterplot representation of a collection of films (*Courtesy Chris Ahlberg*)

Figure 3.6 provides an example of a scatter plot not only representing the date of production and the duration of a collection of films, but employing colour to denote the genre of each film (Ahlberg et al. 1992; Ahlberg and Shneiderman 1994). As we shall see later, the provision of interaction can further enhance the value of such a scatterplot.

3.3.4 Patterns

It is almost inevitable with mass-produced products that some will fail and be returned to the manufacturer. The manufacturer will wish to derive insight into the records of returned products in order to improve the manufacturing process. The representation of Fig. 3.7 can help. For each returned product a record is made of the month of production and the number of months that have elapsed before the faulty product was returned (Months in service). For a given combination of these two variables the black circles in Fig. 3.7 have an area proportional to the number of returned products. The production manager can easily and usefully identify patterns indicating (by the blue line) products that were all made at the same time (a so-called epidemical failure) and (by the red line) products that all failed roughly at the same time – a 'seasonal influence'.

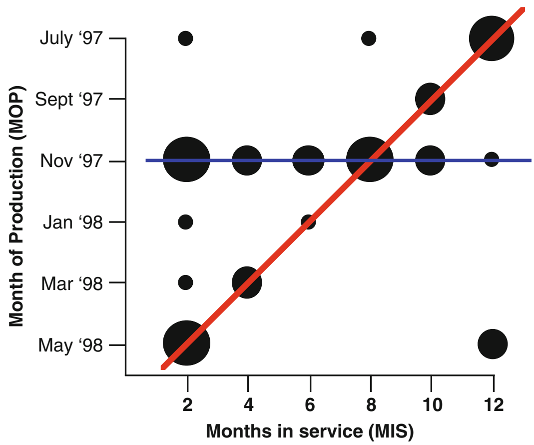


Fig. 3.7 A record of returned faulty products, with circles encoding, for a given month of production and duration in service, the number of returned products. The significant concentration identified by the blue line is evidence of epidemical failure, while the red line identifies products that all failed at the same time ('seasonal failure')

3.3.5 Star Plots

In a Star-Plot (Coekin 1969), attribute scales radiate in many directions from a central origin. The illustration of Fig. 3.8 shows, for example, a Star Plot representation of my school report. For each of eight subjects my percentage score is indicated by a point on one of the radiating attribute axes. Thus, for Mathematics my score is 95 %, and it is clear from another radial attribute scale that Sport is not my best subject. Scores on all attributes can be joined together as shown by the red line in Fig. 3.8 to provide a star plot. It may help interpretation if a pass mark (e.g., 50 % for mathematics, as shown) or an average can accompany the star plot. A 'filled in' star plot can be used to compare two objects in so far as their attribute values are concerned. For example, Fig. 3.9 shows star plots for two students, Tony and Bob.

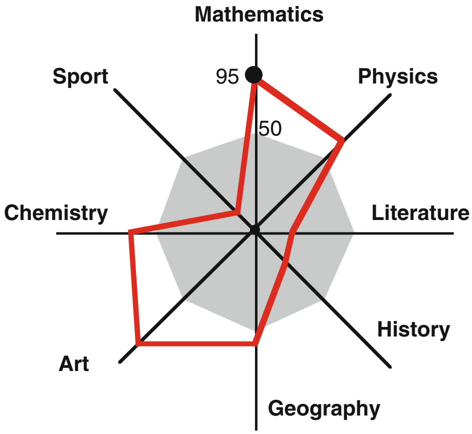


Fig. 3.8 The construction of a star plot for an object (here a student) characterised by the values of eight attributes (here, scores in eight exams)

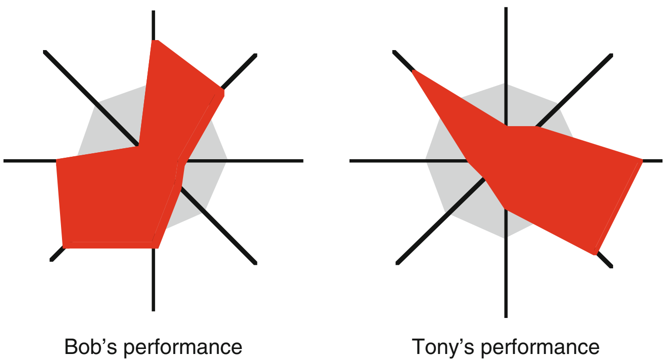


Fig. 3.9 Star plots representing the academic achievement of two students (refer to Fig. 3.8)

Police force achievement and mortgage schemes are two examples for which the star plot representation has been employed. However, as we shall see later, the area of a star plot must be interpreted with caution. An apparently similar but a much more effective representation was devised by a famous nurse, Florence Nightingale, in 1858, as we shall see in Sect. 3.4.

3.3.6 Magnification

The population density for major countries of the world could be indicated numerically on a conventional map. However, because users generally have an idea of the area of such countries, the alternative approach illustrated in Fig. 3.10 has advantages. Here, encoding by magnification is employed to indicate population density. We all

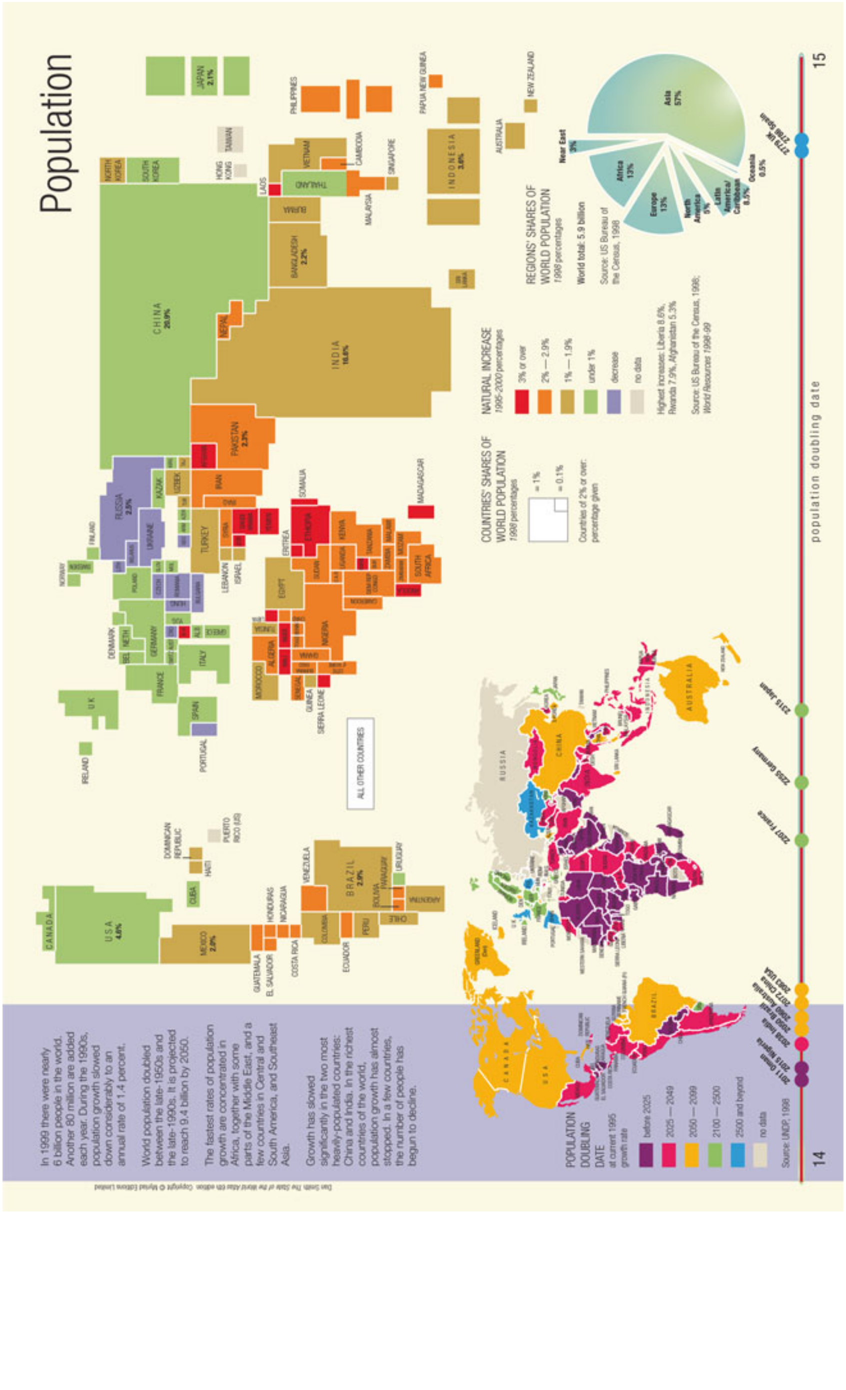


Fig. 3.10 In The State of The World Atlas, magnification encoding is used to give a first impression of population densities. Note the reduced 'size' of Canada and Australia when compared with a conventional map

know, for example, that Canada is very large and usually located at the top left of a map: its small size in Fig. 3.10 immediately suggests a very low population density. For the same reason, the size of Australia is much smaller than conventionally shown, though still in the same familiar location of the map. This combination of familiarity with encoding by magnification can convey useful insight quite quickly. The value of encoding by magnification is exemplified by the broad subject coverage of the book *State of the World Atlas* (Smith 1999), from which Fig. 3.10 is taken: other fascinating pages refer, for example, to military power and food production.

3.3.7 Parallel Coordinate Plots

One technique developed for dealing with the challenging task of representing high dimensional data is called Parallel Coordinate Plots (Inselberg 1985). As the name suggests, attribute values are positioned on scales that are arranged to be parallel to each other. A very simple example involving just two attributes is shown in Fig. 3.11. The attribute values (Price and Number of bedrooms) of each of two houses A and B are represented (a) conventionally by a single point within two dimensional space. An alternative representation (b), with the two axes separated, will require two points instead of one for each house. Furthermore, connecting lines will be needed to associate a point on the Price axis with the corresponding point on the Number of bedrooms axis.

Why would such an apparent complication be beneficial? The answer becomes clear if we extend the parallel coordinate plot representation to more than two attributes, as shown in Fig. 3.12 for seven attributes A–G. This representation might refer to six cars, each associated with values for HP, miles-per-gallon, Price etc. Thus, one car is represented by seven points, and these points are joined by

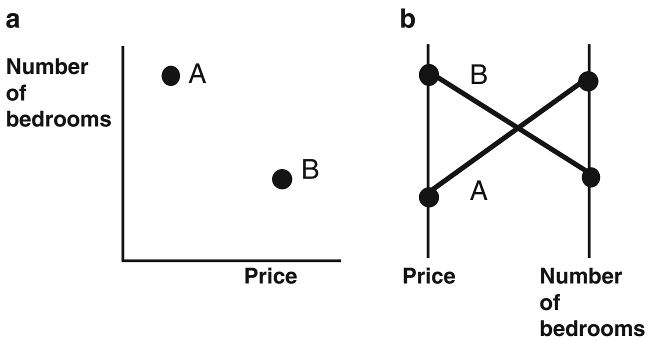


Fig. 3.11 (**a**) the conventional representation of objects characterized by two attribute values: (**b**) the use of parallel coordinate axes requires each object to be associated with two points

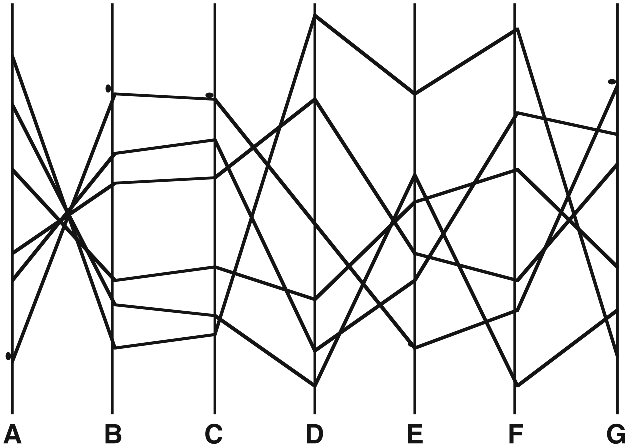


Fig. 3.12 A parallel coordinate plot representing the values of seven attributes for each of six objects

straight lines called polylines. One advantage of the representation can be appreciated by viewing the lines joining points on the A and B axes, and observing that there appears to be a trade-off between A and B. In other words, a car with a high value of A will have a low value of B, and vice versa. Similarly, the lines between the B and C coordinate axes indicate some degree of correlation between B and C values. Unfortunately, while there is also a trade-off between attributes B and E, and a strong correlation between C and G, they are not obvious. Thus, the ordering of attribute axes can limit the insight that can be gained from a parallel coordinate plot.

Despite the limitations of a *static* parallel coordinate plot, the introduction of interaction significantly increases the power of this technique, as we shall see in Sect. 3.5.3.

3.3.8 Iconic Representation

The search for a house to buy sometimes involves the perusal of a textual summary of the properties (attributes) of a collection of houses. Three items on such a list might be as shown in Fig. 3.13. An alternative representation is shown below in Fig. 3.14, employing iconic representations. Here, shape encodes the type of dwelling (house, apartment, houseboat); colour encodes price range; window count encodes number of bedrooms; white and black windows imply good and poor repair; the extent of the green area encodes garden size; and so on. An experiment (Spence and Parr 1991) comparing the two representation approaches in a task involving an optimum choice among 56 dwellings found that the task was completed twice as fast using the iconic representation.

house	flat	houseboat
£400,000	£300,000	£200,000
garage	no garage	no garage
central heating	central heating	no central heating
four bedrooms	two bedrooms	three bedrooms
good repair	poor repair	good repair
large garden	small garden	no garden
Victoria 15 mins	Victoria 20 mins	Victoria 15 mins

Fig. 3.13 The textual description of three dwellings

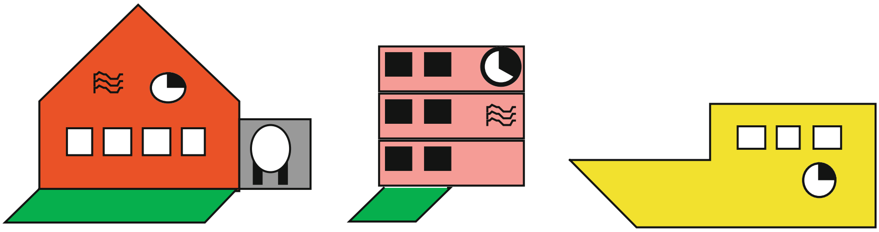


Fig. 3.14 An alternative representation of the three dwellings described in Fig. 3.13

Table 3.1 Details of the Titanic disaster

			Class			
Survived	Age	Gender	1st	2nd	3rd	Crew
No	Adult	Male	118	154	387	670
Yes			57	14	75	192
No	Child		0	0	35	0
Yes			5	11	13	0
No	Adult	Female	4	13	89	3
Yes			140	80	76	20
No	Child		0	0	17	0
Yes			1	13	14	0

3.3.9 Mosaic Plots

The idea behind mosaic plots can be demonstrated by a representation of the Titanic disaster of April 1912 when 1,731 of the 2,201 passengers and crew were lost (Dawson 1995). Table 3.1 shows the raw numerical data involving, for each person on board, four attributes: class, gender, adult/child and survival. It is not easy, without detailed examination, to gain insight from Table 3.1. By contrast, a so-called mosaic plot (Friendly 1992, 1994, 2000) can be generated in the three steps shown in Fig. 3.15. At each step area is proportional to the number of persons belonging to

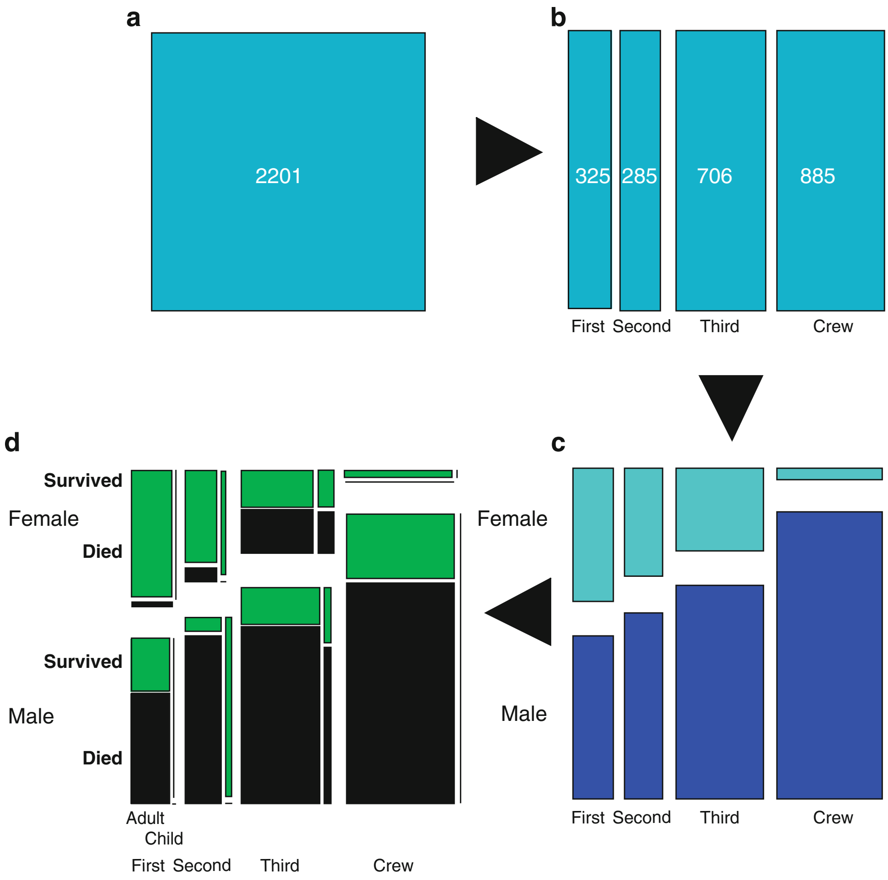


Fig. 3.15 Circular from top left: (**a**) the entire number of persons on board the Titanic, (**b**) that area segmented according to class of travel, (**c**) further segmentation according to gender, and (**d**) segmentation according to adult/child and survival (*black* = died, *green* = survived)

each defined sub-group. From the final mosaic plot (d) certain aspects of the disaster are quite easy to identify:

- Very few children traveled in First Class
- Very few female crew
- Proportionately, females safer in First class
- Proportionately, more female children survived than male
- All second class children survived
- More female adults survived than male adults

Such observations would not have been so easy to make from examination of Table 3.1. Unsurprisingly, such understanding generates new questions: "Why did the vast majority of first class females survive?", "who were the females traveling third class, and what was their relation to those traveling in higher classes?" Such an outcome is frequently the result of an effective representation.

3.3.10 Chernoff Faces

Professor Chernoff, a statistician at Stanford University, observed that human beings are very sensitive to a wide range of human facial features. If you are debating a contentious point with a colleague, for example, and notice his eyebrow rise by just a millimeter, or see an almost imperceptible change in the shape of his mouth, you receive some powerful indication of his reaction to your words. Chernoff (1973) suggested that facial features – such as eye size and the length of a nose – are not only numerous (he identified 18) but could, in a cartoon face (Fig. 3.16) take on a sufficiently large number of 'values' to offer a useful encoding mechanism. He applied this idea to the study of geological samples, each characterized by 18 attributes including salt content and water content, and found that the display of so-called Chernoff Faces facilitated the identification of interesting groups of samples.

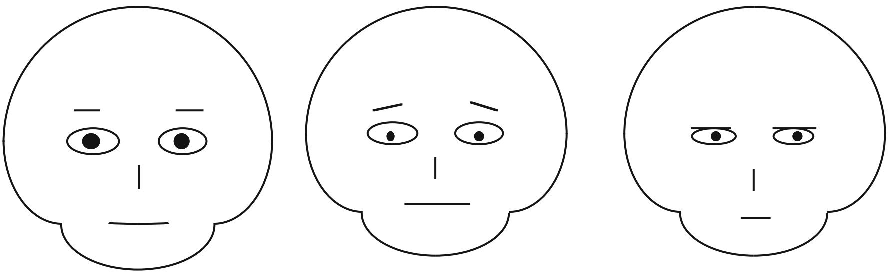


Fig. 3.16 There are many attributes of a cartoon face that can be used to encode data

3.3.11 Text

Given a body of text, it is often the case that some sort of fast and 'parallel' overview would be useful before beginning the detailed and often time-consuming sequential process of reading. The Word Cloud (Tag Cloud) has been advocated for this purpose. Briefly, it contains single key words found in a body of text, and presents those words in a compact 'cloud' in which the relative importance or frequency of occurrence of a keyword is encoded by its presented size, colour or other attribute(s), singly or in combination. The words in the cloud may be hyperlinked to relevant items. An example is shown in Fig. 3.17.

Tag Clouds, however, are not without their critics (http://www.nngroup.com/articles/tag-cloud-examples/).

Fig. 3.17 An example of a Tag Cloud (*Courtesy S. Anand*)

3.3.12 Time-Varying Data

As Aigner et al. (2011) remark, "Time is an exceptional dimension", and there are many examples of time-varying data into which we wish to gain insight. Indeed, Aiger et al. provide both a detailed study and a catalogue of relevant techniques, with a brief illustration of each. We select, as examples, two of the many available techniques.

3.3.12.1 ThemeRiver

The ThemeRiver technique (Havre et al. 2000) uses a 'river' metaphor to show changes in multivariate data over time. Figure 3.18, for example, shows a ThemeRiver representation of media mentions of news concerning Cuba around 1960 and 1961. Each topic is encoded as a coloured 'current' whose width can represent the number of reported items. The river itself provides an overview of the multivariate data, but accompanying annotation provides detail both of the content of each current as well as significant events occurring during the selected time period. The ThemeRiver technique can benefit from the freedom to select a time period of interest, to 'stretch' sections of the 'river' to keep other parts as context, and to interactively 'drill down' into the represented data.

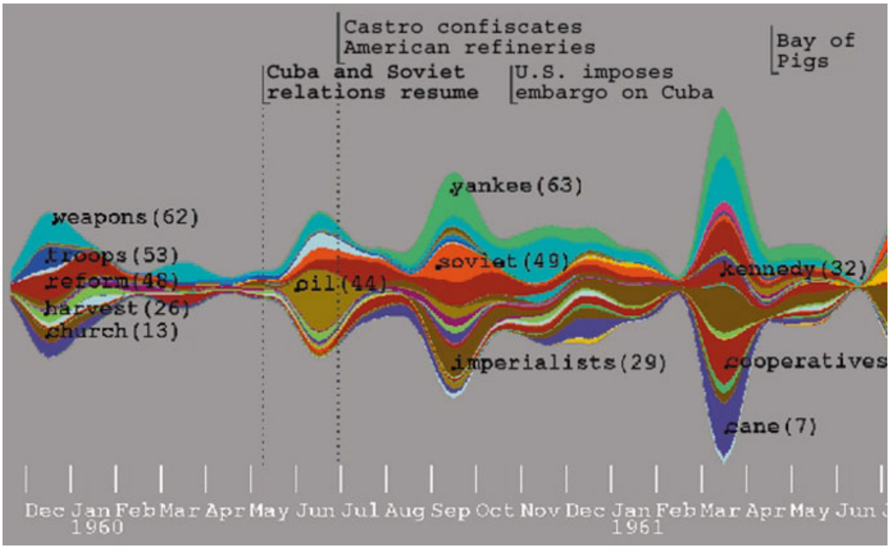


Fig. 3.18 An example of a ThemeRiver representation of the news concerning Cuba during the early 1960s (©2002 IEEE Reprinted, with permission, from Havre et al. 2002)

3.3.12.2 Arc Diagrams

A great deal of data takes the form of a string. The musical notation of a symphony provides one example, and a DNA sequence provides another. As with quantitative data it is often necessary to examine a string to identify significant features.

Where there are potentially interesting subsequences within a string it is useful to be able to represent them in a manner conducive to the acquisition of insight. For this purpose Wattenburg (2002) proposed the use of Arc Diagrams. The underlying principle is illustrated by an arc diagram representing the first line of the musical score of "Mary had a little lamb" (Fig. 3.19). Repeated sequences, of which there are three, are represented by semicircular arcs whose thickness is proportional to the length of the sequence and whose height represents the distance between sequences.

Wattenburg (2001) discussed the relevance of arc diagrams to DNA sequences which, of course, can be very long, and pointed to various issues involved. As Wattenburg remarked, many potential developments require investigation: the value of interaction (for example to specify the extent of subsequences to be displayed), a drill-down facility, and the use of colour encoding.

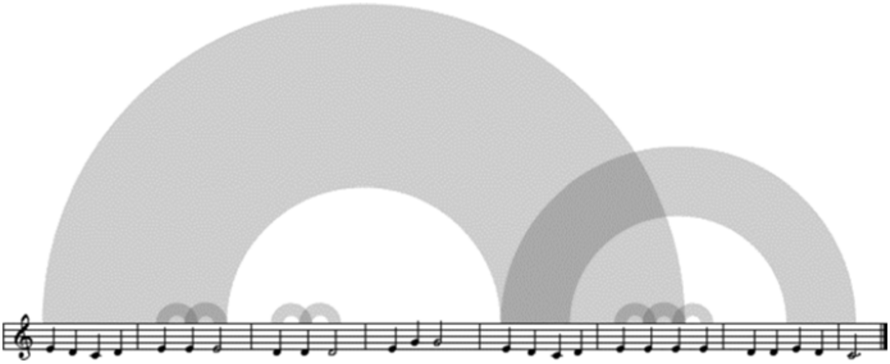


Fig. 3.19 An arc diagram representation of the first line of "Mary had a little lamb" (*Courtesy Martin Wattenburg*)

3.3.13 Closing Note

As already stated, the techniques briefly reviewed above have of necessity illustrated a fraction of those available. However, for the newcomer to information visualization there are plenty of well-illustrated books whose contents need only be glanced at to appreciate the many impressive techniques available for the representation of data. Here are some:

Now you see it by Stephen Few
Information is beautiful by David McCandless
Information Graphics Sandra Rendgen
Information Graphics Wildbur and Burke

Also, a visit to gapminder.com and a view of the irrepressible and entertaining Hans Rosling will provide some feeling for the potential of interaction and animation.

Happy and fruitful browsing!

3.4 The Human Factor

The aim of the previous Sect. 3.3 was to provide a simple introduction to representation techniques, at the same time illustrating the wide range of fields in which representation can be used to support the acquisition of insight into data. Intentionally, the treatment was kept simple, even though many perceptual and cognitive properties of users are such that the representation techniques must be applied with care.

Therefore, rather than simply presenting more techniques, of which there are many, we now go back and re-examine those already discussed and show how their use – or perhaps their redesign – depends crucially upon an understanding of the human visual system and a user's cognitive ability. The section headings now refer to the aspect of the human user that is particularly relevant.

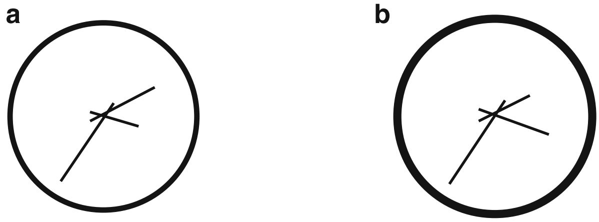


Fig. 3.20 Diagrammatic sketches showing two altimeter displays

Fig. 3.21 An image very similar to that shown in Fig. 3.22. The reader is invited to identify the difference (*Courtesy Christopher Healey*)

3.4.1 Change Blindness

We saw, in Sect. 3.3, an early altimeter (Fig. 3.1.3) together with the comment that it was the cause of many accidents. The obvious question is “why?” The reason is illustrated in the diagrammatic sketch of Fig. 3.20. The pilot looks at (a), observes that the aircraft is at a considerable height and therefore safe. Then, maybe after looking at other instruments, talking to the co-pilot and to air-traffic control, the pilot glances again at the altimeter (b) and observes no change, and concludes that safety is no problem. However, closer examination of (b) shows that the aircraft has dropped almost 20,000 ft. Such an experience is a result of what is called Change Blindness (Rensink 2002). Since most uses of visualization tools involve users being aware of some change, this human characteristic is significant in many situations, not just those involving altimeters. The reader can get an experience of Change Blindness by observing the image of Fig. 3.21 and attempting to identify how it differs from the image of Fig. 3.22 (www.csc.ncsu.edu/faculty/healey/PP/).

Fig. 3.22 An image very similar to that shown in Fig. 3.21. The reader is invited to identify the difference (*Courtesy Christopher Healey*)

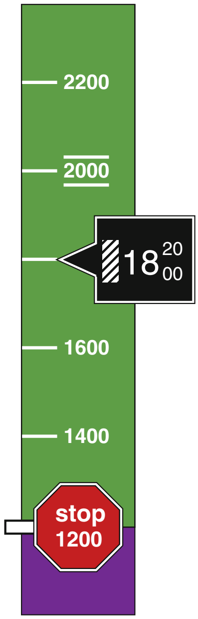


Fig. 3.23 A modern aircraft altimeter

The problems associated with the old altimeter and, of course, advances in technology, have led to the modern altimeter design shown in Fig. 3.23, and it is instructive to see how that design handles the various levels of information relevant to a pilot.

A first consideration, of course, is whether the aircraft is flying at a safe height. The answer is immediately (e.g., within about 250 ms) clear from the fact that a black area representing the plane lies within the green 'safe' region and not within the purple 'danger' region. For this purpose the numeric information is irrelevant. A second consideration is that the pilot should, to a reasonable approximation, be aware of height. This need is provided for by the white numbers on the green background. At this stage, as before, the numerical information within the black box is irrelevant. If more accurate information about aircraft height is needed, then that is available within the black box.

However, notice should be taken of the relative size of the numerals ‘1’ and ‘8’ compared with ‘2’ and ‘0’; this emphasises the fact that representation designs should always take careful note of a user’s convention namely, in this case, that pilots think in terms of hundreds of feet. A further source of insight for the pilot is the rate at which the ‘tens and units’ ‘wheel’ rotates, providing some feel for the rate of ascent or descent. The design of the modern aircraft altimeter provides an excellent illustration of some of the many considerations that must be addressed within a design.

3.4.2 Perception of Value

If a Star Plot employs the same scale for each attribute there is a temptation to interpret the area within it as indicating an overall ‘score’. This is not the case. Figure 3.24 shows two Star Plots representing identical data, the only difference being the order in which the attribute axes have been arranged. Thus, Star plots might not be a useful representation scheme for school reports, since the visual ranking of students could be in error. An alternative to Star Plots was, in fact, proposed by Florence Nightingale (Fig. 3.25) and used in her report (Nightingale 1858)[1] to the British Government

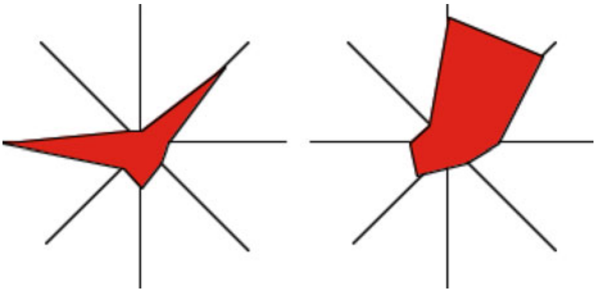


Fig. 3.24 The ordering of the attribute axes in a Star Plot can considerably affect the perception of overall scores. In this example the raw data is identical, only the attribute axis ordering is different

Fig. 3.25 Florence Nightingale

[1]The second half of this report contains food recipes of the day. However, it is strongly recommended that grim details of the Crimean hospitals should not be perused before eating Nightingale’s – or indeed anyone else’s – recipes!.

about hospital conditions in Scutari during the Crimean War of 1858. She devised the ‘rose’ diagram shown in Fig. 3.26, the principle of which is clarified in Fig. 3.27. The aim of the representation was to show the reduction in death rates in the hospitals of Scutari due to the improvements she had put in place. As Fig. 3.27 illustrates,

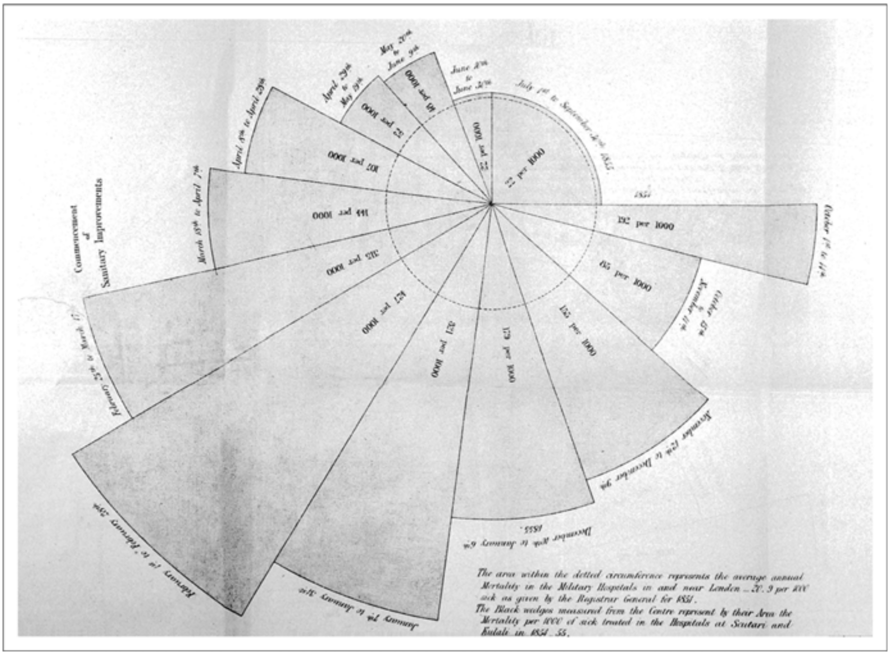


Fig. 3.26 Florence Nightingale’s diagram showing the dramatic reduction in death rates in the hospitals of Scutari following the changes she introduced

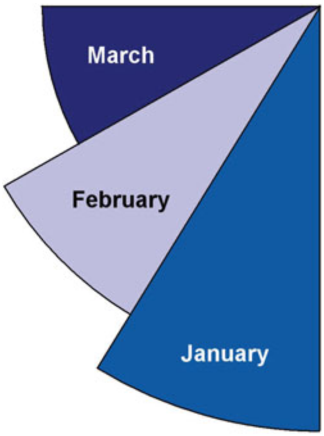


Fig. 3.27 Showing the principle of the Nightingale ‘Rose’ diagram

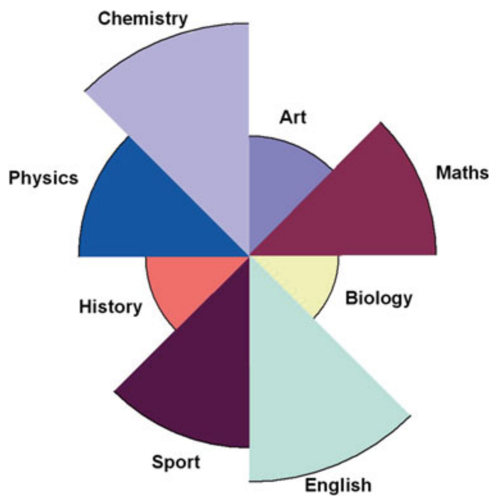


Fig. 3.28 Replacement of a Star Plot by a representation based on Nightingale's

each month is represented by a circular segment whose angle is proportional to the number of days in the month and whose area is proportional to the number of deaths during that month. Additional encoding, also to be found in Nightingale's original report, brings home the fact that most military deaths were not due to bullets, etc, but rather to disease – cholera, typhoid and dysentery. Her report also provides a simple comparison with the death rate at military hospitals in England.

To return to the Star Plot, we may now conclude that scores in eight subjects might better be represented by adopting Nightingale's 'rose' plot as shown in Fig. 3.28, where each subject's mark defines, not a point on an axis, but the area of a circular segment. The total enclosed area is then proportional to the total marks independently of how the subjects are ordered.

An obvious question arising from the above discussion is whether any experimental study has been carried out to determine the 'best' way of representing a single value and, indeed, to rank the most familiar methods. It has: it was carried out by Cleveland and McGill (1984) and its result is shown in Fig. 3.29. The result is not surprising, but should be applied with caution. For example, while colour density lies at one (apparently undesirable) extreme, we know that colour is used extensively on maps to indicate height: familiarity plays a part, as does the absence of many numerical values and the ability to easily acquire an overview of a region. Similarly we have seen by examples how area – fourth in the list – can be used effectively as with Nightingale-type representations.

But the pioneer in issues of this kind was Jacques Bertin (1967, 1981, 1983) (Fig. 3.30, inset), who identified four tasks common to information visualization and identified the encoding mechanisms suited to those tasks. He presented his conclusions in a diagram similar to that shown in Fig. 3.30, using the term 'mark' to

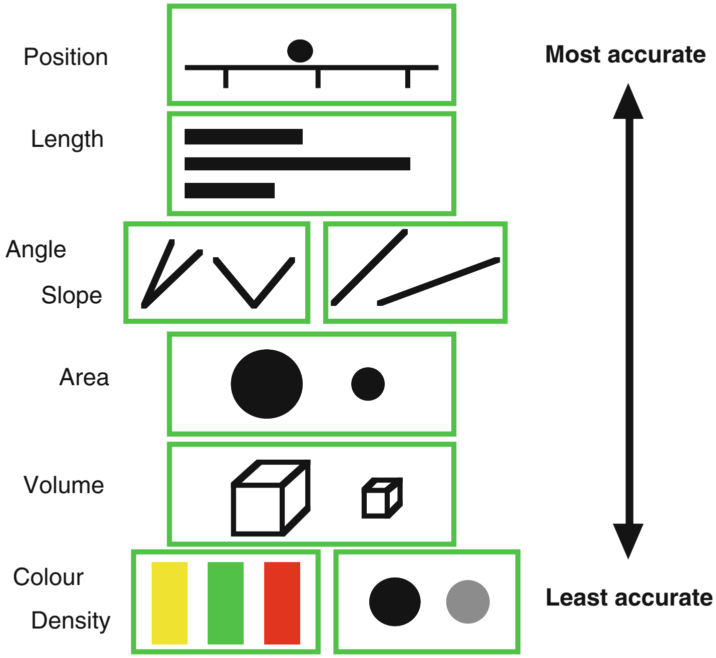


Fig. 3.29 The relative difficulty of assessing quantitative value as a function of encoding mechanism, as establish by Cleveland and McGill

denote the result of encoding (e.g., a line or a coloured circle). There are four columns associated with some fundamental tasks. They are:

Association: the question here is 'how well the marks can be perceived as similar'
Selection: here Bertin was concerned with whether the marks can be perceived as different, 'forming families';
Order: Can the marks be perceived as ordered?
Quantity: the question here is whether the marks can be perceived as proportional to each other.

The encoding mechanisms – *retinal variables* as they are often called – that he considered were size, value,[2] texture, colour, orientation and shape. As seen from Fig. 3.30, Bertin ordered these roughly according to the number of tasks each encoding mechanism can usefully support. Examination of the figure shows the guidance to be intuitively reasonable. However, the most appropriate encoding mechanism is very dependent upon context and the guidance is certainly open to debate.

[2] As defined by Bertin (1967, 1983, p 73), 'value' is not restricted to a grey scale. As Bertin remarks, "One can pass from black to white by greys, by blues or by reds …'

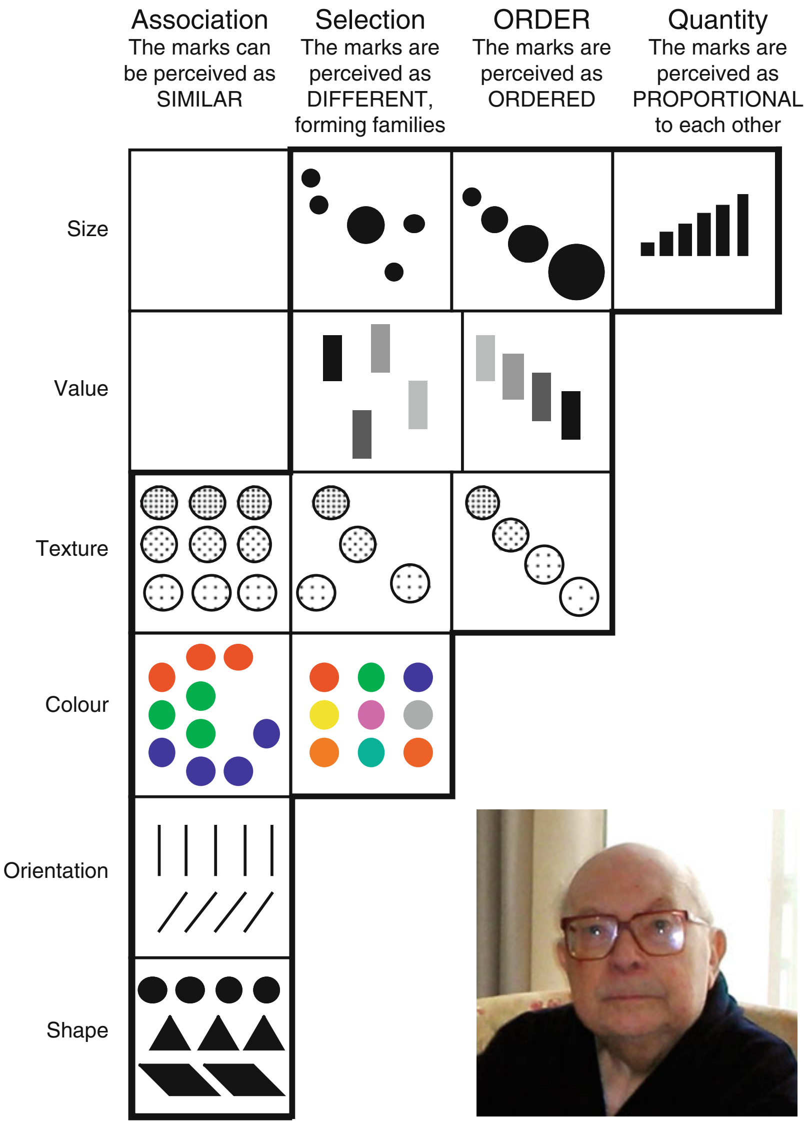


Fig. 3.30 Interpretation of Bertin's guidance regarding the suitability of various encoding methods to support common tasks (*Inset*: Jacques Bertin *Courtesy Dr. Brock Craft*)

3.4.3 Object and Attribute Visibility

Two related concepts have been proposed to help characterise a representation, and can be illustrated by examples already discussed. Take the example of a class of five students who have taken exams in eight subjects (the subject of Exercise 3.3).

We can employ a ‘Nightingale rose’ (Fig. 3.28) to characterise each student. But who would be the intended user of that diagram? Certainly the child and the parent, because both have an obvious interest in what the ‘rose’ is saying: the subject performance of the child. And a collection of five of these ‘roses’ – one for each student – might also be of interest in that a parent can then compare, qualitatively, their child’s performance with that of its classmates. But is the ‘rose’ representation of any value to the Head Teacher or the Subject teachers, apart from the opportunity it provides to ‘drill down’ into the performance of a particular child? No: for example, it might take careful examination to identify unsatisfactory overall scores achieved in some subjects, and perhaps draw conclusions about the quality of the teaching. By contrast, for the Head Teacher and Subject Teacher, a Parallel Coordinate plot (Siirtola 2000; Siirtola and Raiha 2006) may be a better representation (Fig. 3.31). It is then easier to spot the awful scores achieved in Physics and Chemistry, and to gain some feeling for overall class achievement in other subjects. But we can go a little further to assist the teachers in their study of exam results by using colour coding (red <50 %, green >50 %) to reflect average scores (Fig. 3.32) and allow some immediate assessment of the success of subject teaching.

Two concepts immediately relevant to our discussion are **object visibility** and **attribute visibility** (Teoh and Ma 2005). With object visibility, each object (e.g., student) is represented as a single and coherent visual entity such as a Nightingale rose (Fig. 3.28). This property is desirable when a user (e.g., parent) is interested in the attribute values (subject scores) of a specific child. Thus, the Nightingale rose representation exhibits object visibility, and so (Fig. 3.33) does the iconic representation of a dwelling, a star plot and a Chernoff face. In contrast, the parallel coordinate plot

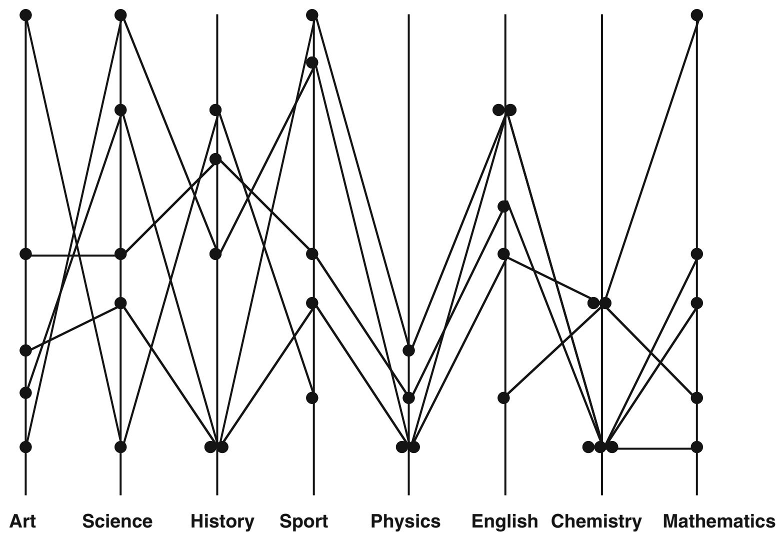


Fig. 3.31 A parallel Coordinate Plot of the scores achieved in eight subjects by five students

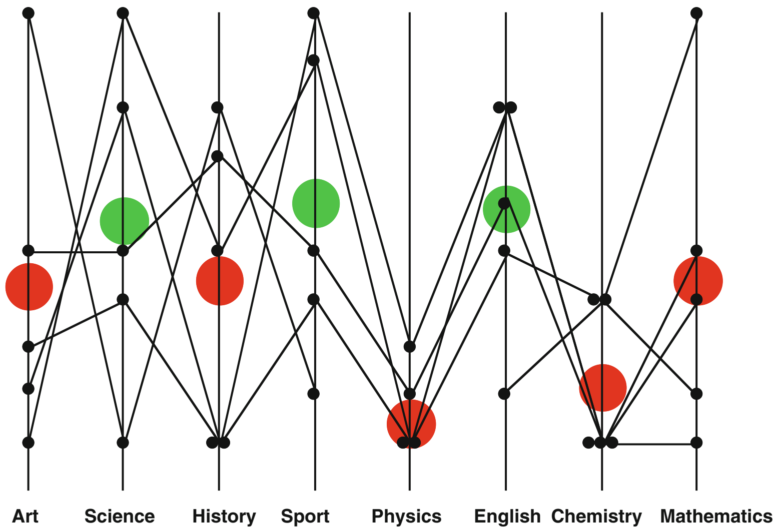
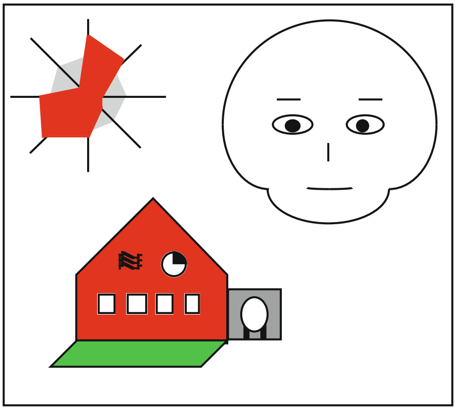


Fig. 3.32 The encoding of average subject scores in colour (red = pass. green = fail)

Fig. 3.33 Representations possessing object visibility



does not possess object visibility because, in Figs. 3.31 and 3.32, a given child's attributes are not described by a 'single visual entity' but rather by a collection of points joined together by straight lines. What the parallel coordinate plot *does* possess is *attribute visibility*: the score for a particular subject (attribute) over the whole class is easy to discern and, in some circumstances, correlations and trade-offs between subject scores may be easy to see.

Before leaving parallel coordinate plots it is useful to point out one obvious fact: the scores are represented by points, but the points are so small that they are overwhelmed by the connecting lines. Why make them small? Why not, for example, make them large and colour encoded according to the child to whom they refer

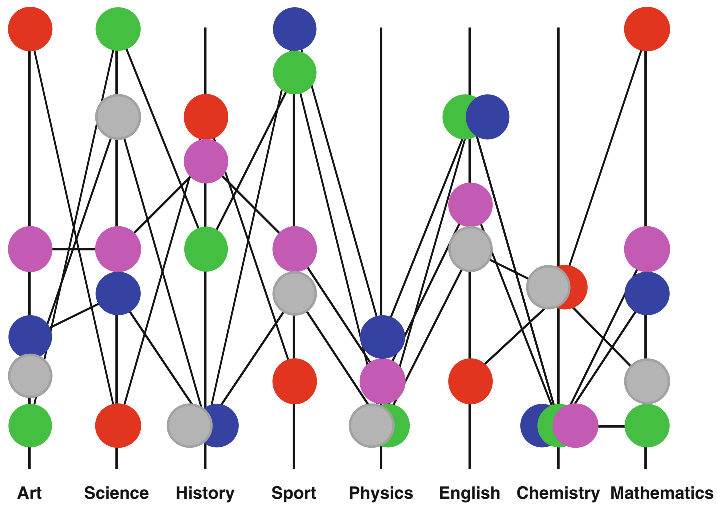


Fig. 3.34 Large points encoded with colour can be used to enhance visibility and perhaps allow a single student's scores to be more easily perceived

(Fig. 3.34)? The degree of object visibility may thereby be enhanced, but there are obvious disadvantages arising from scale, such as running out of colours that can be easily distinguished, a problem with the current map of the London Underground.

3.4.3.1 Further Reading

In an introductory book it is inappropriate to discuss all the many design considerations influenced by human perception and cognition, especially since an excellent reference is already available. Especially in his third edition, Ware (2012), in his own words, " . . make(s) the design implications of research in perception clearer" and, indeed, provides, throughout his text, many succinct and detailed guidelines of immediate value to interaction and visual designers.

3.5 Interaction

Techniques for the static representation of data were discussed in Sect. 3.2 and have an immense range of applications; after all, reports and displays are extensive and make good use of data representations. What we examine in this section is how the power of those representation techniques can be enhanced, often to a very great extent, by their ability to change in response to interaction by a user, or simply by their ability to 'move'. From the many techniques available we choose five for illustration.

3.5.1 Reordering

A very simple example of the use of interaction is provided by the illustration of Fig. 3.35 in which interaction has resulted simply in the rearrangement of data. Part (a) shows the results of experiments carried out on a collection of crops (1, 2 … 10) subject to a range of treatments (A–F), with black indicating that a treatment was successful, and white the reverse. Little insight can be gained from this representation. However, a simple automatic rearrangement of rows and columns results in the representation of Fig. 3.35b, in which a pattern is immediately noticeable and, in all probability, leads to many questions regarding the nature of certain crops and the corresponding beneficial treatments. The Figure provides just one example of the value of taking a different view of data.

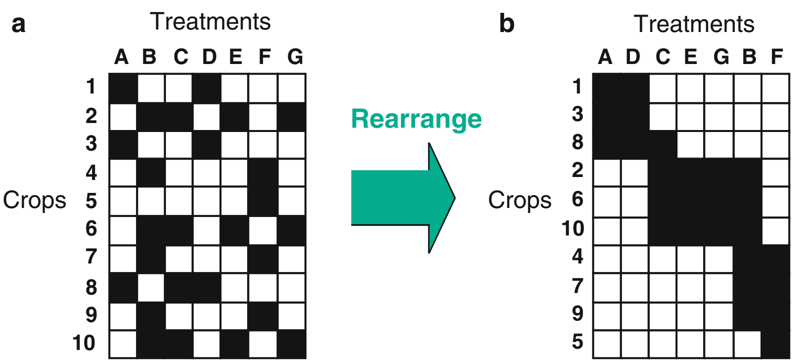


Fig. 3.35 A simple rearrangement of rows and columns can lead to a representation permitting greater insight into the underlying data. Here, black squares indicate the successful treatment of a crop, while white squares indicate the opposite

3.5.2 Filtering

It is often helpful to the process of acquiring insight to remove irrelevant data although, as we shall see in the discussion of the Attribute Explorer (Sect. 3.5.4) one must be very careful before deeming certain data irrelevant. A simple example of filtering is illustrated in Fig. 3.36 by the Dynamic Queries interface (Williamson and Shneiderman 1992). Sliders allow limits to be placed on house price, number of bedrooms and time to reach one's workplace, whereupon only those houses satisfying all those limits are represented by red dots on a map. The Dynamic Queries interface is selected as an example to illustrate certain issues associated with interaction in Chap. 5, Sect. 5.2.

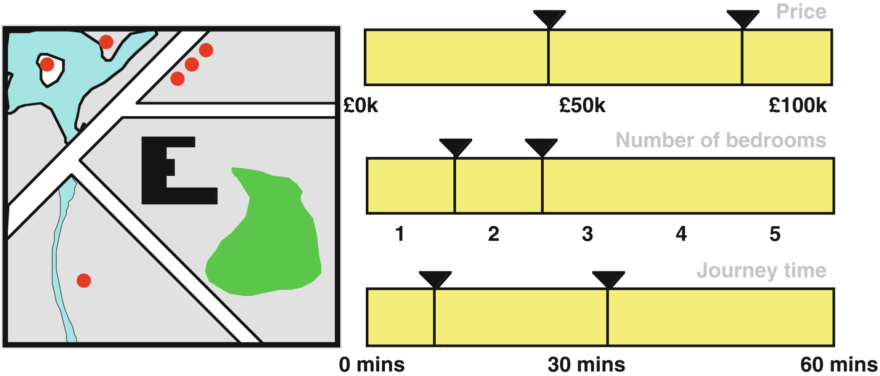


Fig. 3.36 Outline sketch of a Dynamic Queries interface supporting the exploration of the location of houses satisfying specified limits on three attributes

3.5.3 Parallel Coordinate Plots

The Parallel Coordinate Plot (Inselberg 1985) representation technique was introduced in its static form in Sect. 3.3. In that form it does have some useful features, but drawbacks arise from its inflexibility. However, the potential of this technique can be immensely enhanced if interaction is permitted, as will be apparent from the examples we now discuss.

The interactive selection of attribute limits – either singly or in combination – results in those polylines representing objects satisfying those limits being highlighted, as shown in Fig. 3.37 which relates to a collection of 406 cars and contains data for each of 9 dimensions. There are 406 polylines, and the user has interactively assigned lower and upper limits to three attributes: MPG, weight and the 0–60 mph acceleration time. To maintain context, the polylines of all cars failing any one or more of those limits are still visible, but are dimmed. The investigator can now explore the data set by interactively and smoothly varying either the position of a range, or the limits, on any of the three attributes, and viewing the consequential changes. A specific outcome of interacting with the representation of Fig. 3.37 by moving the range of 1 year up and down the Year coordinate was to notice that, following the oil crisis in 1973, there was a trend towards better mileage, a drift from eight and six cylinder engines towards more economical four-cylinder engines, a decline of engine displacement and horsepower, and a trend towards lighter vehicles.

Other valuable features of interactive parallel coordinate plots are illustrated in the three following figures. Figure 3.38 shows that, on request, a modified Tukey Box Plot can be provided for any coordinate.[3] Figure 3.39 shows the result of a more complex

[3] Only the 25 %, 50 % (median) and 75 % quartiles are shown. Whiskers are omitted to reduce visual clutter.

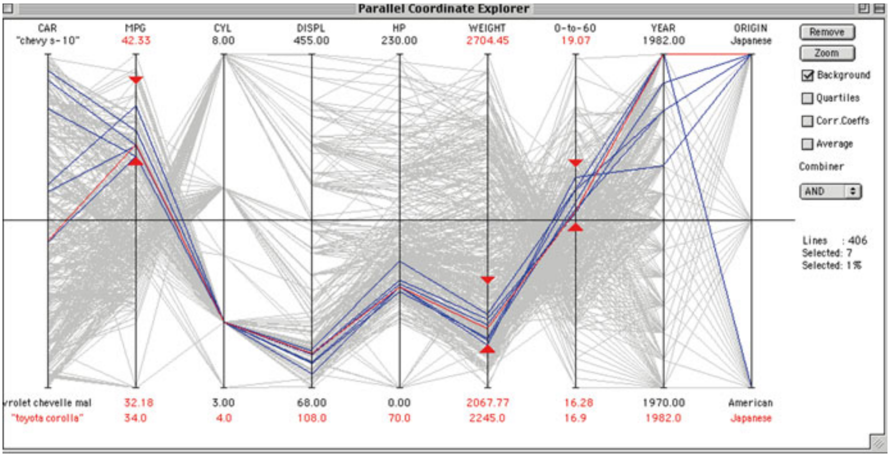


Fig. 3.37 A parallel coordinate plot representation of 406 cars, each characterised by nine attributes. From *left* to *right* they are: Make and model (CAR); fuel economy (MPG); Number of cylinders in the engine (CYL); engine displacement in cubic inches (DISPL); output of engine (HP); vehicle weight in US pounds (WEIGHT); 0–60 mph acceleration time (0–60); model year (YEAR) and origin (ORIGIN). Upper and lower limits have been placed on three attributes, causing the polylines associated with cars satisfying all three limits to be highlighted. One of the polylines has been selected and automatically encoded *red*, with the corresponding attribute values indicated, also in *red*, below the axes (©2000 IEEE Reprinted, with permission, from Siirtola 2000)

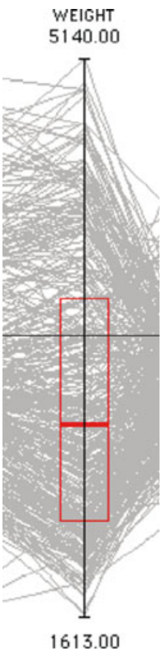


Fig. 3.38 Tukey Box Plots are available for all attributes (©2000 IEEE Reprinted, with permission, from Siirtola 2000)

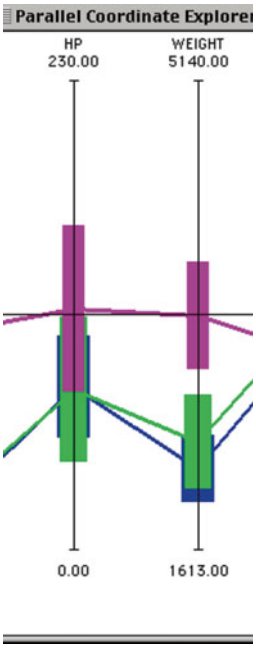


Fig. 3.39 A comparison of the average values and standard deviations of HP and WEIGHT for American (*purple*), European (*green*) and Japanese (*Blue*) cars (©2000 IEEE Reprinted, with permission, from Siirtola 2000)

enquiry, allowing a comparison of American (purple), European (green) and Japanese (blue) cars in the database with regard to HP and weight. Here, polylines have been replaced by lines passing through their average values, and correspondingly coloured bars represent one standard deviation above and below the average. From this display we see that European and Japanese cars are almost identical with regard to HP and weight, while American cars are heavier and have better HP.

The last of many possible illustrations of the versatility of interactive parallel coordinate plots is shown in Fig. 3.40. We first recall from Fig. 3.12 that for attributes exhibiting strong correlation a distinctive pattern of polylines was evident, whereas for negative correlation a very different pattern was noticeable. In Fig. 3.40 these two situations are illustrated: automatically generated green and red bars, respectively, supplement existing patterns with more noticeable indications of correlation.

More detail of the advantages of parallel coordinate plots has been described by Siirtola (2000), Siirtola and Raiha (2006) and Inselberg and Dimsdale (1990).

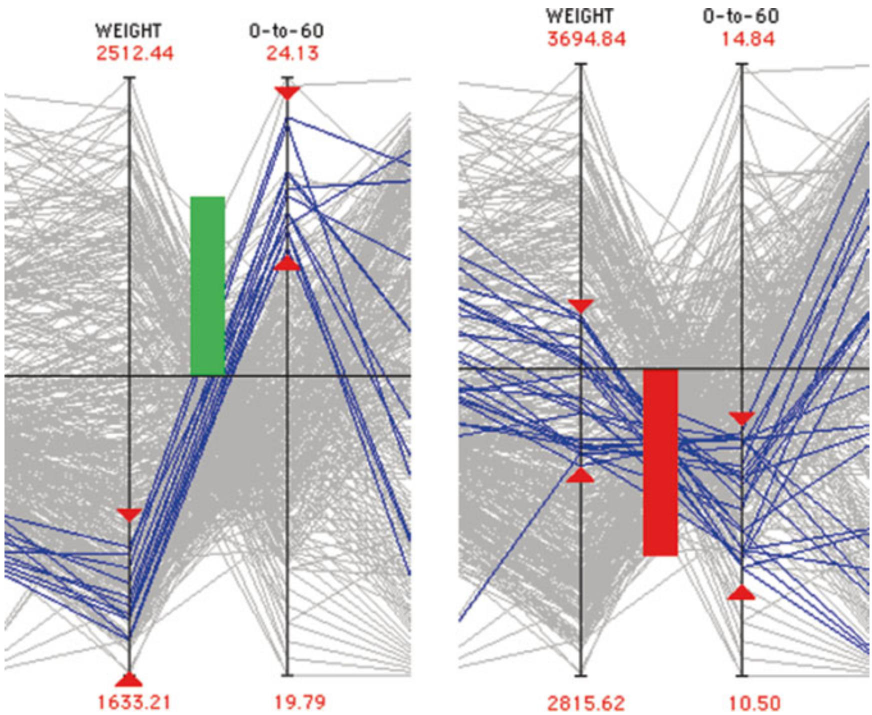


Fig. 3.40 Correlation between the attributes within selected adjacent subsets can be represented by appropriately *coloured bars* (©2000 IEEE Reprinted, with permission, from Siirtola 2000)

3.5.4 Brushed Histograms

We return to the task that was used in Chap. 2 to identify issues associated with information visualization – that of finding a car to buy. A user engaged in this activity will formulate many questions: for example, "I want to spend no more than £5,000 on the next car, but it must have a reasonably high Miles-per-gallon (MPG) and preferably be of Japanese manufacture". After a while a familiar question may be of the type "I wonder what choice would be available if I could spend another £500".

An interactive visualization tool called the Attribute Explorer (Tweedie et al. 1994; Spence and Tweedie 1998) employs brushed histograms to support such a task as well as many others.

The principle of the Attribute Explorer can be explained by considering the Price and MPG rating of a collection of 50 cars. Histograms A and B of Fig. 3.41 represent that data. By themselves, as static representations, the two histograms serve a useful purpose, giving the user an overview of the data. Each car is represented in both histograms, as illustrated in Fig. 3.42.

But one thing that is missing from the combined histograms A and B is, of course, the *relation* between Price and MPG; an inexpensive car could, for example, be associated with a low, medium or high MPG and this would not be evident from

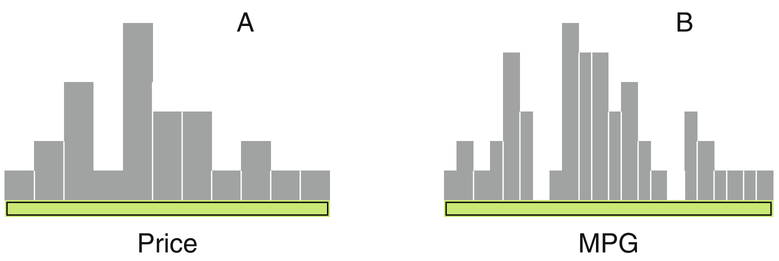


Fig. 3.41 Histograms of two attributes (Price and Miles per Gallon) of a collection of cars

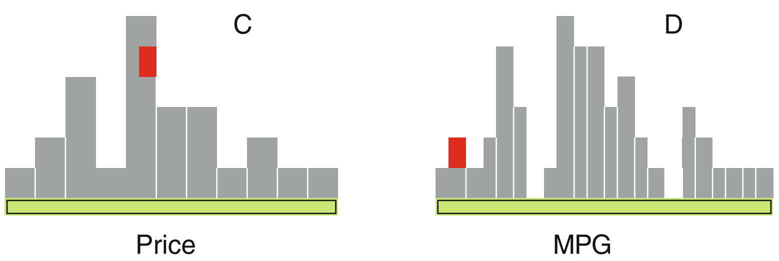


Fig. 3.42 A single car contributes to both histograms

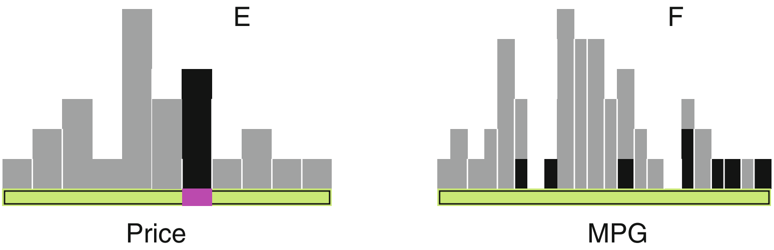


Fig. 3.43 Cars selected by a Price range are brushed to the MPG histogram

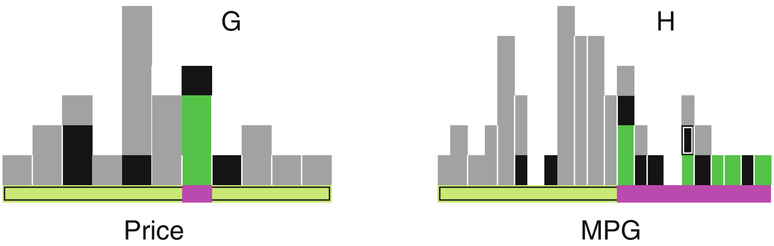


Fig. 3.44 Additional specification of a range of MPG now shows, as *green*, cars that satisfy both specifications. Cars that fail one of the specifications are coded *black*. *Grey* cars fail two limits

the two histograms. Some idea of this relation, however, can be gained by the selection of a group of cars defined by a price range, as shown in histogram E in Fig. 3.43. Now, all the cars whose Price falls within the selected attribute range are coloured black, not only in the histogram (Price) where the selection was made but also in the second histogram (MPG). We say that the selection of Price has been *brushed* into the second histogram, based on the underlying car data represented by the two histograms. Note that black houses fail one requirement – the limit placed on the Price attribute. Figure 3.43 immediately illustrates advantages that accrue from the ability to *interactively* adjust limits. For example, smooth movement of the combined lower and upper Price limits and observation of the corresponding changes on the MPG histogram can provide a useful exploratory overview of any trade-off between Price and MPG.

The user may now decide to specify a minimum acceptable MPG as shown by the purple selection bar in H of Fig. 3.44. This and the previous Price selection results in those cars that satisfy *both* the selections on Price and MPG being encoded green on both histograms (there are eight such cars). Black encoding, as before, still identifies those cars that fail one requirement.

3.5.4.1 Sensitivity

Why should the black encoding be of interest? For a very important reason indeed: it tells the user what relaxation of a limit on one attribute will lead to more houses satisfying the combined limits, and thereby supports exploration. This knowledge is especially useful in the case of 'near misses' where, for example, a very small increase in Price might identify houses of potential interest. The value of the black houses is illustrated in Fig. 3.45. Here, the upper limit on Price has been increased by a small amount to include two previously black houses (refer to histogram G), whereupon brushing into the MPG histogram occurs and changes the corresponding black houses to green. In this way the black encoding provides *sensitivity information* that explicitly tells a user how many additional houses would satisfy all limits if a specific limit were to be relaxed: recall the question "I wonder what choice would be available if I could spend another £500".

The value of sensitivity information is highlighted by an example in which it is absent. In Fig. 3.46 all cars coded black and grey are removed. The user is consequently given no guidance as to the effect of adjusting attribute limits, and exploration becomes challenging. Another example of the value of sensitivity information is provided by Fig. 3.47. A user seeking a house has placed limits on its Price, the Number of Bedrooms and the size of the garden, not realizing that no house is available that satisfies those *combined* limits. Fortunately it is obvious, from the positions of black houses lying outside the limits, what changes – some attractively

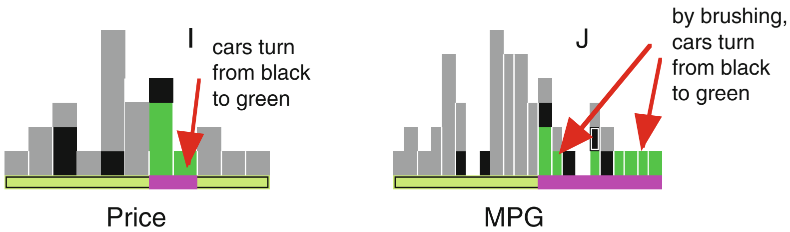


Fig. 3.45 The upper Price limit has been increased to include a *black* car, which now turns *green*

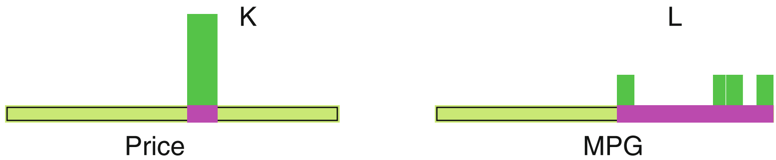


Fig. 3.46 The appearance of the histograms G and H when sensitivity information has been removed

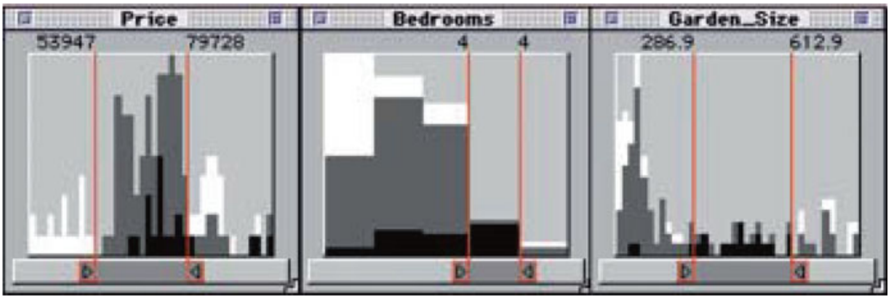


Fig. 3.47 Illustrating actions suggested by the *black* sensitivity data that will lead to the appearance of one or more *green* houses satisfying the new attribute limits

small – need to be made to convert a ‘near miss’ situation to one in which ‘green’ houses can be examined to see if they are acceptable. The situation depicted in Fig. 3.47 is often encountered during the use of estate agent websites in which no indication is given as to how attribute limits might usefully be adjusted.

Potential applications of the Attribute Explorer become apparent in many situations: when trying to arrange flights on specific dates at convenient times at affordable cost and with few stopovers, or when trying to decide which mobile telephone, tablet or washing machine to purchase. Combination with other techniques could prove useful, such as the availability of a histogram along each axis of a parallel coordinate plot and the consequent facility to explore attribute correlations and trade-offs. The effectiveness of the Attribute Explorer has been studied (Li and North 2003) by comparing it with a Dynamic Query interface (see Sect. 3.5.2) in the context of a number of tasks. It was observed that the ‘brushing histograms’ as the Attribute Explorer was called, tended to offer advantages with the more complex tasks.

While originally invented to support the selection of one object from many on the basis of its attribute values, the Attribute Explorer also offers considerable potential to support exploration with the goal of acquiring insight into data. Two examples of its use as an investigative tool are provided in the Case studies of Chap. 7. One is its application to the study of communication during emergency situations and the other is its use to analyse activities taking place during a football match.

3.5.5 Bargrams

The EZChooser (Wittenburg et al. 2001) has already been visited in Chap. 2 during an identification of the issues raised by information visualization. Nevertheless, in view of its exploitation of interactivity it is appropriate to revisit the interface here and elaborate briefly upon relevant features (Fig. 3.48).

Two features are of particular relevance to a discussion of interaction. One is the straightforward specification of acceptable attribute ranges by simple bargram interaction, thereby defining a logical AND operation between attribute ranges. Another is the representation, by outline cars above the bargrams, of objects – cars in this case – that fail only one of the attribute specifications, a feature that relaxes the need for unrealistic precision and goes some way towards supporting exploration. Another important feature, also exploited by other interfaces reviewed in this section, is the use of brushing to identify a particular car on all bargrams and within the car images.

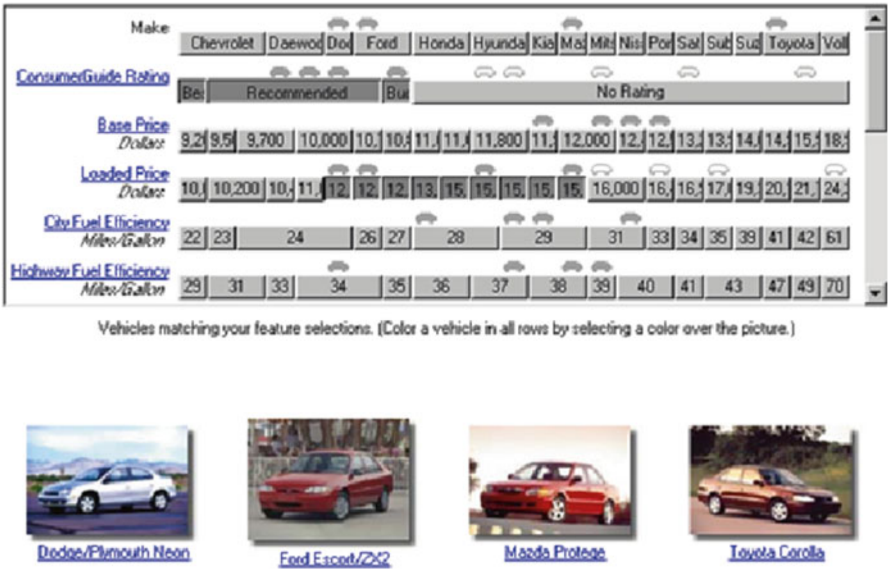


Fig. 3.48 An example of the EZChooser interface. The outline cars above bargrams identify cars that fail only one of the selected attribute ranges (*Courtesy Kent Wittenburg*)

3.5.6 Scatterplot Matrices

The Scatterplot technique for the representation of binary data was introduced in Sect. 3.3 but considered there as a static representation. We now examine the opportunities offered by its extension both to multivariate data and to the provision of interaction.

The basic two-attribute scatterplot was introduced in Sect. 3.3 as a way of representing bivariate data, but would be of little interest if it did not extend to multivariate data. A simple illustration of how such an extension can be valuable is provided by the drawbacks associated with the use of a familiar 'three-dimensional' coordinate system to represent four houses possessing three attributes (Price, Number of bedrooms, journey Time to work) as shown in Fig. 3.49 (left). A major problem with this representation, of course, is that relative as well as absolute values are extremely

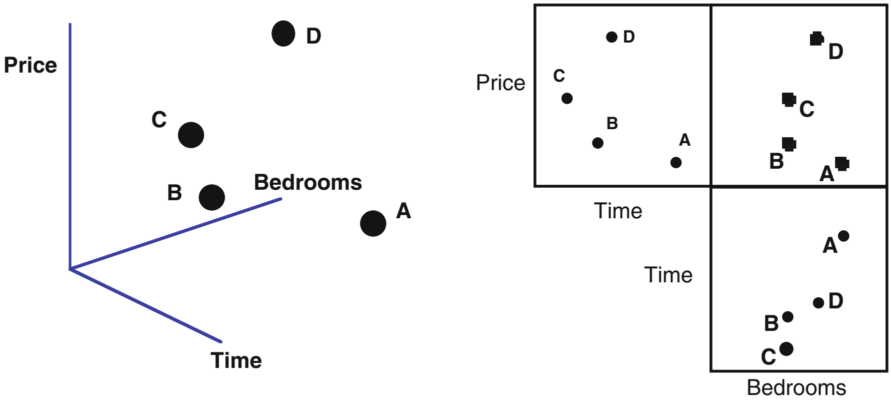


Fig. 3.49 (*left*) A conventional '3D' representation of the attribute values of four objects. (*right*) The result of projecting the four points onto planes, each containing a pair of attribute axes. For clarity, absolute attribute values have intentionally been omitted

difficult to judge. Does House A, for example, cost more than House B? However, projections of the four points onto three planes, each defined by a different pair of attribute axes, allows both relative and absolute values to be noted (Fig. 3.49 right). It is now obvious that house B costs more than house A. The alignment of the component two-dimensional scatterplots as shown in the figure is known as a Scatterplot Matrix.

The concept of a Scatterplot Matrix will extend to any application having many more than four objects and three attributes. Nevertheless, such an extension brings with it a number of problems, some quite daunting. One concerns user acceptability: we note the remark of Matthew Ericson[4] to the effect that two-dimensional scatterplots are considered too difficult to understand for readers of the New York Times except when one of the axes is time. Not an auspicious beginning when considering an extension to scatterplot *matrices*! Next, the association of a label with each object (point) would be a challenge due to the lack of space. Furthermore, as the number of attributes increases, the number of component scatterplots in the matrix increases factorially, not linearly, so that 2, 3, 4 and 5 attributes require matrices with 1, 3, 6 and 10 component scatterplots. A glance at a scatterplot matrix (Fig. 3.50) representation of 1,000 cameras, each characterized by 13 attributes, reveals an additional challenge, that of navigating through such a representation.

Bearing in mind the drawbacks we have identified, how can a user be helped to gain insight into data represented by a scatterplot matrix? One solution is to introduce interactivity: in the very simple case shown in Fig. 3.51 the selection of low cost houses – perhaps by a 'rectangular lassoing' action – leads to the same houses being highlighted within the remaining scatterplots, thereby allowing the user to form some mental model of the general relations between attributes for a given collection of objects. Such an activity is the *brushing* technique encountered earlier. A

[4]A comment taken from Matthew Ericson's keynote address at IEEE InfoVis 2007.

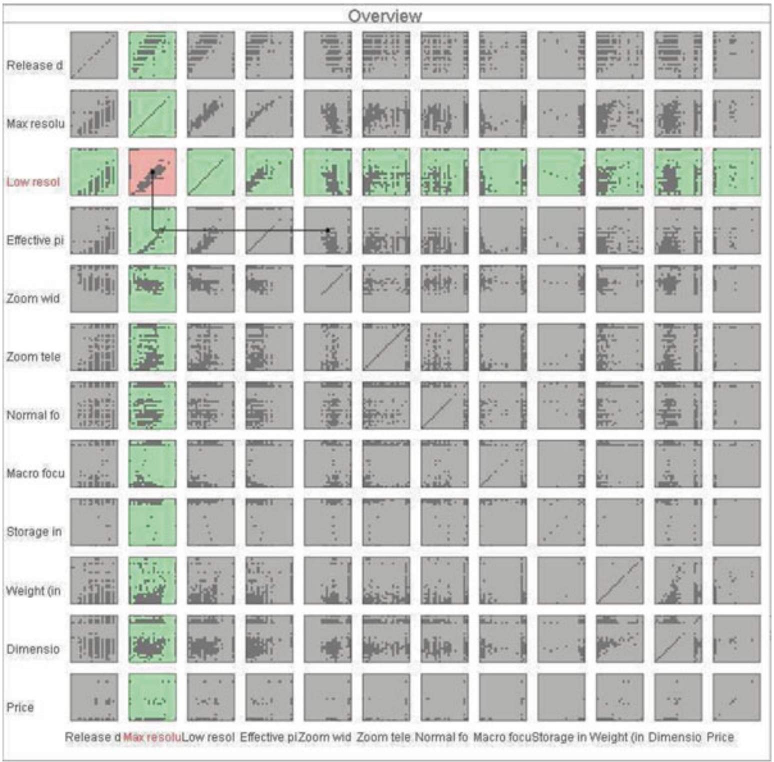


Fig. 3.50 showing the extent of a scatterplot matrix representation of 1,000 cameras characterised by 13 attributes, and involving 45,000 points (©2008 IEEE Reprinted, with permission, from Elmqvist et al. 2008)

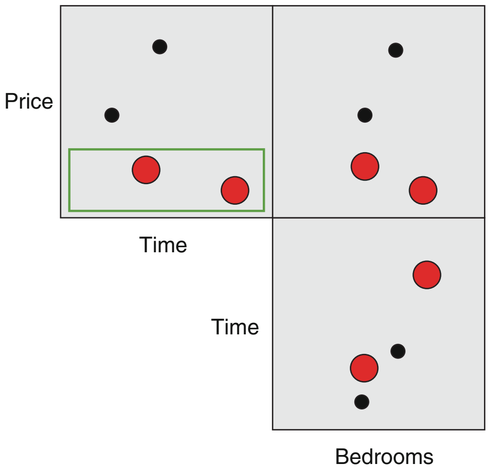


Fig. 3.51 Illustrating interaction within one plane of a scatterplot matrix, and the brushing of selected points into the remaining planes

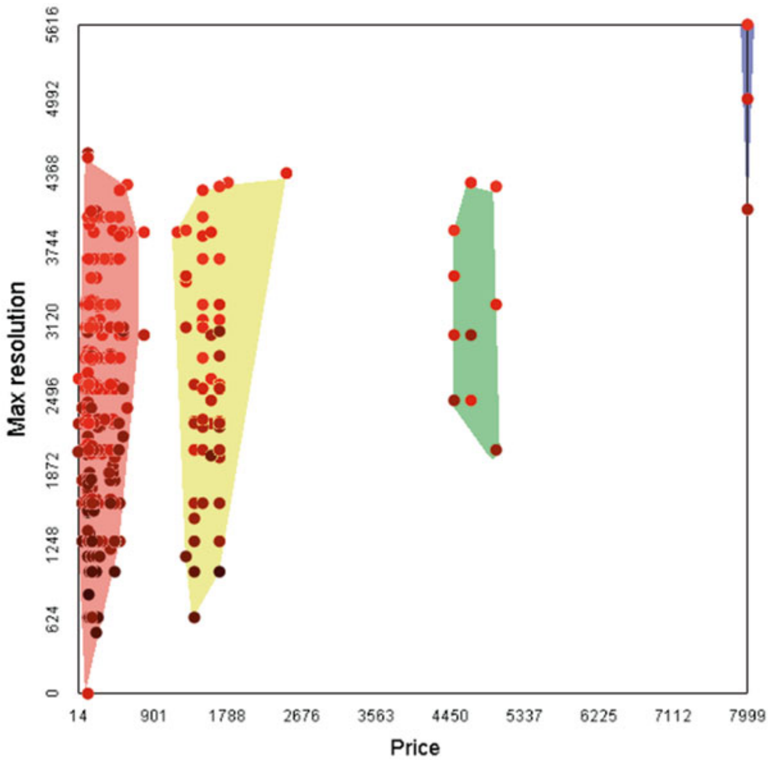


Fig. 3.52 Illustrating the result of sculpting an enquiry in 2-dimensional space (©2008 IEEE Reprinted, with permission, from Elmqvist et al. 2008)

detailed – but nevertheless important – observation is that a temporary (e.g., 1 s) enlargement of associated points can go a long way towards overcoming the effects of Change Blindness: a change from a very small black point to an equally small red point is not easy to detect, especially with widely dispersed points.

Using as an illustration the task faced by a person wishing to buy a camera, and who is provided with details of 1,000 available cameras, each characterised by 13 attributes,[5] Elmqvist et al. (2008) describe a number of techniques used to ameliorate many of the drawbacks otherwise associated with scatterplot matrices.

First, they allowed users to *sculpt* their queries by 'drawing' a line around points that are of interest, as shown for Price in Fig. 3.52. Next, they supported smooth transition between individual scatterplots, acknowledging the well-known fact that sudden changes in the layout of a representation can be disruptive because they

[5]The 13 attributes are: Model; Release date; Max resolution; Low resolution; Effective pixels; Zoom wide (W); Zoom tele (T); Normal focus range; Macro focus range; Storage included; Weight (inc. batteries); Dimensions; Price.

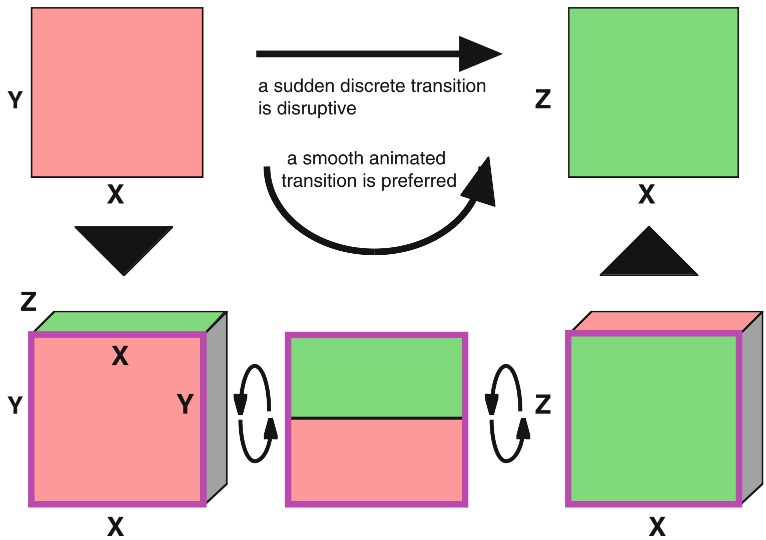


Fig. 3.53 Diagrammatic illustration of a smooth animated transition between scatterplots sharing a common coordinate. *Brown* represents the starting scatterplot, and *green* the desired final scatterplot. *Purple frames* show the view experienced by a user

prevent users from tracking changes over time.[6] Animated transitions (Fig. 3.53) allow a user to begin with a view of a scatterplot having axes x and y; then introduce a third dimension z providing a view of 'depth'; then animating a rotation so that the 3D 'box' rotates to provide a full view of axes x and z (a new scatterplot) with y as the depth dimension; finally, to remove the new depth dimension. More detail, and a view of the animation in action, can be found at http://www.aviz.fr/~fekete/scatterdice/. The animated transition is one of the techniques that can support navigation through a large scatterplot matrix.

An ever present problem with the use of a scatterplot matrix is, however, the rapid increase in the number of component scatterplots as the number of attributes increases. By contrast, the number of histograms in the Attribute Explorer for 1, 2, 3, 4 and 5 attributes is, respectively, 1, 2, 3, 4 and 5, a linear as opposed to a factorial relation.

3.5.7 Summary

It is useful to summarise the advantages that can accrue from interaction and movement, as illustrated by the examples in this section:

- Graphical rearrangement exploiting the human being's ability to perceive visual patterns (Crop data, 3.5.1)
- Filtering, to remove data judged to be irrelevant (3.5.2)

[6]The beneficial effect of animated transitions is revisited in Sect. 3.6.

- Brushing to highlight links between objects and attributes (Parallel Coordinate plots, 3.5.3; EZChooser, 3.5.5; Attribute Explorer, 3.5.4; Scatterplot Matrices, 3.5.6)
- Ability to exploit sensitivity information, especially during exploration (Attribute Explorer 3.5.4; EZChooser, 3.5.5)
- Fluent use of logical operations (EZChooser, 3.5.5; Attribute Explorer, 3.5.4)
- Smooth variation of limits and ranges to support dynamic exploration (Parallel Coordinate Plots, 3.5.3; Attribute Explorer, 3.5.4)
- Smooth animated transitions between views to avoid the disruptive effect of sudden transitions (Scatterplot Matrices, 3.5.6)

There are, of course, many other examples illustrating the potential offered by interaction and movement. Chapter 7 is specifically devoted to interaction and its design.

3.6 Relations and Connections

A great deal of data has to do with relations. The genealogist is tracing the antecedents of John Smith. A fraud investigator needs to know if a suspect was in Los Angeles when a bank transfer was made. A tourist wants to know which metro lines link a nearby station to his destination. And a history teacher is seeking a way to describe warfare in Anglo-Saxon England that will be memorable for her students.

The examples that follow have been selected to illustrate important concepts associated with the representation of relations, concepts that are pivotal to the formation of a mental model of those relations. In the illustrative examples it should not be found surprising that the representation of value is additionally involved, or that encoding techniques for value are equally useful for relations.[7]

The illustrations will be separated into general networks and then an important subset that relates to hierarchical relations.

3.6.1 General Networks

3.6.1.1 History

Fundamental to the representation of relations is the concept of **nodes** and **links**, a concept illustrated in Fig. 3.54 which provides a representation of warfare in Anglo-Saxon England between 550 AD and 700 AD (Arnold 1997). For each

[7] Many representations of relational data require prior, and sometimes extensive, computation. This important topic is extensive and is not the subject of this book.

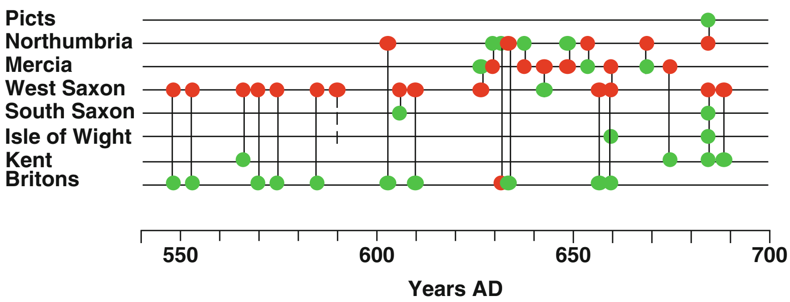


Fig. 3.54 The incidence of warfare in early Anglo-Saxon England between 550 AD and 700 AD. *Red* denotes the aggressor, *green* the attacked

encounter represented by a link between tribes, a red node indicates the aggressor and a green node the attacked. The war-like nature of the West Saxons immediately stands out, as does the fact that Britons continually took a beating. The representation of Fig. 3.54 not only presents data in a form more comprehensible (for me!) than text, but additionally triggers fascinating questions: How were the various tribes positioned geographically? Did rivers or mountain ranges inhibit otherwise possible conflicts?

3.6.1.2 Fraud

An example of the detection of mortgage fraud is one of the striking illustrations of the value of information visualization. Fraud investigators provided with printed data took eight person-years to (successfully) identify the perpetrator, a figure that was reduced by around 100 times when an interactive display of recorded data was provided. Not only was the time involved drastically reduced – the final form of the display indicated clearly the identity of a hitherto unknown master criminal.

Figure 3.55 is a representation of mortgage activity. Nodes on the periphery are associated with major actors (Lenders, Estate Agents, etc.) arranged in groups, and the connections between them (e.g., Applicant X *borrows* from Lender Q) are represented by straight lines within the inner circular area. In the form shown in the figure very little if any insight can be gained. However, by interactively excluding normal house purchases, a pattern (Fig. 3.56) began to emerge providing the investigator with evidence leading to the arrest of a person suspected of engaging in mortgage fraud (Davidson 1993; Westphal and Blaxton 1998).

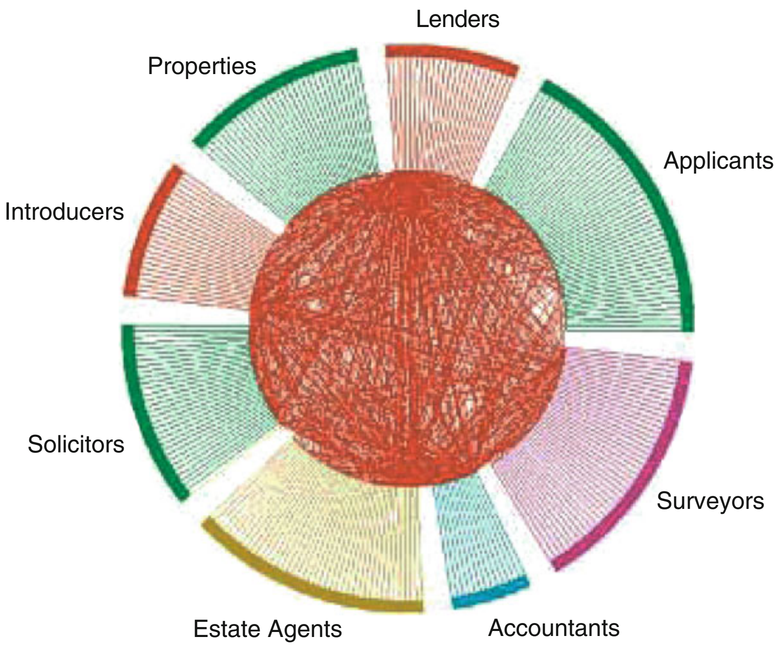


Fig. 3.55 A representation of mortgage activity

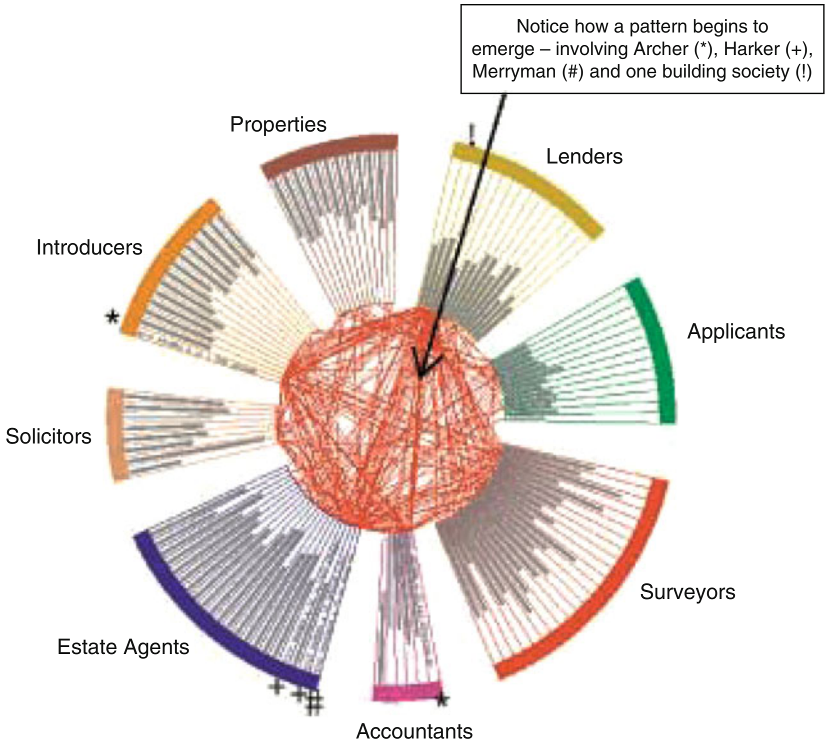


Fig. 3.56 The result of suppressing normal activity

3.6.1.3 Intelligence Analysis

Many techniques employed for the representation of relations fall within the umbrella term of intelligence analysis. A simple illustration is shown in Fig. 3.57: it is far easier to gain insight into the nature (*not* the content) of a collection of telephone calls from a node-link representation (centre) than from a list, and even more insight can be obtained if analysis of the node-link network can identify separate components (right).

Many powerful visualisation tools have been developed to support tasks that fall within the umbrella term of intelligence analysis. One such is IBM® i2® Analyst's Notebook® which is used widely for law enforcement and forensic investigations. Figure 3.58 shows a fictional chart depicting associations within a criminal network, with node representation enhanced by images and coloured frames.

Similar diagrammatic representations are used for a wide variety of fields, including (Fig. 3.59) the ties of friendship among Facebook users.

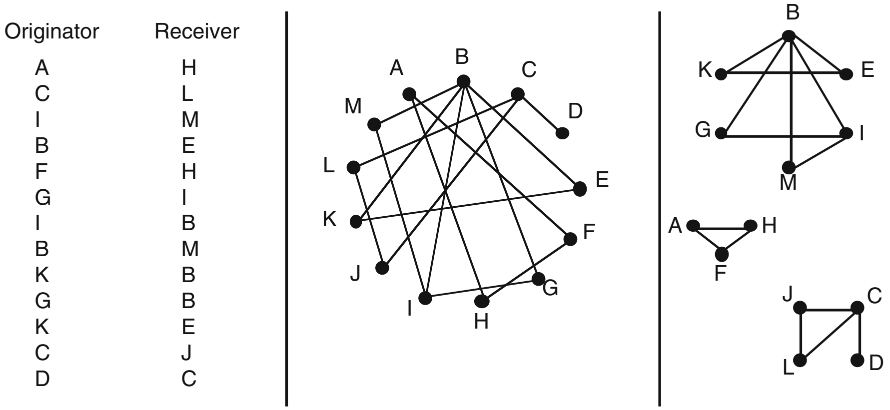


Fig. 3.57 Alternative representations of a list of telephone calls

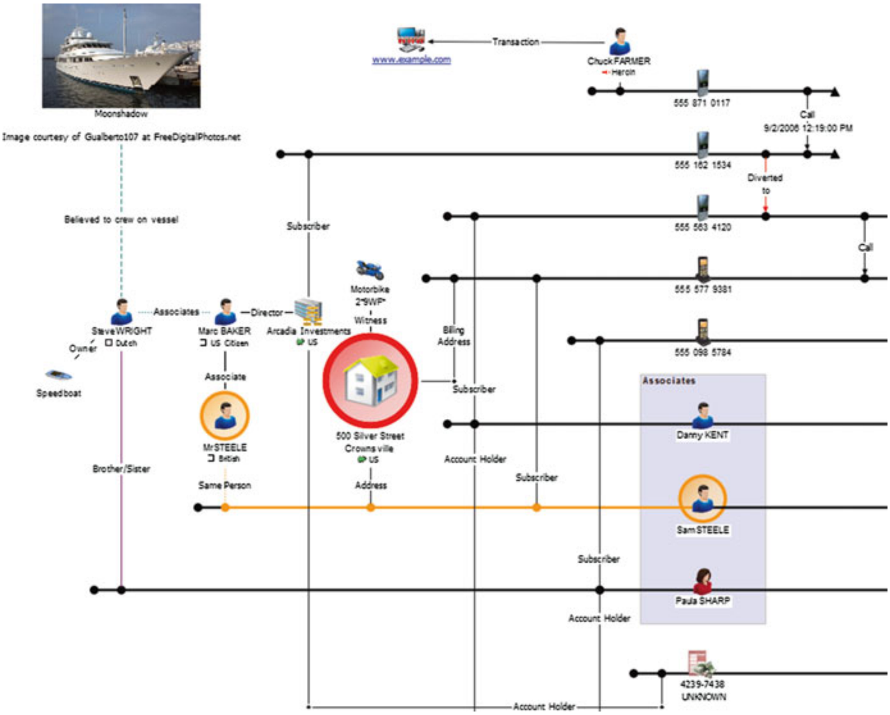


Fig. 3.58 A section of a mixed ‘association’ and ‘timeline’ style chart depicting fictional associations and connections within a criminal network. (*Courtesy IBM*)

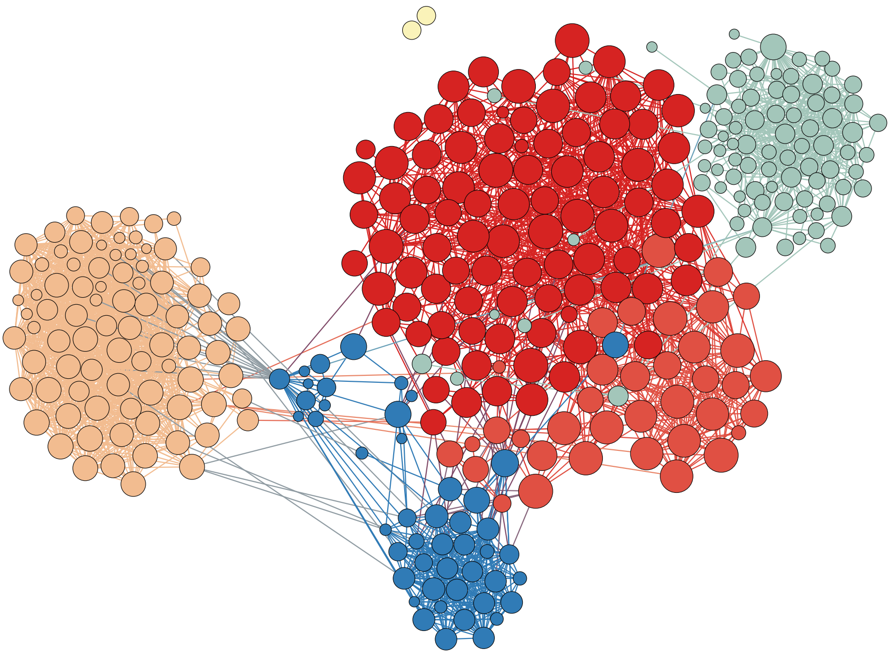


Fig. 3.59 Friendship ties between users of Facebook (*Courtesy Eric Bellm (bellm.org)*)

3.6.1.4 Invisible Links

Within a given representation there may be so many links that their explicit display could result in a crowded image and, moreover, reduce the likelihood of gaining a useful mental model. A solution may be to use encoding to *imply* a link. We have seen such an approach earlier when looking at the EZChooser in Fig. 2.8, repeated here as Fig. 3.60, where a link is implied by colour coding. Interactive exploration to reveal implicit connections by brushing can be a very powerful tool.

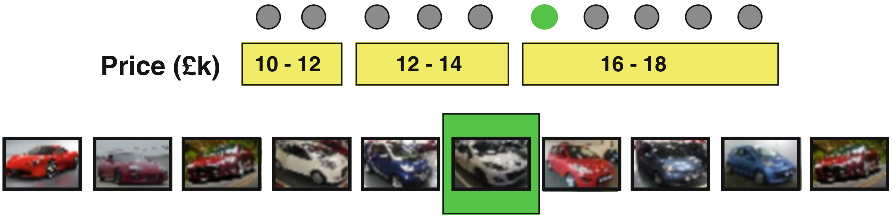


Fig. 3.60 A car is represented in two different ways – its appearance and its position on a bargram

3.6.1.5 Social Networks

The result of an analysis of social data is shown in Fig. 3.61 (Freeman 2005). Marbella Canales, a colleague of Freeman, collected data about the social connections among the employees in the cosmetics section of an upmarket department store. In an attempt to discover any underlying basis for the social connections various features were explored to little effect: Fig. 3.61 (left) shows individuals colour-coded according to their marital status, for example, showing that they did not choose others according to their marital status. However, an exploration of the significance of age (Fig. 3.61 right) showed that individuals tended to choose their recreational partners on the basis of age.

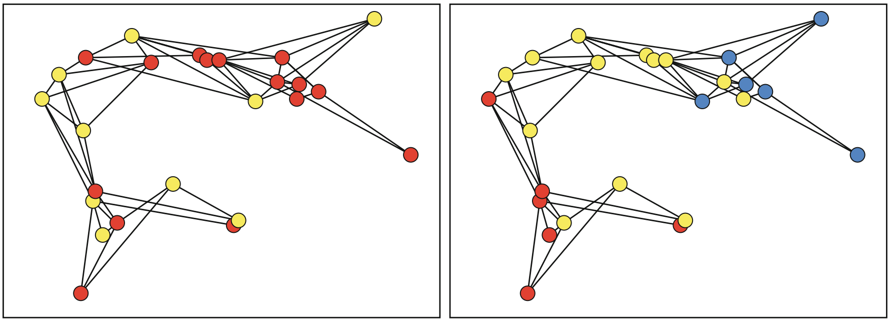


Fig. 3.61 (*left*) Social choices among employees, with marital status encoded (*yellow* = married, *red* = single) (*right*) social choices with age encoded (*blue* <30, 30< *yellow*, 40, *red* >40) (*Courtesy Lin Freeman*)

3.6.1.6 Venn Diagrams

The definition of ‘relation’[8] includes logical association, a simple example of which appears in Fig. 3.62 and describes the facilities associated with seven hotels. An alternative representation of the data is offered by the familiar[9] Venn diagram, as shown in Fig. 3.63. Clearly, such a diagram can accommodate many more hotels. Nevertheless, a problem occurs when more than three hotel facilities are involved: as the number of facilities increases above four the diagram becomes complex and not easy to understand and use.

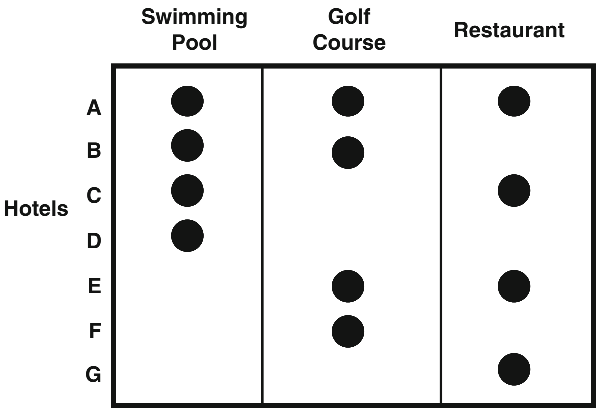


Fig. 3.62 Facilities offered by seven hotels

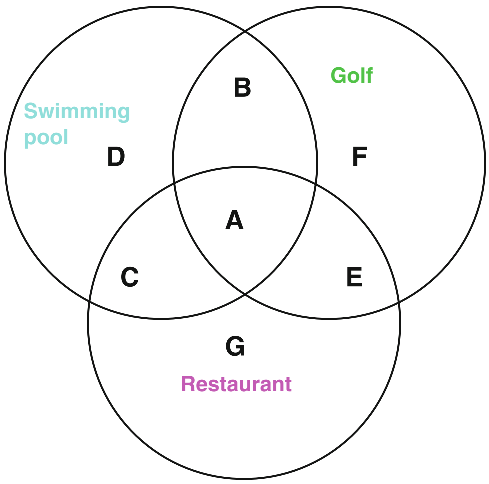


Fig. 3.63 A Venn diagram representation of the data shown in Fig. 3.62

[8] **relation** (n): a logical or natural association between two or more things; relevance of one to another; connection.

[9] If, as discussed in Sect. 3.5, the typical reader of the New York Times feels challenged by scatter plots, it would be of interest to know their reaction to, and understanding of, Venn diagrams.

3.6.1.7 Cluster Map

An alternative to the Venn diagram, and which may be easier to understand, is offered by Cluster maps, of which one representing a collection of 24 hotels is shown in Fig. 3.64. Each node is a facility (*not* an hotel) and its associated number shows how many hotels offer that facility. In the present example confusion may arise because the node numbers do not add up to the total number of hotels: an hotel with a restaurant and a gym, for example, will contribute to both corresponding nodes.

A Cluster Map example taken from the field of pharmacology (Stuckenschmidt et al. 2004) is shown in Fig. 3.65. A researcher wishes to browse through the existing literature on ***aspirin***, and on entering that term is required to choose one of four relevant keywords. Choice of ***acetylsalicylic acid*** results in the retrieval of up to 500 most relevant documents about acetylsalicyclic acid which, grouped under broader keywords, are then presented to the investigator. The user's selection of ***mortality***, ***practice guideline***, ***blood clot lysis*** and ***warfarin*** then leads to the display of a cluster map (Fig. 3.65) which shows how the document sets overlap. Each small sphere represents an individual document, its colour indicating its type such as a full document or an abstract. It is seen from the cluster map, for example, that significant overlap exists between the keywords ***blood clot lysis*** and ***mortality***.

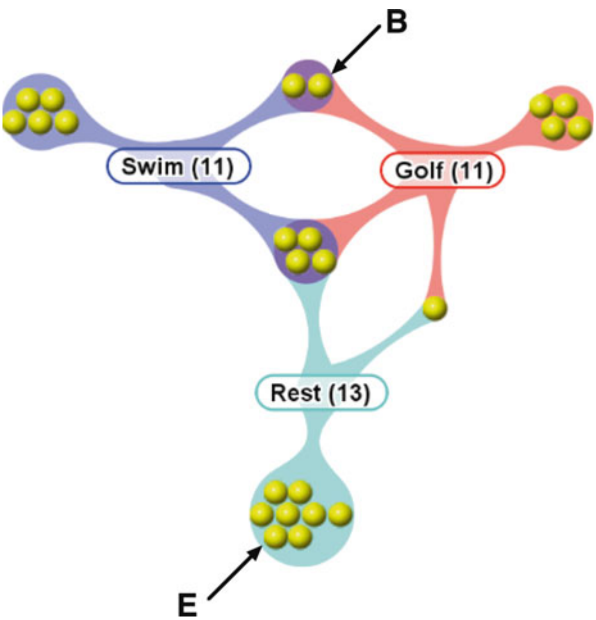


Fig. 3.64 A Cluster Map representation of 24 hotels (*Courtesy Christiaan Fluit*)

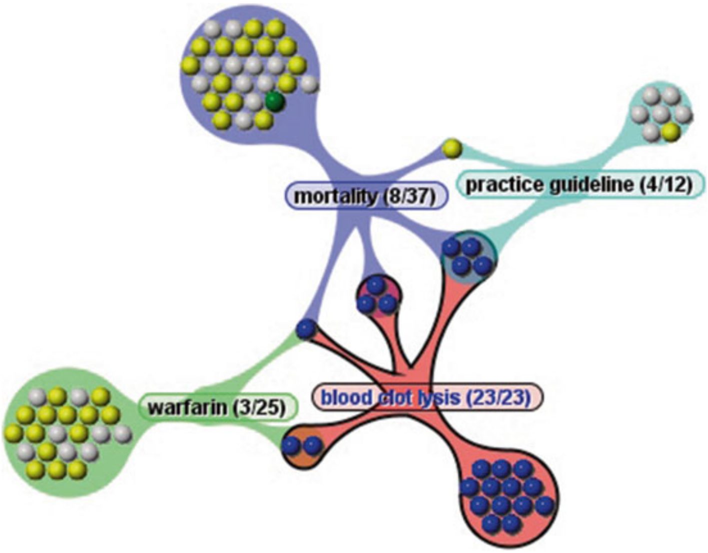


Fig. 3.65 A cluster map resulting from a researcher's interest in aspirin, and following the choice of four generic keywords (*Courtesy Christiaan Fluit*)

3.6.1.8 Geon Diagrams

The human ability to recognise objects and their interconnection led to the concept of a Geon Diagram (Ware 2012; Biederman 1987). One such diagram and the conventional UML (Unified Modelling Language) diagram it represents are illustrated in Fig. 3.66. Geons (e.g., cylinders, cones) are used to represent the principal components of the UML diagram, and the strength of the connections between them is represented by the linking structures.

Irani et al. (2001) evaluated the geon representation of Fig. 3.66 by comparing it with the corresponding UML diagram. Experimentation showed that when users were asked to identify a substructure it took 4.3 s, with 13 % errors, with the geon diagram and 7.1 s, with 26 % errors, with the UML diagram. The influence of colour was also investigated. Without colour the same task led to 22 % memory errors with the geon diagram and 42 % memory errors with the UML diagram.

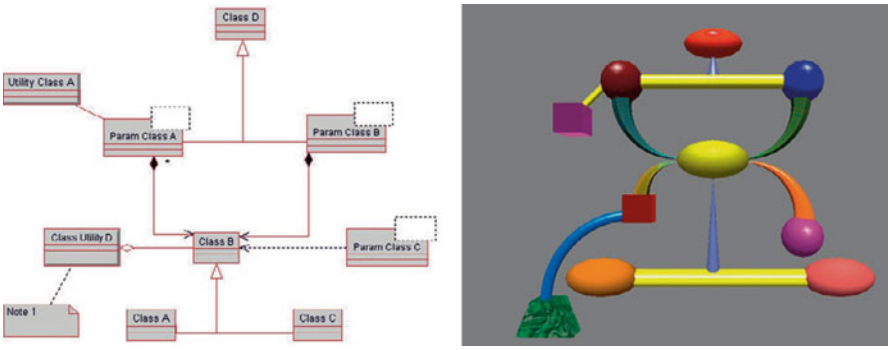


Fig. 3.66 (*left*) A UML diagram and (*right*) its representation by a geon diagram (*Courtesy Morgan Kaufmann*)

3.6.1.9 Metro Maps

Probably the most familiar representation of a network is that of a metro map: essentially the representation of the interconnection of a number of transportation routes. First introduced by Harry Beck (Garland 1994) for the description of the London Underground system in 1931 it has been adopted by virtually every metro system in the world (Ovenden 2003). Design issues include the incorporation of geographical detail within an essentially topographic representation. The metro map of Sao Paulo is shown in Fig. 3.67.

Fig. 3.67 The metro map of Sao Paulo

3.6.1.10 Human Relationships

The representation of relations between human beings by the familiar family tree has a long history but is limited: only marriage, death and the birth of legitimate children is addressed, and it is difficult to gain insight into temporal relations. A more recent representation catering for many different relations as well as factors such as geographical location is exemplified by the representation shown in Fig. 3.68. It represents a range of fictional relations (family, romance, occupation, Visit from Richard, etc.) each represented by a colour-coded link, between the characters of a TV series.

Links need not just be colour-coded: thickness and taper can encode other attributes.

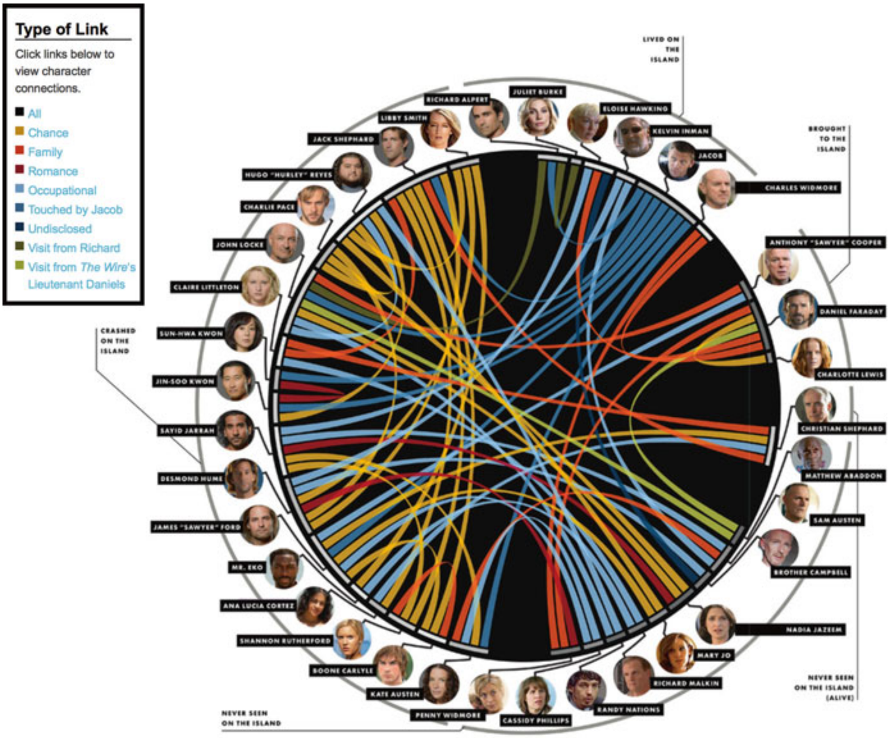


Fig. 3.68 'The Web of Intrigue' showing various relationships between the characters of a TV series (*Courtesy Martin Krzywinski*)

3.6.1.11 Combined Representations

All the examples so far presented have mainly been discussed in isolation, and indeed might be used in that way if there is a single important message to be communicated, as with Nightingale's success in hospital revolution. But there are many situations in which a rich corpus of data exists, and where a user can benefit if many aspects of that data can be included in a representation without detracting from the user's ability to form an appropriate mental model. One such example is shown, both in its entirety and in detail, in Fig. 3.69.

The data relates to customer behaviour in car transactions. For example, many people exchange their SUVs for smaller cars, and an interesting question concerns how people move their choice between different brands and car segments. The image of Fig. 3.69 is the representation of an extensive corpus of data relevant to that question. The reason for including Fig. 3.69 (with detail in Fig. 3.70) is to

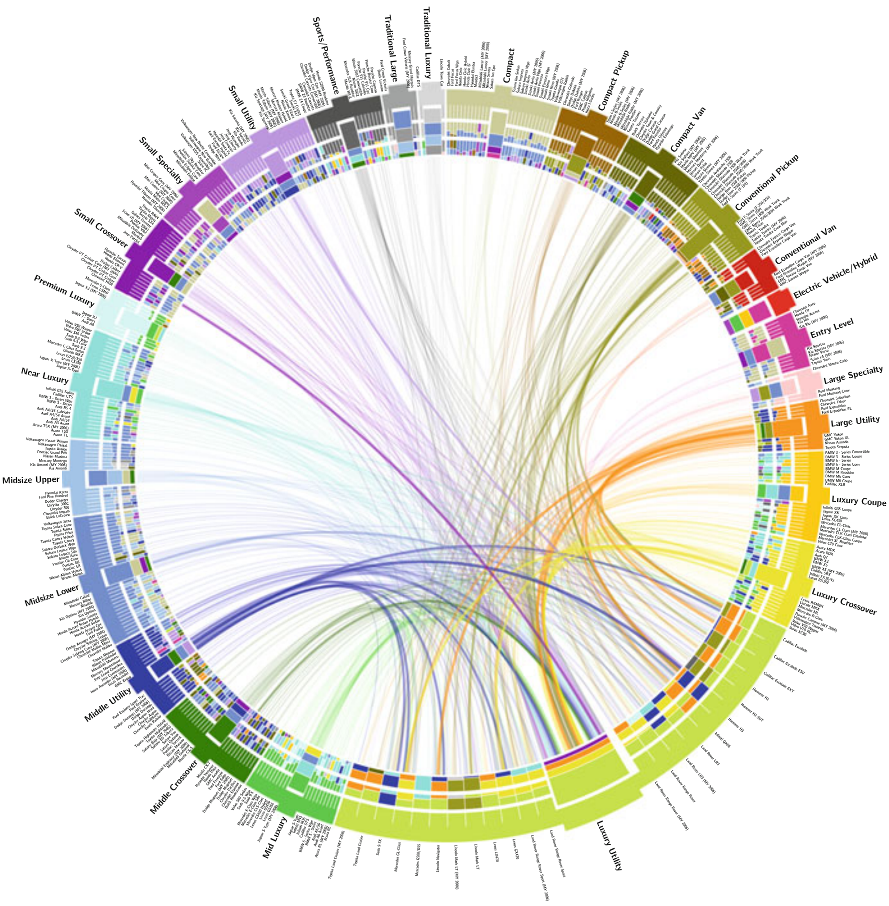


Fig. 3.69 A representation associated with car transfer data (*Courtesy Martin Krzywinski*)

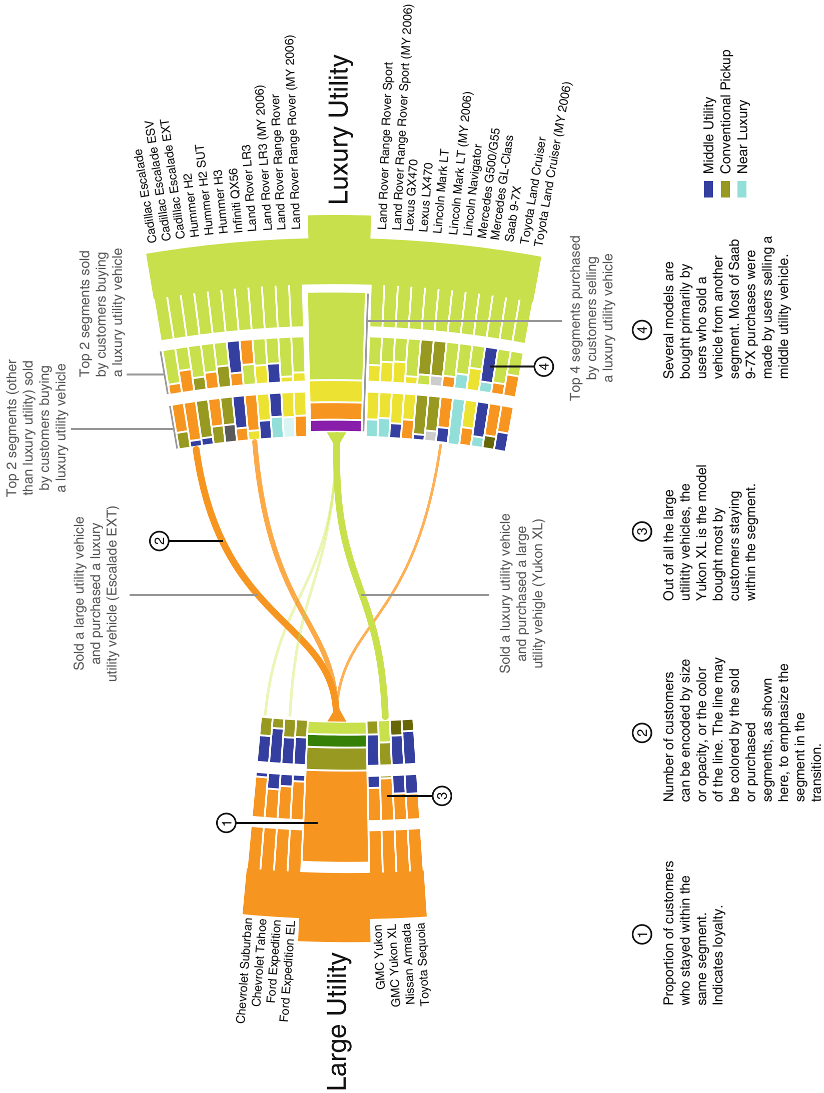


Fig. 3.70 Detail of Fig. 3.69 (*Courtesy Martin Krzywinski*)

provide a glimpse of complexity combined with clarity, and overview combined with detail, that may be appropriate and possible in some applications. Detail about the data from which Fig. 3.69 is generated is discussed in an introduction to a powerful concept called circos at http://circos.ca/intro/general_data/. Circos finds extensive application in genome studies (Krzywinski et al. 2009).

3.6.2 Hierarchies

In the examples discussed in Sect. 3.6.1 there has been no restriction as to which node is connected to any other node: no topological restrictions apply so that loops, for example, are permitted. We now address a special class of network having significant practical application in which topological restrictions arise from the fact that the network is a **tree** and, thereby, can refer to the important class of hierarchical relations. The definition of a tree is a network of nodes and links so connected that no loops are present.

To introduce some no doubt familiar terminology we consider the simple tree shown in Fig. 3.71.[10] The considerable interest in trees arises from the many

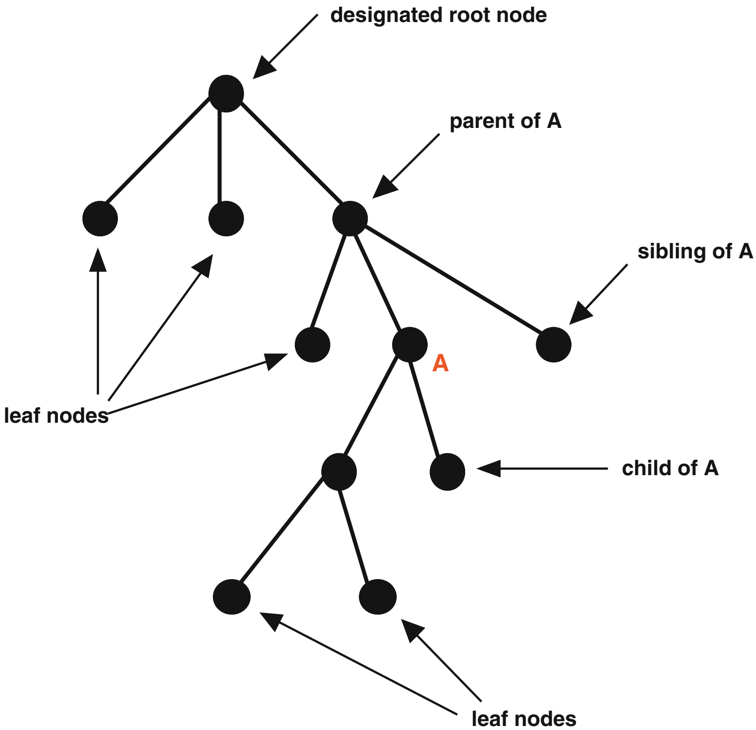


Fig. 3.71 Tree definitions

[10] Note the designated root node: you can pick up a tree by any other node and it still has the properties of a tree.

situations that are hierarchical in nature: for example, the root node of a company organisation chart is typically the president and every employee has a precisely defined reporting path. 'parent' and 'child' nodes are termed 'superordinate' and 'subordinate' respectively: thus, a leaf node has no subordinate nodes and the root node has no superordinate node.

3.6.2.1 Cone Tree

The representation shown in Fig. 3.72 is often unsuited to the representation of tree-structured data. A major drawback is its size; after three levels of hierarchy the width of the tree, especially if node labels are attached, exceeds the width of most displays. A solution to this problem is to imagine the original tree (Fig. 3.72) to be arranged into a 3D structure such that all nodes subordinate to a given node lie on a horizontal circle which, together with the given node, defines a cone as shown in Fig. 3.73. The resulting 2D view of that structure, called a Cone Tree (Robertson et al. 1991) is now more compact than the original representation and, notwithstanding some occlusion, is easier to handle. A horizontal version of the Cone Tree is called a Cam Tree and may be better suited to the assignment of text to each node.

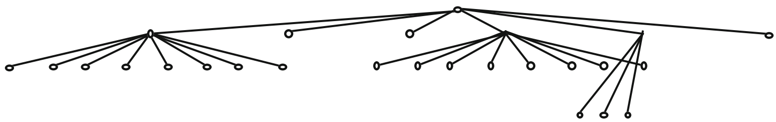


Fig. 3.72 A tree

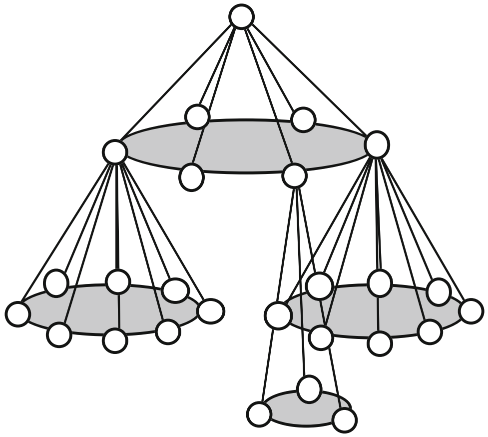


Fig. 3.73 The Cone Tree corresponding to the tree of Fig. 3.72

An interesting feature of the Cone Tree, especially when contemplating its design for interaction, concerns the rotation of the individual cones. Suppose that the tree represents the organization chart of a company, and a user wishes to find the reporting path of an employee located some way down the tree. Bearing in mind that the same – or a previous – user has left the cones in an arbitrary position, it is necessary now for most or all cones to rotate in order to show, at the front, the reporting path of the employee of interest. Such a rotation can be sudden or animated. The disadvantage of a sudden change is that the user's previously formed mental model of the tree is disrupted. By contrast the enormous benefit of repositioning the cones by animation – lasting perhaps no more than one second – is that as a result of our perception of object constancy (in other words, physical cones tend to retain their shape) the user's mental model suffers far less disruption. As Card puts it in a video demonstration, "without animation it takes several seconds to reassimilate the relationships between the parts of a tree". The design of the original Cone Tree (Fig. 3.74) bears careful inspection: the visual designer has arranged that the cones lead to shadows on a 'base plane, shadows that enhance a user's perception of the movement of the cones.

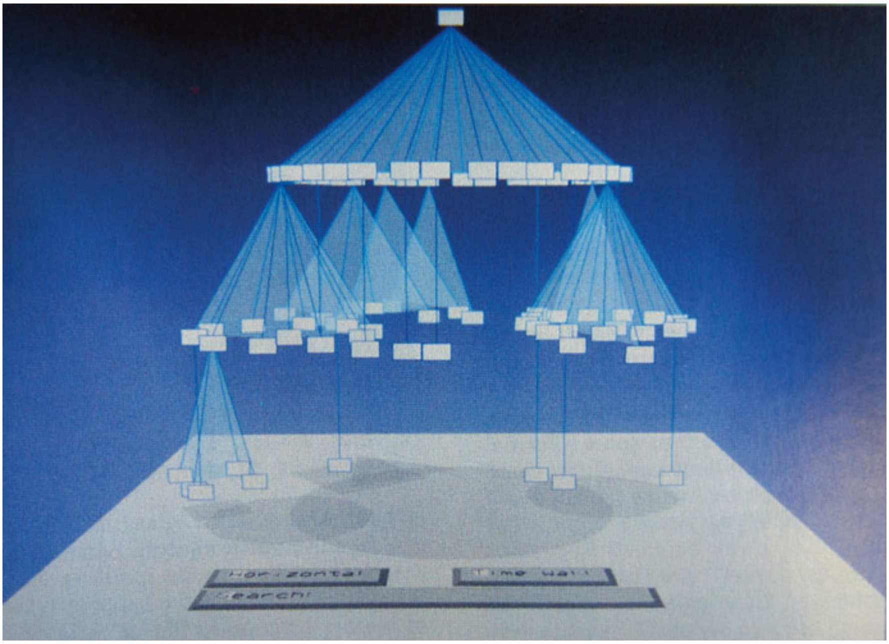


Fig. 3.74 The original Cone Tree, showing the 'shadows' cast by the individual cones (From Robertson et al © 1991 Association for Computing Machinery, Inc. Reprinted by permission)

3.6.2.2 Tree Maps

An alternative representation of a tree is the Treemap (Johnson and Shneiderman 1991). Its derivation from the original tree is illustrated in Fig. 3.75. Starting with the designated root node one draws a rectangle – often filling most of the available display space – passing through that node. Within that rectangle are similarly constructed smaller rectangles, each corresponding to an immediately subordinate node. This construction is repeated until all nodes are accounted for.

A principal disadvantage of the tree map that is easily overcome is the very large number of very thin rectangles that, for example, do not easily accommodate text or images. A solution (Fig. 3.76) is the 'slice-and-dice' approach in which rectangles are alternately generated, vertically and horizontally, from the nodes at successive levels of the tree. A typical example is illustrated in Fig. 3.77, showing an author's collection of reports. An advantage of the Tree Map is that it can support an awareness of leaf nodes, though it has sometimes been said that the hierarchy is not easy to discern.

The Tree Map has found a variety of applications. One (Wattenberg 1999) is to be found on the website Smart.money.com (Fig. 3.78). The root node is the collection of companies, and the immediately subordinate nodes are rectangular areas associated with major industrial sectors such as energy and healthcare. At the next level, individual companies are represented by rectangular areas whose size reflects

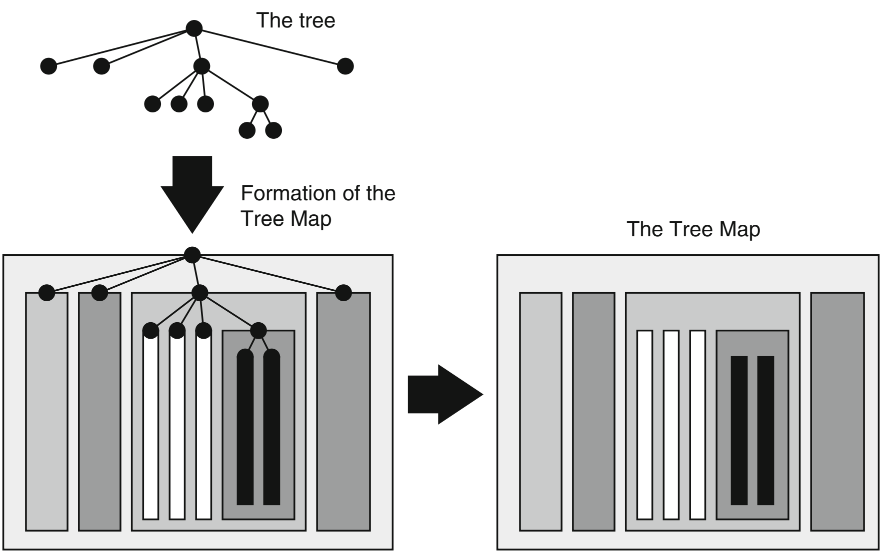


Fig. 3.75 The construction of a tree map

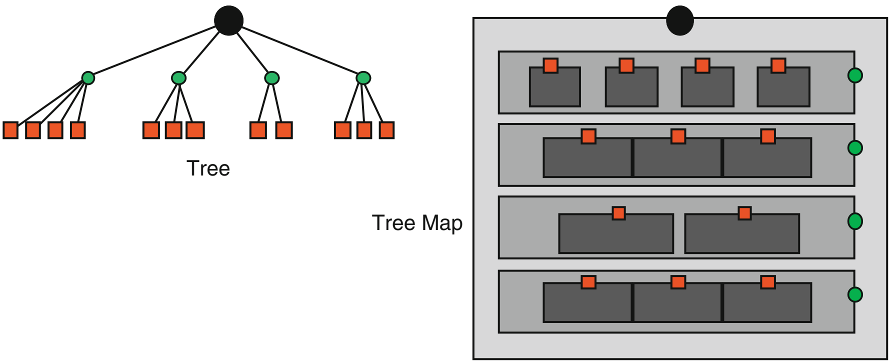


Fig. 3.76 The 'slice-and-dice generation of a tree map

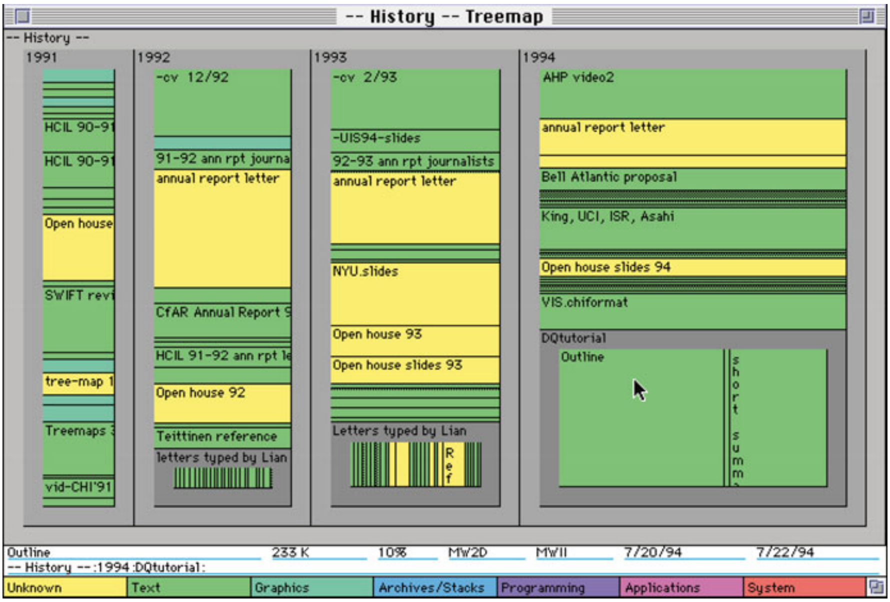


Fig. 3.77 A tree map display of a person's collection of reports (*Courtesy Ben Shneiderman*)

the value of that company and whose colour encodes some aspect of its profitability. Additional detail regarding any company can be obtained by a drilling-down interaction. With a Tree Map we do not see conventional nodes and links, rather, 'child' objects are located within 'parent' objects.

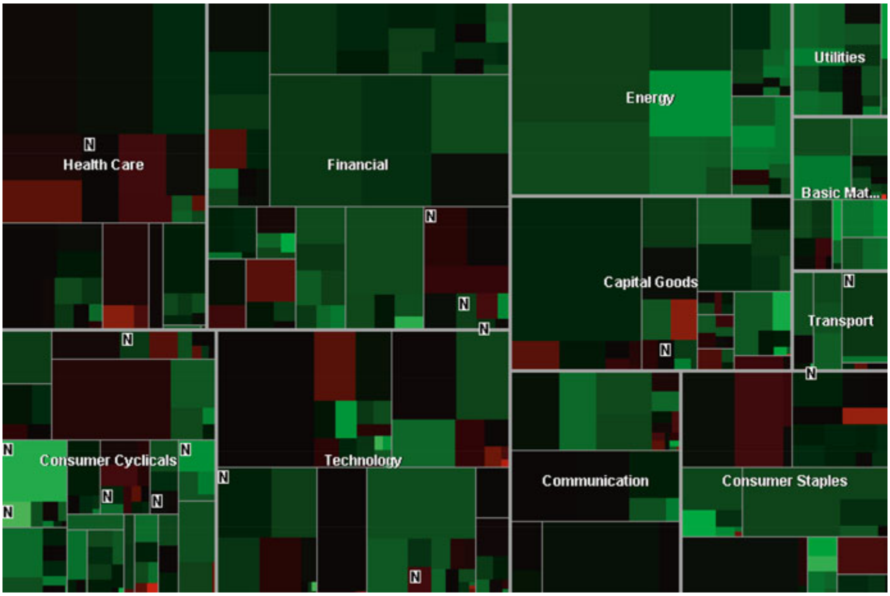


Fig. 3.78 The smartmoney.com representation of the financial status of companies within a number of sectors

3.6.2.3 Hyperbolic Browser

It is often desirable to have an entire tree represented within available display space, yet so arranged that the immediate context of any node can be inspected without difficulty. Such a facility is provided by a novel technique called the Hyperbolic Browser illustrated diagrammatically in Fig. 3.79. Without going into sophisticated mathematical detail (Lamping et al. 1995; Lamping and Rao 1994, 1996), the technique involves a hyperbolic geometric transformation that transforms the conventional appearance of a tree to the form shown in Fig. 3.79. A node occupies progressively less space towards the outer edge of the representation, and is positioned closer to its superordinate and subordinate nodes. Whatever interaction occurs, all nodes within the tree theoretically remain within the display, but in practice only within the pixel resolution.

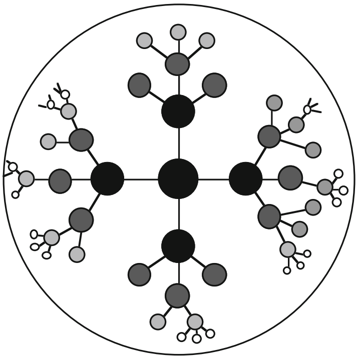


Fig. 3.79 A diagrammatic illustration of the hyperbolic representation of a tree

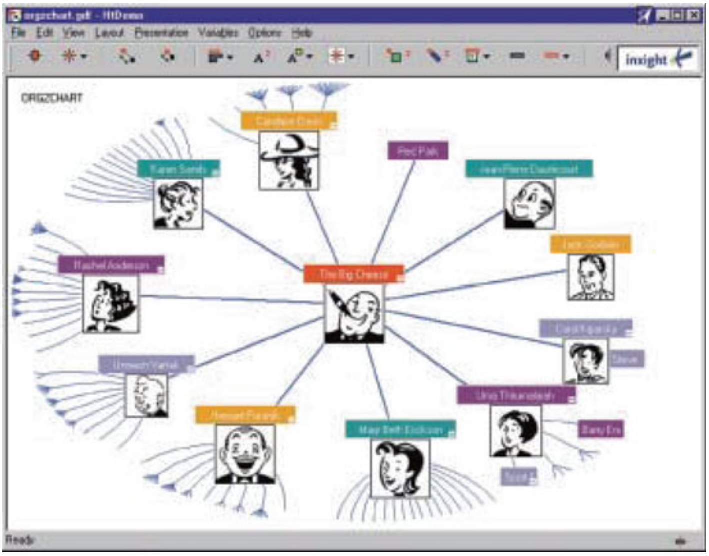


Fig. 3.80 The reporting structure within a company

It is the interactive nature of the Hyperbolic Browser that is its principal advantage, as illustrated by a hierarchical representation of the employees within an imaginary company with Big Cheese at its head (Fig. 3.80) and ten pictured senior employees reporting directly to him. A user may be more concerned with contacting the department headed by Rachel Anderson, in which case she is interactively moved towards the centre of the display (Fig. 3.81) with the consequence that details of the 11 people reporting to her are now visible. One of them, Eliza Doolittle, may be the person to contact, in which case appropriate details will be revealed when she in turn is moved towards the centre. Big Cheese, who may be inappropriate to the enquiry, is appropriately moved away from the centre.

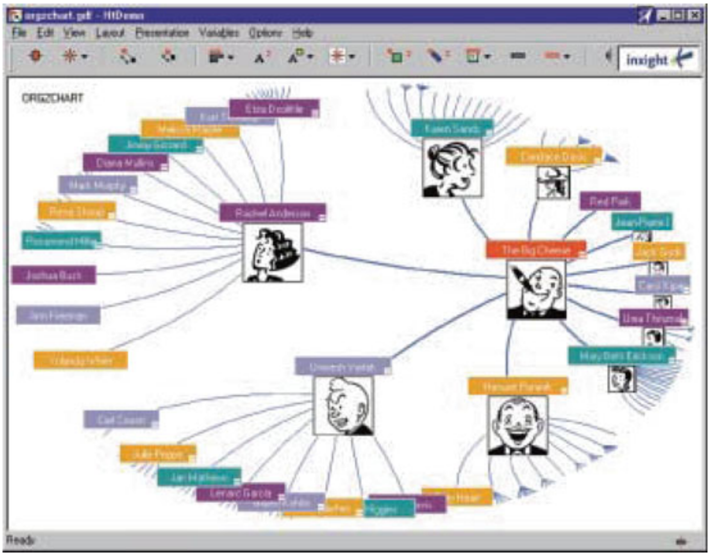


Fig. 3.81 Rachel Anderson has been moved towards the centre to reveal details of her subordinates

3.6.2.4 Sunburst Display

An alternative representation of a tree (Andrews and Heidegger 1998) – referred to as Information Slices or Sunburst displays – is shown in Fig. 3.82.[11] The root of the hierarchy is represented by a central annulus. That is surrounded by concentric annuli ('nested rings') whose distance from the root corresponds to their depth in the hierarchy. Each section of an annulus, at whatever level, is sized according to the number of subordinate leaf nodes, as shown in the simple example of Fig. 3.82.

Many variants of the Sunburst display are possible (Stasko and Zhang 2000). Modifications have been suggested regarding amelioration of the small size of peripheral slices, the ability to focus on one item while retaining valuable context, and issues of navigation.[12]

[11] The Sunburst display is often classed as a 'Space-filling technique' in view of its tendency to make maximal use of display space, though the Tree Map can occupy a full rectangular display.

[12] See the discussion of 'Focus+Context' in Chap. 4.

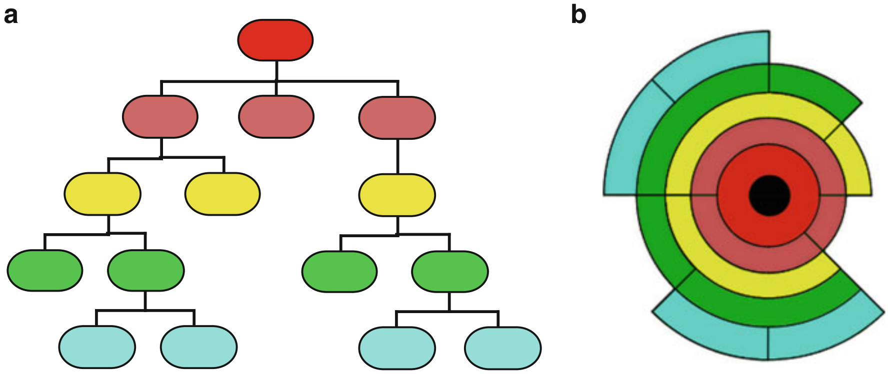


Fig. 3.82 (**a**) A tree (**b**) its representation by a sunburst display

3.7 Alternative Canvasses

Most academic treatments of information visualization carry the implication that the 'canvas' on which a representation is rendered is either paper (or an equivalent material) or a computer display, and reflects the importance attached to printed and digital representations of data. But it would be ignoring the wider relevance of much of the material in this book if we did not consider other possible 'canvasses'. In this brief discussion we discuss four examples – brief because much has already been written about alternative canvasses.

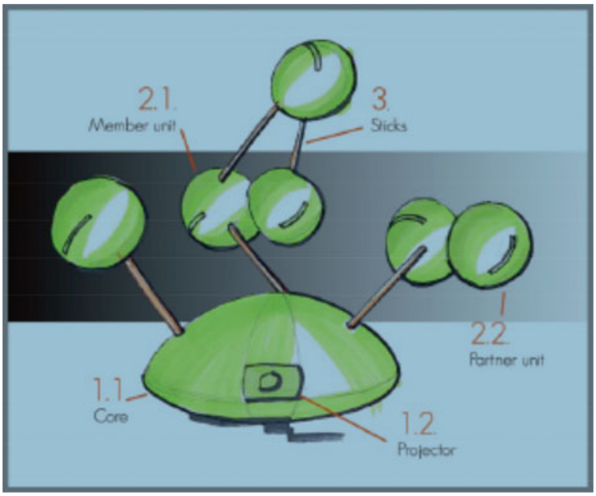


Fig. 3.83 A representation of family relations, with inbuilt communication facilities (*Courtesy Hester Bruikman, Toon van Craendonk and Valentina Occhialini*)

A recent educational design exercise (see Exercise 3.7) concerned with alternative family tree representations resulted in two 3D solid solutions. One is the Connectivitree shown in Fig. 3.83. The structure, which could be made of plastic, represents a family consisting of two grandparents, their children, the spouses of their children and their own offspring, the grandchildren. The device might be found on the living room table both of the grandparents in England and one of their children in Australia. Inbuilt communication facilities would allow a grandchild, wandering through their house in Australia, to touch the base of the structure and say “Hi Gran!”, a greeting received by the grandparents in England. Such a design is obviously technically possible and has undoubted social benefit.

The initial and creative stage of the second design, put together very quickly but thoughtfully, is shown in Fig. 3.84. Individual people are represented by solid shapes, their inter-relation (e.g., marriage, parentage) by rods and significant time parameters by the lengths of vertical rods. It was immediately apparent that the idea might be relevant, for example, to exhibition displays, and subsequent development of the idea led to the tentative illustration of Fig. 3.85. Here, the human representations have been designed to have specific shapes and colour encoding to enhance the value of such a 3D model and to provide a useful alternative view – for example, when viewed ‘from above’.

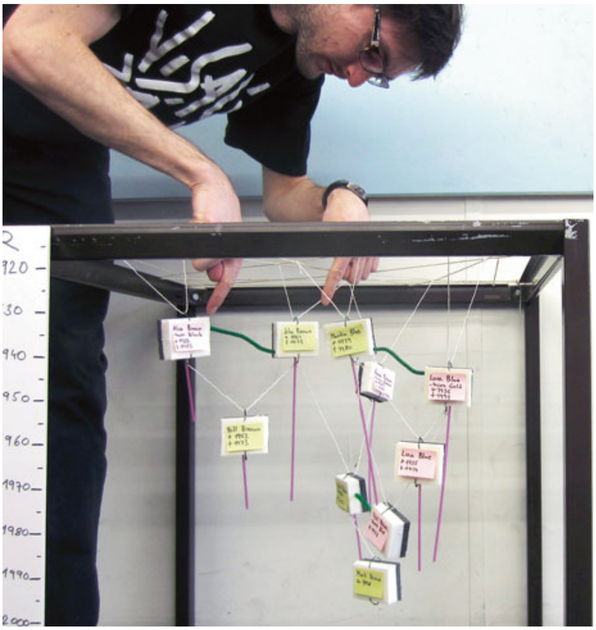


Fig. 3.84 A first draft of a 3D representation of a family tree (*Courtesy Petr Kosnar*)

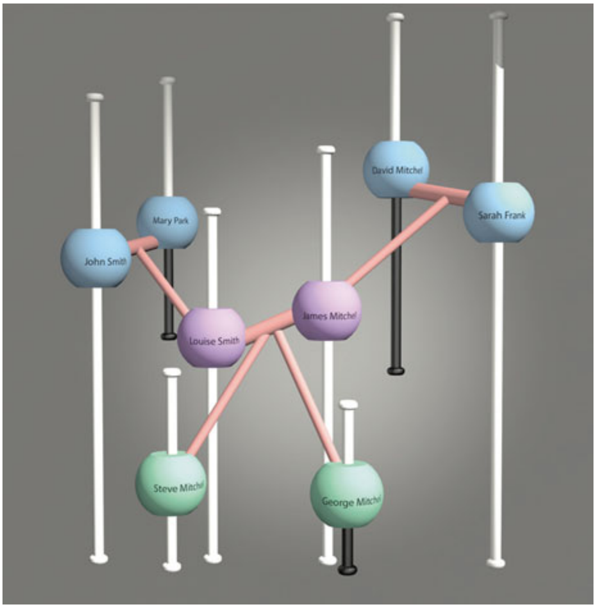


Fig. 3.85 A development of the idea shown in Fig. 3.84. *Vertical rods* indicate date of birth and, if *black*, additionally the date of death. *Shapes* representing individuals are such that a colour-coded '*top-down*' view could convey useful information (*Diagram courtesy of Robert Michael Spence*)

Fig. 3.86 A wooden map representing the coast of Greenland, designed to be perceived tactilely by someone in a kayak in cold and dark conditions (*Courtesy Greenland National Museum and Archives*)

A third example is of interest for many reasons. The artefact shown in Fig. 3.86 will almost certainly not be recognised unless you habitually paddle a kayak off the coast of Greenland or have read the stimulating book by Bill Buxton (2007). What you see in Fig. 3.86 is a wooden map, made of driftwood. It represents the coastline, including fjords, mountains and portage locations of East Greenland. Buxton presents this and another wooden map as excellent designs. In a kayak, during the 6 month winter darkness, conventional navigation aids are inappropriate. A PC is out of the question, as is a tablet incapable of obtaining cellular service: the latter may be wet, with a dead battery and require the removal of mittens to use. Moreover it would sink if dropped overboard. By contrast, a wooden map can be carried inside your mittens, requires no batteries or signals and will float if dropped in the water.

An elegant solution! What is of relevance in the context of information visualization is that we have a representation that will often be perceived in a tactile manner, as required in the dark and cold, and support the formation of a mental model of terrain in what could be a life or death situation.

The example of wooden maps serves to emphasise that data need not only be encoded visually, and that aural, tactile and olfactory (smell) encoding also have their place.[13]

The fourth example (Fig. 3.87) is a tribute to Nelson Mandela, erected at the remote location where he was arrested. The 50 columns represent the number of years elapsing between that occasion and the creation of the sculpture. But look (Fig. 3.88) at that sculpture from a different viewpoint!

Fig. 3.87 Tribute to Nelson Mandela (*Courtesy Marco Cianfanelli*)

[13] The encoding of vital human signs such as blood pressure in sound was found to be supportive of an anaesthetist's task during long operations (Watson et al 1999; Watson and Sanderson 2004). An example of olfactory encoding is provided by the practice adopted by drivers of express steam locomotives of embedding aniseed balls within those parts of the engine that might get overheated and, in so doing, release the smell of anis that could be detected in the driver's cab.

Fig. 3.88 Nelson Mandela tribute seen from a different viewpoint (*Courtesy Marco Cianfanelli*)

Four examples of alternative canvasses are sufficient for our purpose – hopefully to trigger creative thoughts and application of the concepts discussed in this book.

Exercises

Exercise 3.1

Five students have taken exams in eight subjects and for each subject a maximum mark of ten has been assigned. Make a list of the questions that might be asked of this data by (a) a parent (b) a student (c) a subject teacher and (d) the head teacher. Aim for a total of at least ten questions. Write the questions on Post-Its and stick them on a wall, together with those of your colleagues, for reference during Exercise 3.2.

Exercise 3.2

The exam performance of the five students mentioned in Exercise 3.1 is shown below

Student	A	B	C	D	E
Subject					
Art	10	1	5	3	2
Science	1	10	5	4	9
History	8	5	7	1	1
Sport	2	9	5	10	4
Physics	–	1	2	3	1
English	2	8	6	8	5
Chemistry	4	1	1	1	4
Mathematics	10	1	5	4	2

Without using a computer in any way, design and sketch one static representation of this data: no interaction with the representation is to be considered. Then see if it answers any of the questions generated in Exercise 3.1. Decide whether your representation exhibits object visibility or attribute visibility.

Exercise 3.3

See if you can effectively modify the representation you designed for Exercise 3.2 to indicate whether each exam result was an improvement on the score achieved the previous year.

Exercise 3.4

Figure 3.89 shows a student's suggested representation of the data shown in Exercise 3.2. Critique this design, commenting on its advantages and disadvantages, and decide how the representation might usefully be modified. Incorporate these modifications in your own redesign.

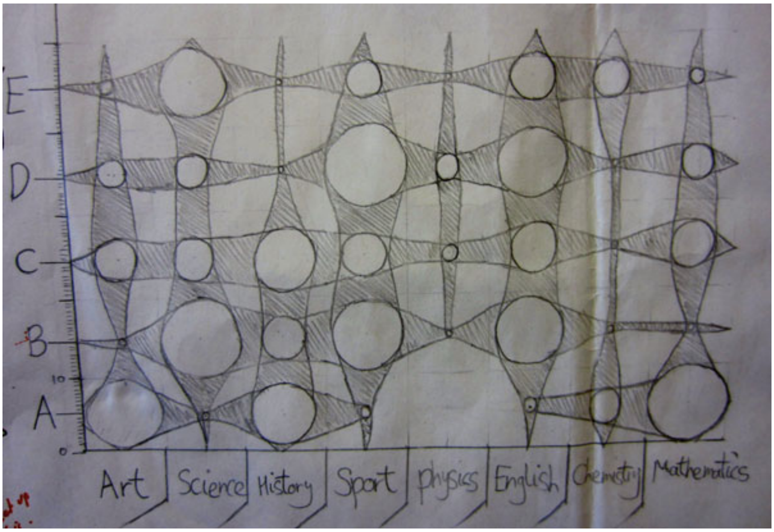


Fig. 3.89 Sketched representation of the data of Exercise 3.2 (*Courtesy Max A.C. Poynton*)

Exercise 3.5

Compose a mosaic plot representation of the Titanic data (Table 3.1) but using a different sequence of steps (for example survival – > gender – > class – > adult/child). List the observations that can readily be made by looking at the result. Are they different from those triggered by the representations derived from Fig. 3.15?

Exercise 3.6

The London Underground transportation map contains no distance or journey time encoding. With sketches, show how this data can be represented. Would it be useful?

Exercise 3.7

For your school or university or department (real or imaginary) design a representation of scholastic achievements (e.g., marks in 12 subjects in each of 5 year groups) that will show not only the general level obtained but also (1) the way in which achievement levels are changing, (2) the proportion of students obtaining better than a pass mark, and (3) the number of students taking a particular subject. Design the representation so that it can be printed on a card that slides easily into the pocket (e.g., one-third of A4).

Exercise 3.8

Sketch possible static representations of human relationships, both formal (e.g., marriage, births, deaths, divorce) and informal (e.g., co-habiting), test them on real examples and identify the advantages and disadvantages of each.

Exercise 3.9

Bus, metro and train routes are typically represented by annotated lines between nodes. However, in some large cities (London, for example) there are so many routes that a journey may well involve intermediate changes and be very difficult to plan. Explore the potential of adding, to the node-link route representation, some overall directional indicators that give a 'first glance' suggestion as to which route might be best for a given journey.

Exercise 3.10

Select one of the folders on your laptop which contains at least two levels of hierarchy and draw a treemap representation of its contents.

Exercise 3.11

Repeat Exercise 3.10 and sketch a hyperbolic browser representation.

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Chapter 4
Presentation

The many ways in which raw or derived data can be represented were discussed in the previous chapter. We now examine how these representations can best be **presented** – i.e., laid out on a display – for viewing and interaction by a user. While presentation (Fig. 4.1) is now the focus of our attention, its inevitable links with representation and interaction, as well as the characteristics of the user, will need to be taken into account.

When designing a presentation of represented data – in other words, its spatial and temporal layout – there are three principal resources available for beneficial exploitation by an interaction designer. One is the available display **space** which can range from that of a mobile to the vast area of a wall display. Another is the **time** available for the performance of the task that the presentation is designed to

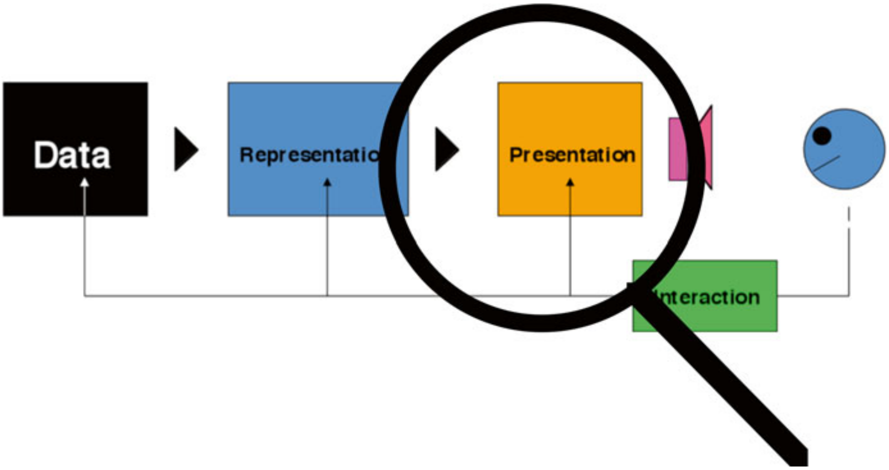

Fig. 4.1 The focus of this chapter is on presentation, but links to representation and interaction are important

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support. A third comprises the characteristics of the human **user**. This last resource is fundamentally fixed by the very nature of the human visual processing system. Although its effectiveness can be modified, for example by training, it cannot fundamentally be changed by the designer and will therefore be discussed first. And because most data representations are visual we focus on the fascinating – and still not completely understood – properties of the human visual system.

4.1 Human Vision

Put very simply, a user ***looks*** at something and tries to ***make sense*** of what has been seen, processes broadly called ***perception*** and ***cognition***.

4.1.1 Retinal Image

The scene in front of a user – the view out of a window or a mixture of text and images on a display screen – is projected, via the eye's corneal lens, onto the retina of each eye. While the appearance (Fig. 4.2) of a retina conveys little if anything of its function, more is identified by the three regions sketched in Fig. 4.3. In the centre is the foveal region of the retina within which part of an image can be seen in considerable detail and with good colour rendition. Around this foveal region, as one moves via the parafovea to the periphery, visual acuity – the ability to distinguish detail – falls off dramatically.

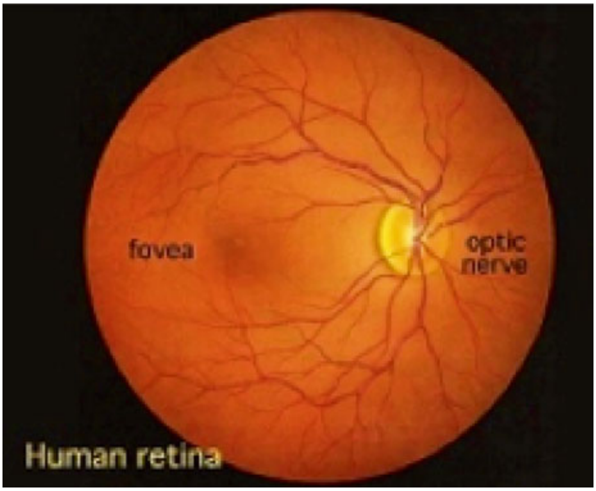


Fig. 4.2 The human retina. Fovea is within the *dark* region left of centre

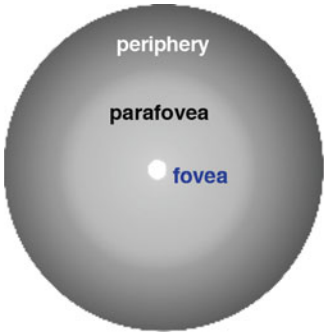


Fig. 4.3 Functional regions of the retina (radial distance not to scale)

4.1.2 Fixations and Saccades

It is unfortunate, therefore, that the foveal region corresponds to a viewing angle of only about 2° (Fig. 4.4), an angle subtended at the eye by a fingernail held at arm's length (try it!). This very restricted detailed view of a scene is the reason why the eye must normally and quite rapidly be moved around so that different parts of the scene fall, in turn, on the fovea. A first 10-s view of a painting by Dali, for example (Fig. 4.5), resulted in a person's gaze (i.e., that part of a scene currently focused by the muscles of the eye on to the fovea) moving quite rapidly around the painting: each location (fixation) lasts around 200 ms, and the fixations are connected by very fast (e.g., 20 ms) saccades.

Fig. 4.4 Illustration of the extent of foveal (*yellow*) and parafoveal (*green*) vision

But precisely what causes gaze to be directed to a new location in a scene, whether that scene is a painting or a report containing diagrams? As gaze moves over a scene in a sequence of fixations and saccades (a procedure we shall simply call 'looking') the user may only be *glancing* at part of the scene rather than paying attention to it. After all, if fixations occur at the rate of about 5 per second, a 20 s

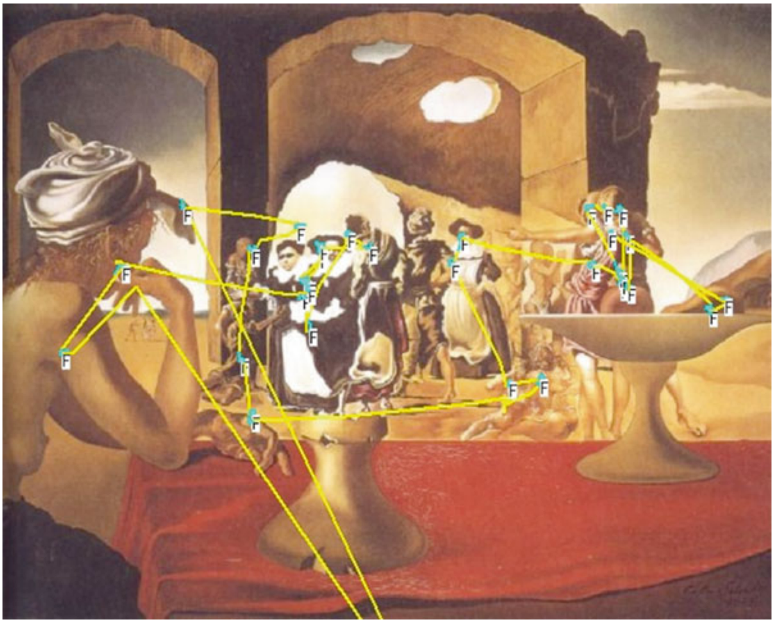


Fig. 4.5 Record of the eye-gaze locations (fixations **F**, lasting on average 200 mS) during a 10-s viewing of a Dali painting. Very fast transitions (saccades, approx 20 mS) between fixations are shown *yellow*

viewing of a painting involves around 100 fixations, and it is likely that careful attention – **overt attention** – is only being paid to a few of those locations. By contrast, simultaneous ***covert attention***, sensitive to items within the parafoveal and peripheral regions, helps the brain to decide where gaze might next be usefully directed (e.g., to an unidentified person silently approaching).

4.1.3 Preattentive Processing

The last feature of the human visual processing system of which we need to be aware for the moment is a surprising and remarkable one, and concerns what happens within the first 200 ms (approx) of viewing a scene. It is best illustrated by three experiments. In the first (Treisman 1985, 1991; Treisman and Gormican 1988) the image shown in Fig. 4.6 is presented for only 50 ms on an otherwise blank screen. During that very brief glance a user will notice, and afterwards report, the presence of the single red dot among the many blue 'distractors'. There is no time for a user to 'pay attention' in the normal sense of that phrase (after all, a fixation typically lasts for only 200 ms), which is why the phenomenon is referred to as '**preattentive processing**'. In the second experiment (Kundel and Nodine 1975) trained radiologists were presented with lung X-rays for a duration of only 200 ms: nevertheless, they were able to detect anomalies in 70 % of cases.[1] In the third

[1] Performance rose to 97 % under unlimited viewing conditions.

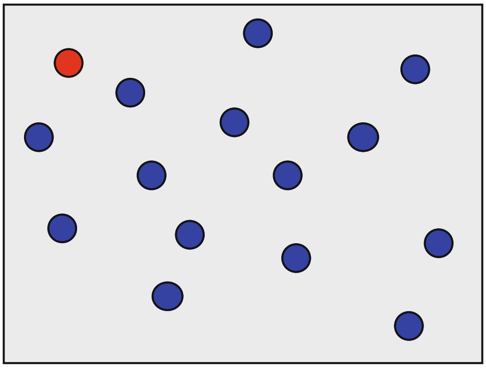


Fig. 4.6 A display lasting 50 mS, but nevertheless allowing a viewer to report the presence of a *red dot* among many *blue dots* (distractors)

experiment, Tse et al. (1998) found that users could successfully acquire the 'gist' of a film after viewing a sequence of twenty 100 ms frames specially selected from that film. Clearly, something unusual and potentially very beneficial is happening during this first short glimpse of a scene, and as interaction designers we must be ready to exploit that potential.

The properties of the human visual processing system we have discussed, and which are relevant to the presentation of represented data in space, are briefly summarised in Fig. 4.7. From what we know about preattentive processing and the typically rapid sequence of fixations and saccades involved in looking at a scene, it might be safe to assume that the 'understanding' of a scene takes on the qualitative form sketched in Fig. 4.8, starting with a step function during preattentive processing.[2]

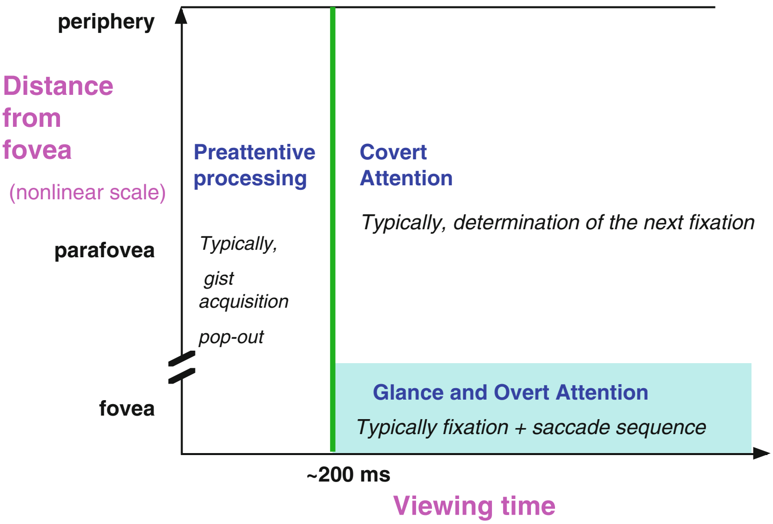


Fig. 4.7 A summary of properties of the human visual processing system particularly relevant to the stage of presentation

[2] The description of the human visual processing system given here is necessarily a gross simplification of current understanding (see, for example, Findlay and Gilchrist 2003), but is nevertheless adequate and useful for the interaction designer.

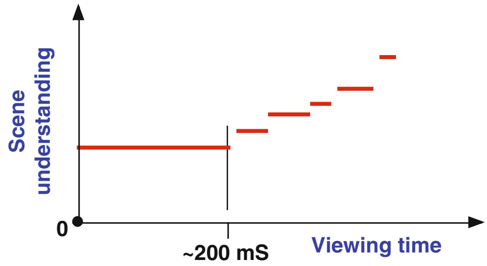


Fig. 4.8 Suggested qualitative variation of the variation of scene understanding with viewing time

4.1.4 Summary

We might usefully summarise the foregoing discussion as follows:

> The narrow field of view associated with the detailed viewing and comprehension of part of an image requires that glance and sometimes overt attention be moved from one part of a scene to another, a movement achieved either by rapid eye movements or by interaction that brings a different image or part of an image into focus. At the same time, covert attention to those parts of a scene falling outside the foveal region helps to decide where gaze should next be focused. In the first viewing of a scene – up to about 200 ms – preattentive processing can capture many features of that entire scene.

In what follows next in Sect. 4.2 we shall see how limits to display area ('*space*') influence the design of presentation, though we shall additionally discover the need to consider the influence of representation and interaction. In Sect. 4.3 we then consider the influence of presentation *time*. Section 4.4 then investigates how both space and time can be exploited, in conjunction with the remarkable properties of the human visual system, to the benefit of the information visualization process. A very brief Sect. 4.5 concerns the representation of presentation.

4.2 Presentation in Space

Let's suppose that I'm composing and editing a page of a report (Fig. 4.9), and that it appears full-size on a display of conventional (e.g., laptop) size. I can easily glance at the content by moving my gaze around the page in order to foveate on and, if appropriate, attend in detail to and interact with, an item of particular interest. And although I may recall the locations of various figures and other items (because I put them there) my parafoveal and peripheral vision helps me, through covert attention, to decide where next to move my gaze in order to pay

Fig. 4.9 A single document page presented for composition and editing (the *purple rectangle* represents the display boundaries)

detailed attention to those items. Thus, with a *single* page, a display of adequate *size*, with no need to *refer* to any other page of the report, and with the task of composition and editing, a simple presentation such as that of Fig. 4.9 may be adequate.

Such a presentation can, of course, be provided by a paper document. However, as we shall soon see, a computer-based display has the potential to provide opportunities that a paper document would find it difficult (or impossible) to match.

4.2.1 Extent

Often, however, it will be necessary to transfer attention to another part of the report – perhaps to check the correct section numbering or to see what the next figure number should be – in which case we have to consider the **extent** of an information space. The current page and the preceding and following pages (Fig. 4.10) are now especially relevant, so the question arises as to how the user can transfer attention to an appropriate item on *another* page. One approach is to 'zoom out', though loss of legibility might accompany the benefit of an overview of a number of pages. Another approach is to permit scrolling, with the consecutive pages joined continuously 'end-to-beginning' as in Fig. 4.10. But an alternative presentation arises if we arrange the pages horizontally as in Fig. 4.11. What are their relative merits?

Fig. 4.10 A scrollable multi-page document

4.2.2 *Scrolling*

The presentation style of Fig. 4.10 lends itself to **continuous scrolling**, especially useful if one is composing a sentence that begins late on one page and rolls on to the next one. However, a major drawback to scrolling is the *masking* effect: most of the report's content is hidden from view and scrolling is needed not only to attend to another part of the report but additionally to return to where editing or composition was previously taking place. Whether or not the user is familiar with

Fig. 4.11 Horizontal scrolling of a document

the document, an especially useful indicator, also useful for interactive scrolling purposes, is the scroll indicator (see Fig. 4.10): its length gives some idea of the ‘size of the universe’ (e.g., the number of pages currently in the report), and its position indicates the location of the currently viewed part within the complete document.

The alternative arrangement of Fig. 4.11 would appear to have little to recommend it. For example, the preparation of a sentence or paragraph spanning two consecutive pages would require attention to be moved to and fro between two pages. Also, while a small vertical movement of the visible content in Fig. 4.10 might be useful and easy to comprehend, a small horizontal movement in Fig. 4.11 could be disruptive: a *vertical* partial view of a page has limited value and can be distracting. So can the artificial, arbitrary and therefore potentially annoying nature of page breaks. One either wants the next page or not, not just a vertical slice of it.

4.2.3 Flipping

But a discrete progression may on occasion be exactly what is needed, in which case the value of the presentation of Fig. 4.11 can be transformed if the document is to be *perused* page by page rather than edited and composed, with individual pages now being regarded as fixed and separate entities. Here the constraint of continuity of movement can be replaced with a ‘flipping’ instead of a sliding interaction. One page is replaced by its neighbour, as suggested by Fig. 4.12, and attention is now directed to discrete pages. Such an affordance supports exploration and/or navigation of a document and is therefore appropriate in such environments as law courts and business meetings where fast access to a relevant page is

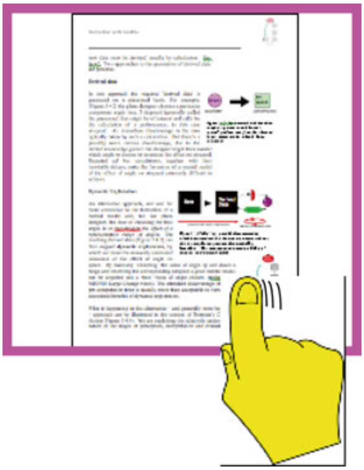


Fig. 4.12 A 'flip' touch action replaces one page with its neighbour

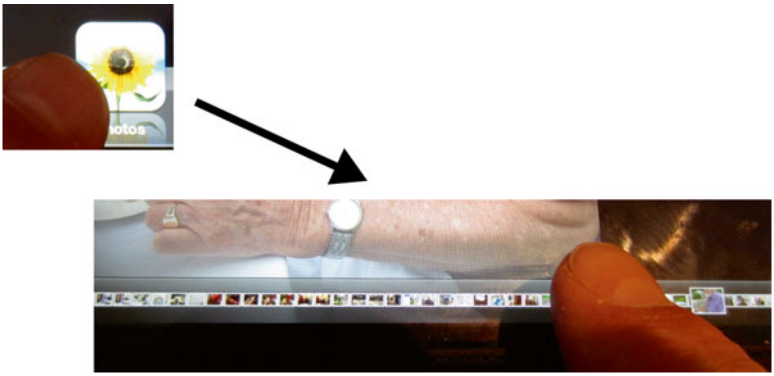


Fig. 4.13 Flipping through photographs on an iPad

needed. With fast flipping in particular, preattentive viewing of each page can be immensely helpful in 'finding one's place', especially if a user remembers the general nature of a needed page ("*not much text*, *table at top*, *reddish diagram at bottom*").

The presentation (and interaction) style indicated in Fig. 4.12 is already employed in the *Photos* app on an iPad (Fig. 4.13). Here we are abandoning altogether the concept of content continuity: we are looking at a *collection* of photographs in which each individual image has no relation to its neighbour except possibly for time of creation. We note that *none of the images move*: they simply appear and disappear as in Fig. 4.12. At speed we are enjoying the benefits of preattentive processing. As we shall see in Sect. 4.3 this combination of presentation and interaction can support the identification of a needed image (say, the Mona Lisa) at an image presentation rate as high as 10 per second, simply because preattentive processing is engaged.

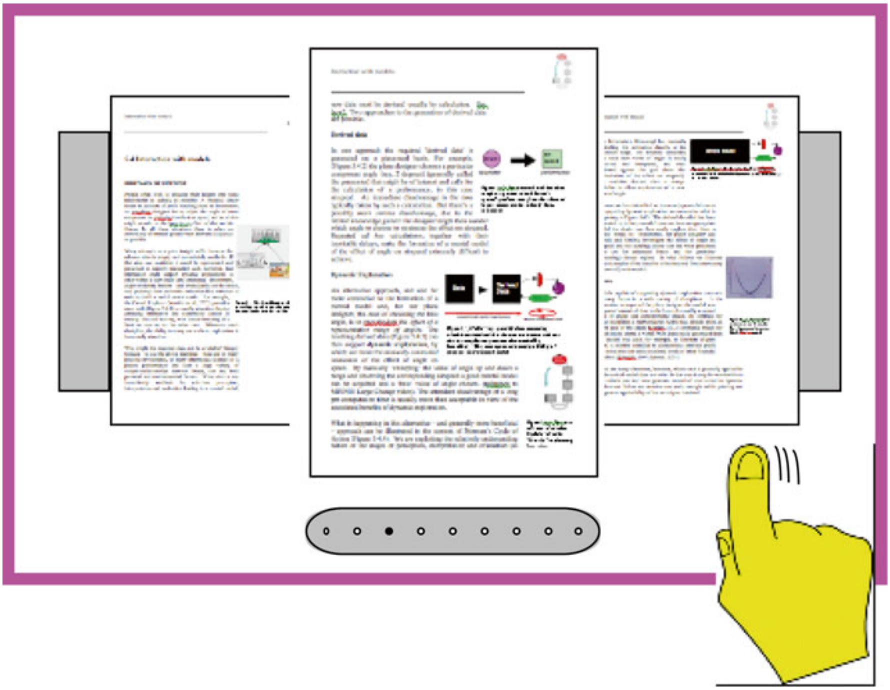


Fig. 4.14 A CoverFlow presentation style. Flipping by touching brings a new item to the forefront

Let's return to the document we were discussing, and again assume that its content is fixed – that is, it is not available for editing and composition. Much can be gained by making the discrete nature of the pages visually explicit, as shown in Fig. 4.14, and again controllable by some interaction mechanism of which there are many to choose from: the figure shows the use of touch. Also shown in this figure is a common technique for indicating the 'size of the universe' and the position of the foremost page in it. It is arguable that this presentation may be preferable to that of Fig. 4.12 in view of the partial ability to 'see ahead'. Because any requirement for continuity or ordering is removed, this style of presentation (often referred to as CoverFlow) is suited to the exploration of *collections* of items such as record labels, books and faces (Fig. 4.15). It is not difficult to imagine an extension (Fig. 4.16) of the CoverFlow presentation technique to vertical as well as horizontal scrolling.[3]

It might be remarked that an image appearing in a CoverFlow presentation is both too small to interpret and impossible to edit, being 'read only'. A simple

[3] Readers of a certain age might recall the card-based Rolodex, and observe the features it shares with Coverflow.

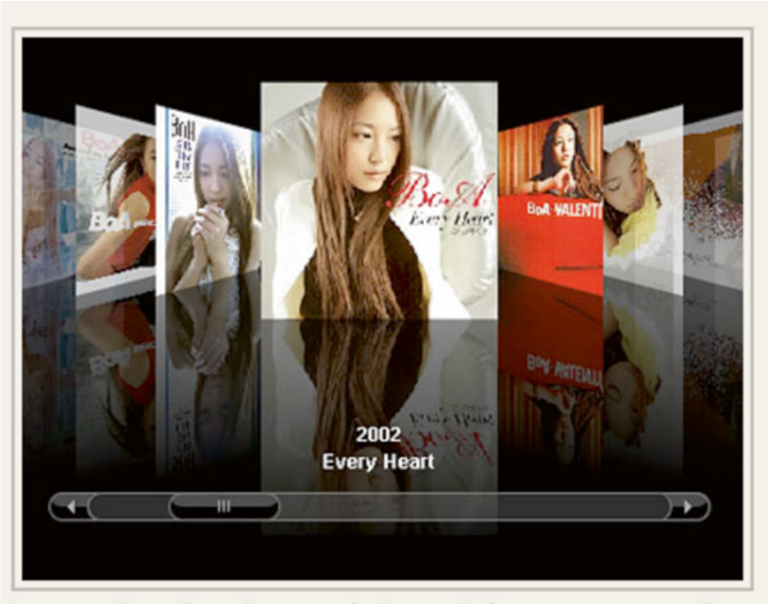
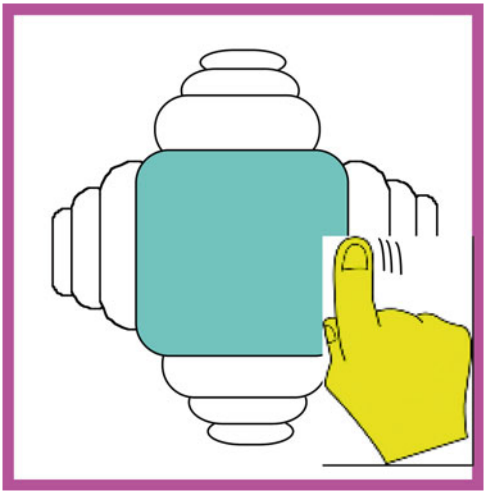


Fig. 4.15 A collection of record labels viewed in a CoverFlow presentation

Fig. 4.16 A possible extension of CoverFlow to two degrees of freedom



solution, already adopted in the *PAPER53* app supporting sketching on an iPad, is to allow the original image to be (reversibly) morphed to conventional display size, as shown in Fig. 4.17, and thereby made available for conventional detailed interaction.

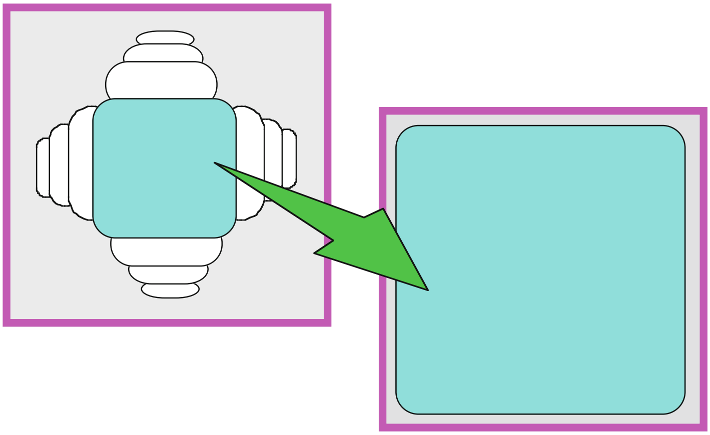


Fig. 4.17 Diagrammatic illustration of the morphing of an image from a Coverflow presentation to fill the available display space and become available for attention and interaction

4.2.4 Context and Detail

It is often pointed out, and justifiably so (e.g., Farrand 1973), that it is frequently necessary to see detail *in its context*. However, significant problems can arise when satisfying this presentation requirement. With a very small display (e.g., a mobile), little space may be available for contextual information as well as detail of current interest. So in contrast with the examples discussed above where attention has had to be paid to essentially one level of detail – the report pages, the iPad photos and the images of record labels – we are now concerned with two levels, generally referred to as Detail plus Context or Overview+Detail.

Take, for example, the task of driving North from London in order to visit my Aunty Mabel in Halifax. The most direct route takes me through the town of Huddersfield so, bearing in mind the frequently imperfect (or even partially absent) direction signage in many cities, I arm myself – or hopefully my navigator does – with two maps, one local (Fig. 4.18, showing Huddersfield in some detail) and one global (Fig. 4.19). The latter is needed for me to learn that, on emerging from Huddersfield, I should be on the main road (A629) that brings me eventually to Halifax. Although the detailed map (Fig. 4.18) can be useful, a disadvantage is that, when driving through Huddersfield, alternation of attention between maps to achieve cognitive integration ("which exit leads on to the A629?") is not easy. Sometimes, this drawback is ameliorated by notes on the detailed map (e.g., 'to A629'), but often not.

As a presentation technique, Overview+Detail finds many applications. For example, when perusing a page of a scientific paper (Fig. 4.20) it can help to have sight of its immediate context, represented by miniatures of adjacent pages

Fig. 4.18 A detailed map of Huddersfield (© *OpenStreetMap contributors*)

Fig. 4.19 A large-scale map showing Huddersfield on the route North to Halifax (© *OpenStreetMap contributors*)

having recognisable features that may support navigation. Similarly, in a video editing suite (Fig. 4.21) there is a useful overview of existing video clips as a reminder of what is available while attending to the detail of a specific instant of time.

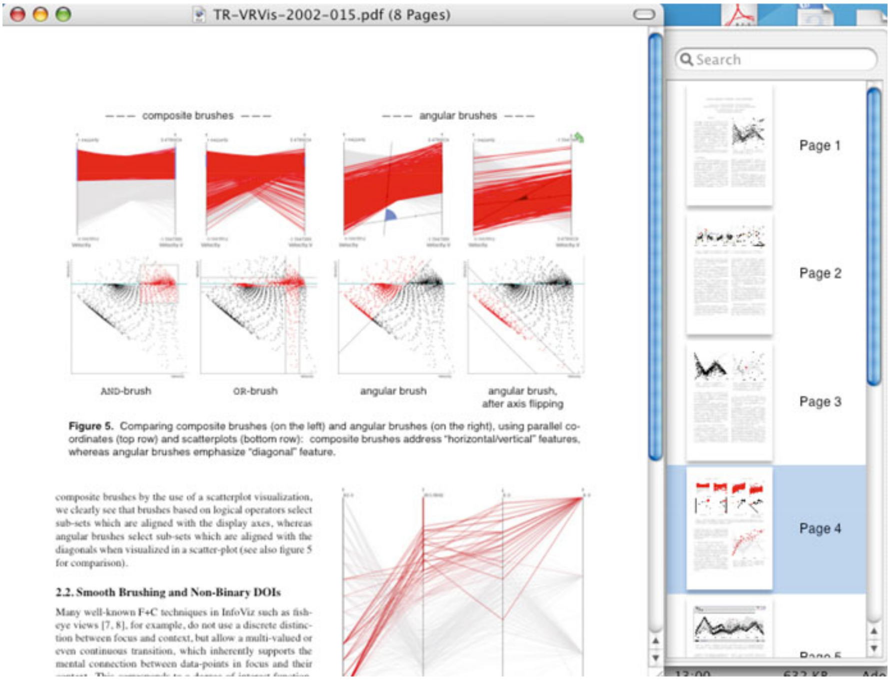


Fig. 4.20 A presentation showing one page of a scientific paper in detail, and adjacent pages in miniature

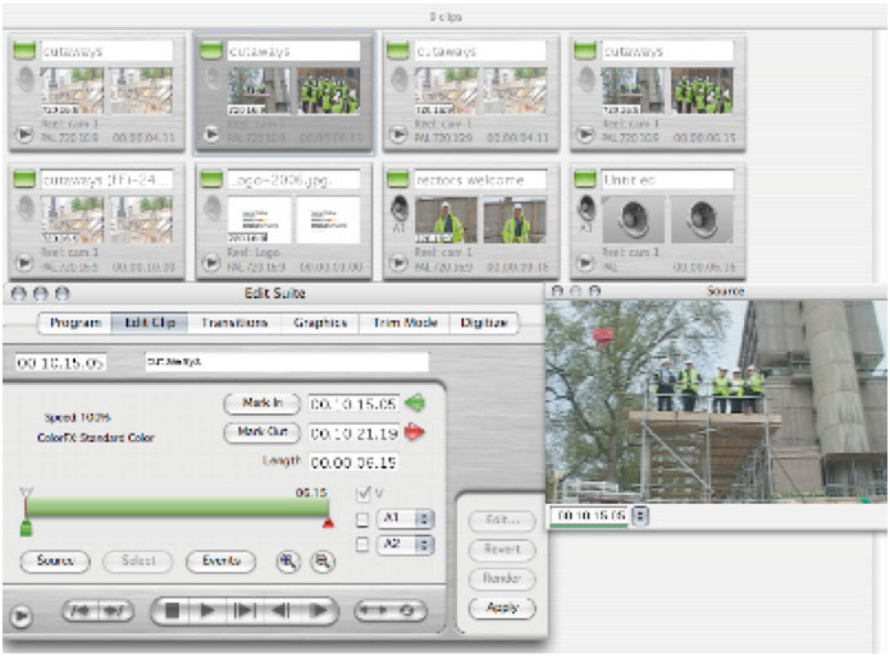


Fig. 4.21 Detailed use of a video editing suite is facilitated by the simultaneous presentation of both overview (eight available video clips at *top*) and detail (the larger 'still' on the *right*)

4.2.5 *Degree of Interest*

An implied assumption in the examples we have studied so far is that as much detail should be displayed as possible. We now challenge that assumption with a view to making displayed information as *useful* as possible.

When viewing a presentation we generally only pay attention to features that are of interest to us. But there is a cognitive load in examining and then disregarding that which is *not* of interest. For example, in the drive North from Huddersfield towards Halifax (Fig. 4.19), I have no interest whatsoever in most of the towns, villages and roads on the global map. The obvious question then arises, "would it help if those uninteresting features could be removed, leaving only those – such as route numbers and landmarks – helpful to my navigation towards Halifax?" The answer is 'Yes', and is an example of the concept of **Degree of Interest**. For the journey in question, application of this concept might replace the conventional global map with the new map shown in Fig. 4.22. Of major interest is the road numbering, but landmarks – such as the motorway across which we travel – are also very helpful to navigation (in the sense that their sighting provides reassurance). Landmarks would be assigned a lower but still significant degree of interest. Obviously, the level of interest in other features of the route could be debated.

The Degree of Interest (DoI) concept[4] (Furnas 1982, 1986, 1999) has very wide application indeed, especially where display space is at a premium. Take, for example,

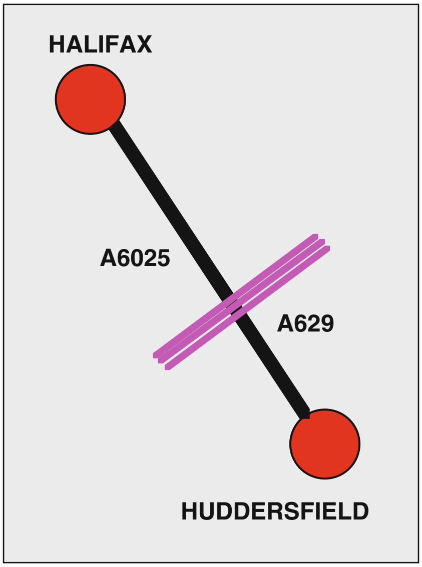


Fig. 4.22 A new map showing essential features of the route between Huddersfield and Halifax

[4] Historically the first application of the Degree of Interest concept was to enhance the understanding of part of a computer program and make better use of display space. Computation of a Degree of Interest for each line of a program relevant to one of particular interest to the programmer results, by the omission of lines momentarily irrelevant, in a more compact display of information which is highly relevant to the programmer. The result is known as a **Fisheye** display.

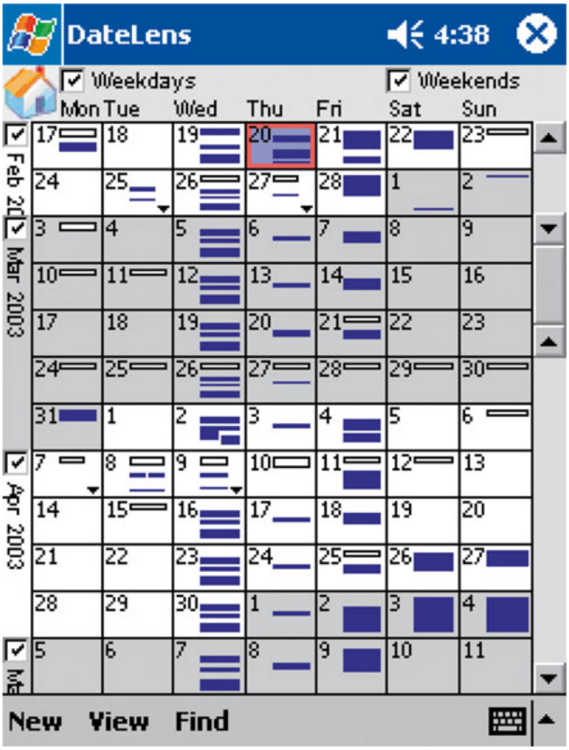


Fig. 4.23 The so-called 'Tiny' view of the DateLens calendar designed for a mobile display (Bederson et al. 2003)

one view (Fig. 4.23) of a diary specifically designed for use on mobiles (Bederson et al. 2003, 2004 – see Chap. 7 Case Studies).

The view (one of four) shown in Fig. 4.23 is principally designed to provide an overview of activity on each day over 12 weeks. That requirement – to represent 84 days on a small display – requires difficult choices to be made about detail that can be shown. As illustrated in a magnified view in Fig. 4.24 there is, in fact, only just enough space in each day cell for six representations: the date; up to around four blue bars indicating scheduled activities; an empty bar indicating an all-day appointment; a background colouring; and a coloured frame. A well-designed use of very little space! Each of those six features will have been chosen according to its anticipated degree of interest to a typical user of the calendar.

Two further examples will illustrate the generality, and hence the power, of the Degree of Interest (DoI) concept.

The maintenance and repair of a complex piece of machinery is a task that occurs on many occasions in a variety of environments. Often a diagram of the machinery is available but is of greater complexity than is relevant to the repair that is to be carried out. The maintenance engineer typically has to examine a very large diagram to see what (usually small) part of it might be relevant to a fault that has developed, and hence to its repair. For example, in the context of an application (Mitta 1990) developed by the US Air Force, Fig. 4.25a shows a conventional 'exploded diagram' of part of an

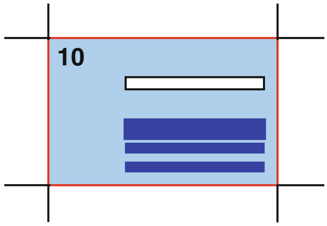


Fig. 4.24 Detail of a single day in the calendar of Fig. 4.23

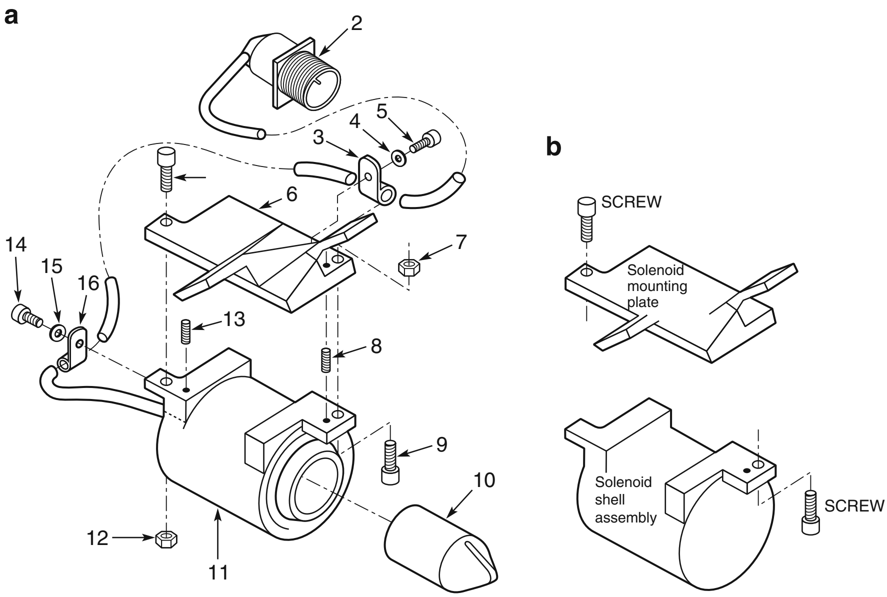


Fig. 4.25 (**a**) Part of an engineering drawing (**b**) a simplification relevant to a suspected fault

engineering drawing, and Fig. 4.25b shows the result of applying a Degree of Interest function relevant to a specific fault. The outcome allows the user to focus attention on the currently relevant part of the mechanism and hence have a better opportunity to build a mental model of (i.e., to visualize) the problem. The idea illustrated in Fig. 4.25 is not restricted to mechanical systems: visualization of the function of a small part of a large electronic circuit could certainly benefit from application of the DoI concept.

The second example introduces the two components of Furnas' Degree of Interest function. One is the *intrinsic* importance of some item; the other expresses the effect of distance – semantic or otherwise – from that item. An illustration of these two separate components of a DoI function is provided in Fig. 4.26 which relates to an enquiry directed to the appropriate person within a large company. Individuals in that company are represented by their position on a tree (a). However, the most important person in connection with an enquiry about production may not be the President, but rather (b) the person P. Therefore, for the purpose of the current

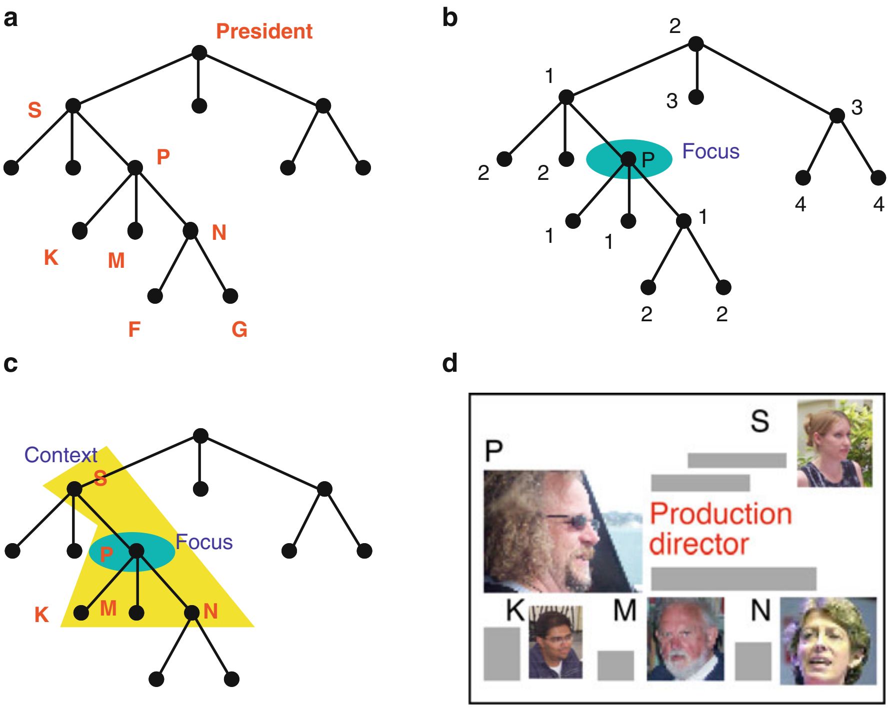


Fig. 4.26 Illustration of the two components of Furnas' Degree of Interest function. (**a**) The organizational tree of a company; (**b**) the focus of attention ('inherent interest') relevant to an enquiry regarding Production, and the 'distance' of various employees from that person; (**c**) definition of an acceptable range of distance; (**d**) a possible automatically generated representation identifying individuals who might be approached in connection with an enquiry regarding production

enquiry, all other employees are characterised by their 'tree' distance away from P *in all directions within that tree* (b). A decision may be made (c) to select those employees within a context of one link away from P, resulting (d) in a display appropriate to anyone enquiring about production. What we see in this example is another illustration of the selective omission and recoding of information.

4.2.6 Focus Plus Context

In considering the Degree of Interest concept we have seen an approach to the general problem posed by the availability of more information than a user can, or needs to, pay attention to. The DoI examples have shown how an approach to this general problem can be achieved by the **selective omission** and, if needed, the **recoding** of information, leading to a technique known as the Fisheye Lens. In essence, the approach recognises the perceptual and cognitive limitations of the human being. The same general approach of selective omission and recoding can take a different

Fig. 4.27 (**a**) The familiar map of the London Underground network (**b**) a focus+context presentation in which text is suppressed in the context region and some relative magnification is present in the focus region. As the focus region is interactively moved within the display, underground lines are continuous across the boundary between focus and context regions

and useful form, however, by recognising another frequently important feature of information to which our attention can usefully be directed, that of **continuity**.

The familiar map (Fig. 4.27a) of the London Underground (Garland 1994) illustrates the approach. Its detailed content is far in excess of anything that can effectively be presented on a conventional display to support attention and interpretation. It may well be the case, of course, that only a part of it is initially relevant to a specific person engaged in travel, but the printing of many different sections of the network would introduce immense confusion and the need for a traveller to specify which is needed. Similarly the Overview and Detail technique is inappropriate. An effective solution, especially if interaction is allowed, is to consider the presented information space to be composed of two – *but continuous* – parts: *focus* (involving detail) and *context*, the latter involving less detail but retaining important features, the two combined in such a way that features that *are* continuous are *presented* as being continuous.

The result (Leung et al. 1995) is shown in Fig. 4.27b. A movable **focus region** containing detail at the same level as the original map is set within the 'squashed' **context** of the remainder of the transportation network. In the context region some detail is suppressed, namely station names, but important features such as line colours and station symbols are retained. The concept illustrated in Fig. 4.27b is referred to as **focus+context**. For this example a major feature is the **continuity** at the boundary of the focus region. As the focus region is moved interactively around the display, the blue Piccadilly Line, for example, is continuous: there is no discontinuity at the boundary of the focus region. This property of continuity is in distinct contrast with the Overview and Detail approach adopted for the journey through Huddersfield: in that example navigation is indeed made difficult by the *absence* of continuity between overview and detail maps.

A general – indeed the original – illustration of the focus+context technique (Apperley and Spence 1980; Spence and Apperley 1982; Apperley et al. 1982), originally called the **Bifocal Display**, is provided in Fig. 4.28.[5] A personal information space containing reports, sketches, images and symbols is represented (a) by the metaphor of a long strip of paper which is far larger than an available viewing frame. The **Focus+Context** technique is illustrated by (b) threading the strip of paper around two uprights, and bending back the two ends such that a viewer (c) can see, 'edge on', an overview of what is in the context regions. In this way, the user is provided with a 'bird's eye view' of the context. The technique illustrated in Fig. 4.29 has often been referred to as a *distortion* technique, since the underlying information space has been distorted, in this case by compression at the two sides. Thus, while editing a document, for example, in the focus region, the user is aware of the presence of other contextual items. He would quickly notice an email from his boss, coloured red.

The illustration of Fig. 4.28 is highly suggestive of the fact that the information space can be scrolled through the focus area without the disadvantage, previously associated with scrolling, of context being masked. Moreover, and of particular importance, *continuity* is preserved across the context boundaries, something that was noticeably and regrettably absent in the maps (Figs. 4.18 and 4.19) used for geographical navigation. Scrolling was originally (Apperley and Spence 1980)

[5] For a comprehensive account of the Bifocal display, including many illustrative video clips, go to interaction-design.org and select 'Encyclopedia'.

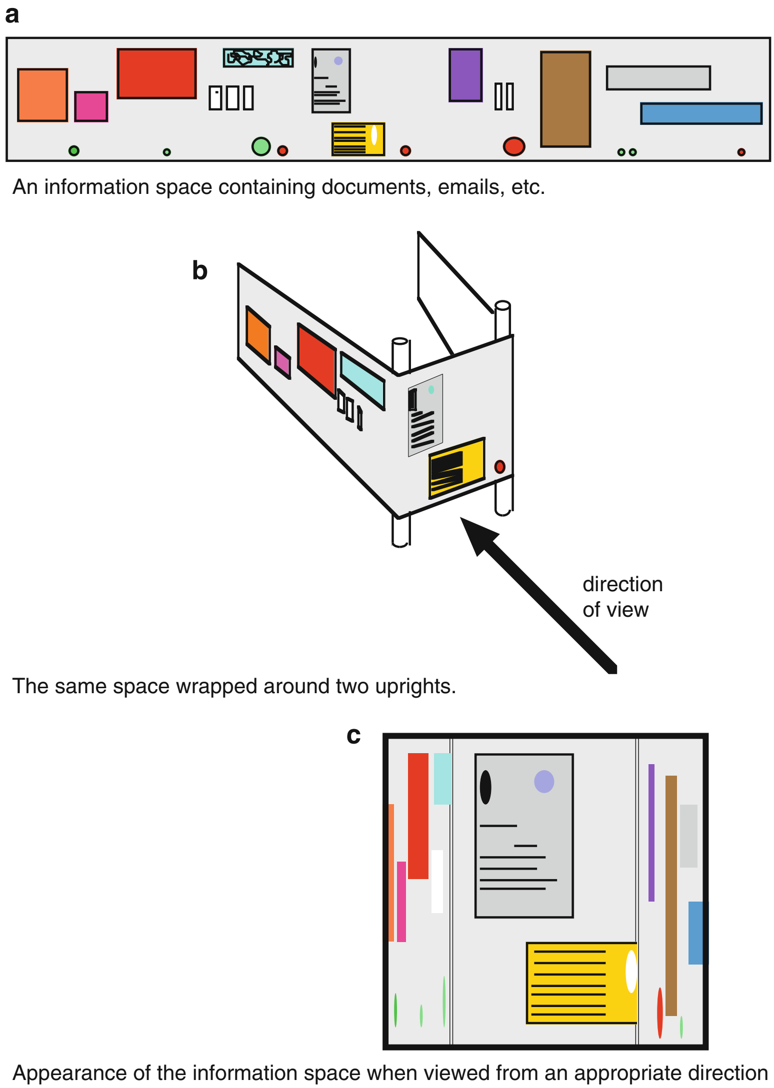


Fig. 4.28 Metaphor illustrating the principle of the bifocal display, the first example of a focus+context presentation

suggested as lending itself to activation by touch, an approach in keeping with modern multi-touch technology.

There is, of course, no point in retaining distorted text in the context regions in view of the impossibility of reading it, so redesign of those regions is required. First, for smooth continuity, the vertical size and vertical position of an item should be identical in both focus and context regions, and relative horizontal spacing should be maintained throughout, otherwise a cognitive dissonance will occur

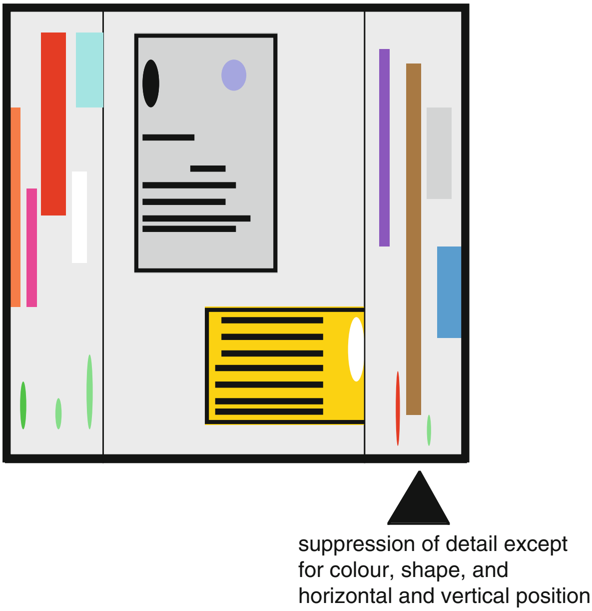


Fig. 4.29 Encoding of context

when the context items are scrolled into the focus region. Second, and again to avoid cognitive dissonance, an item's colour should be identical or very similar in both regions. Third, any text or other markings that cannot be interpreted should be removed (Fig. 4.29).

4.2.6.1 An Abundance of Distortions

A combination of what might be called 'X' and 'Y' distortion was well-suited to the London Tube map of Fig. 4.28, and was originally proposed in the context of calendar presentation (Fig. 4.30). However, since the emergence of appropriate display technology, many new embodiments and variants of the distortion concept have been proposed: we briefly examine a few.

The Table Lens presentation of tabular data (Rao and Card 1994) allows some details to be selected to appear as (multiple) focus entries: Fig. 4.31a shows an application containing data about a large number of baseball players, each originally assigned to such a thin row that names could not be discerned. Groups of names can however be assigned 'focus' status for those names to be readable. The focus+context principle also lends itself well to displays of limited size, as illustrated in Fig. 4.31b by an application supporting inspection of the Boston area transportation network. The third example in Fig. 4.31c shows collaborative table-top interaction with a large map, in which one or more parts can be selected, by one or more independent users, for distortion to permit more effective attention.

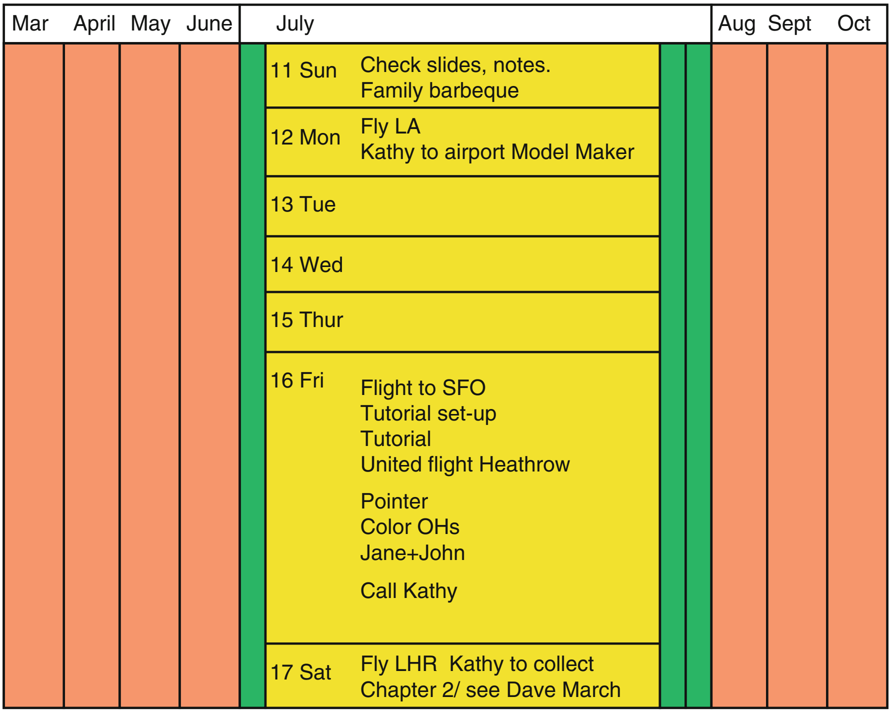


Fig. 4.30 An early (1980) outline proposal for a calendar exploiting the bifocal display concept

When to focus and when to suppress is a common design challenge. However, the Distortion and Degree-of-Interest concepts are both concerned with focus and context, and are not mutually exclusive. An example is provided in Fig. 4.32 and again set in the context of a journey: from Manchester, where a user is located in an hotel, to the home of a relative in Halifax. It employs ‘rubber sheet’ distortion (Kadmon and Shlomi 1978), as illustrated diagrammatically in Fig. 4.33. We first imagine a map of the North of England to be printed in fine detail on a rubber sheet which is then pushed from behind in two regions to reveal the streets in Manchester that lead to the motorway as well as the streets that lead from the motorway to the private home in Halifax. To complement this support of navigation, we imagine a Degree of Interest function to be applied to the remainder of the map to suppress all detail save the essential motorway link and useful landmarks (including a snow shower along part of the motorway). Many other applications of the focus+context concept exist.[6]

[6] See for example, the Neighbourhood Explorer (Apperley et al. 2000), the Flip Zoom technique (Holmquist 1997), the Mackintosh OSX ‘dock’ (Spence 2007) and the Perspective Wall (Mackinlay et al. 1991). The Hyperbolic Browser (Lamping et al. 1995; Lamping and Rao 1994, 1996) discussed in Chap. 3 is another example of the application of distortion. A comprehensive treatment

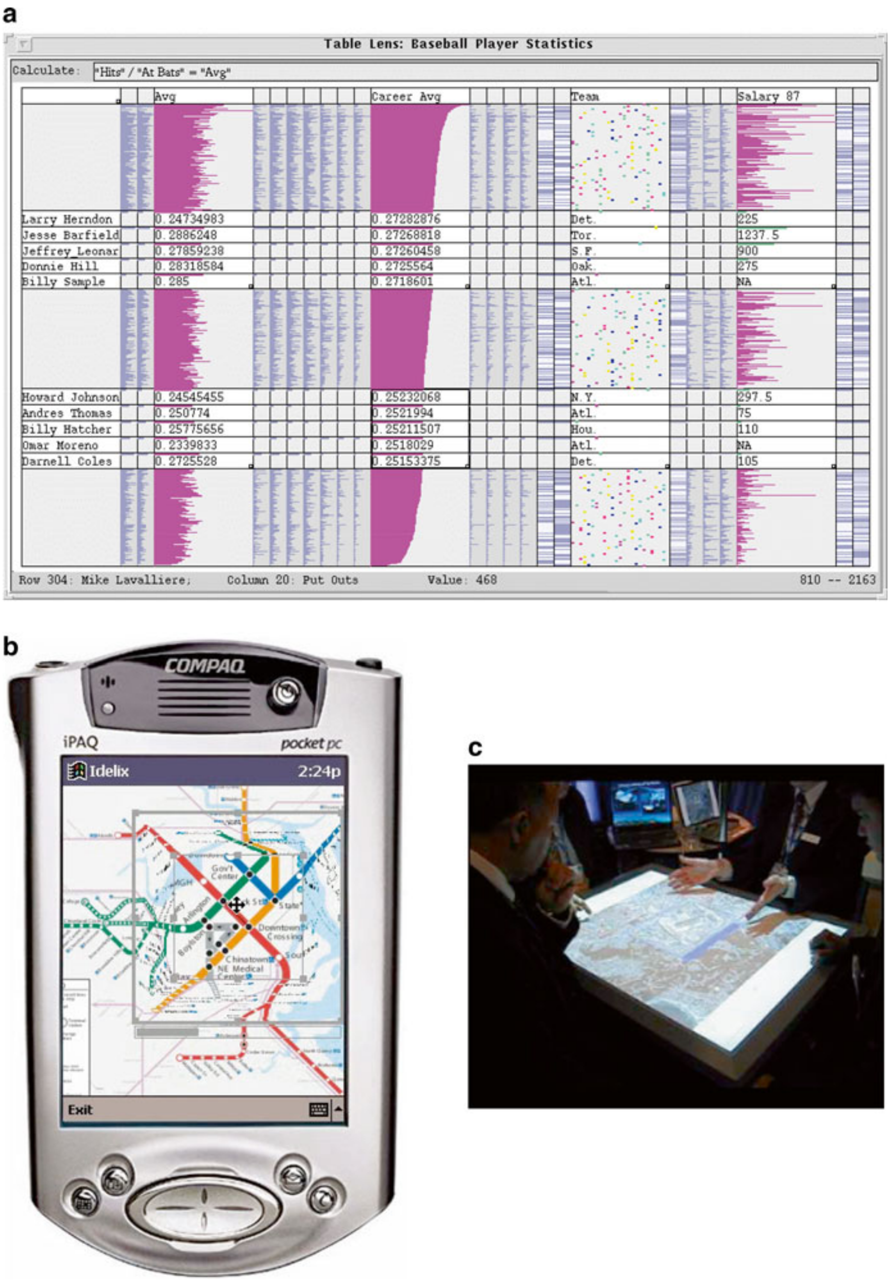


Fig. 4.31 Applications of the Focus+Context principle (**a**) the table lens, here showing data concerning baseball players, with some brought into focus for special attention (*Courtesy Stuart Card*) (**b**) a map of the Boston area transportation network, with X-Y scrollable focus area, showing the continuity across the focus/context boundary of transportation lines and (**c**) a distortable map on an interactive table, supporting collaborative interaction by more than one user

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of the Bifocal Display, together with commentaries by Stuart Card and Lars Erik Holmquist, can be found at interaction-design.org under the heading of 'Encyclopedia'. Many video clips illustrating the bifocal principle are available on the DVD accompanying Spence (2007) and are available on the following website: http:// extras.springer.com

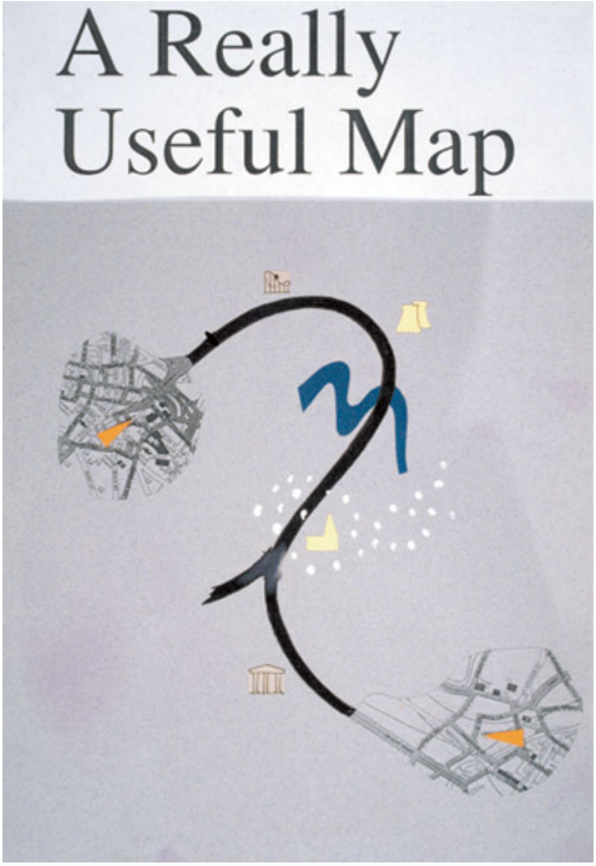


Fig. 4.32 Illustration of the combined application of distortion and degree of Interest to provide a useful map (From Spence 2007)

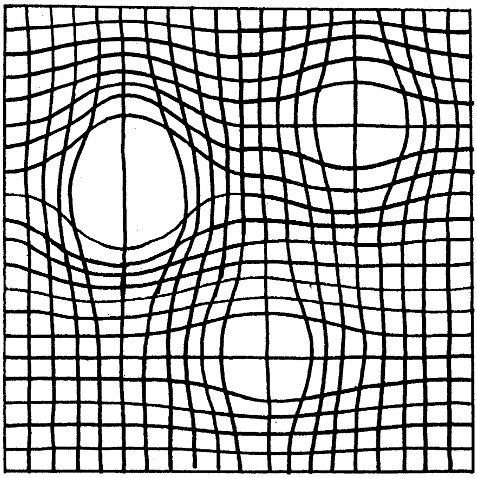


Fig. 4.33 The 'rubber-sheet' distortion technique

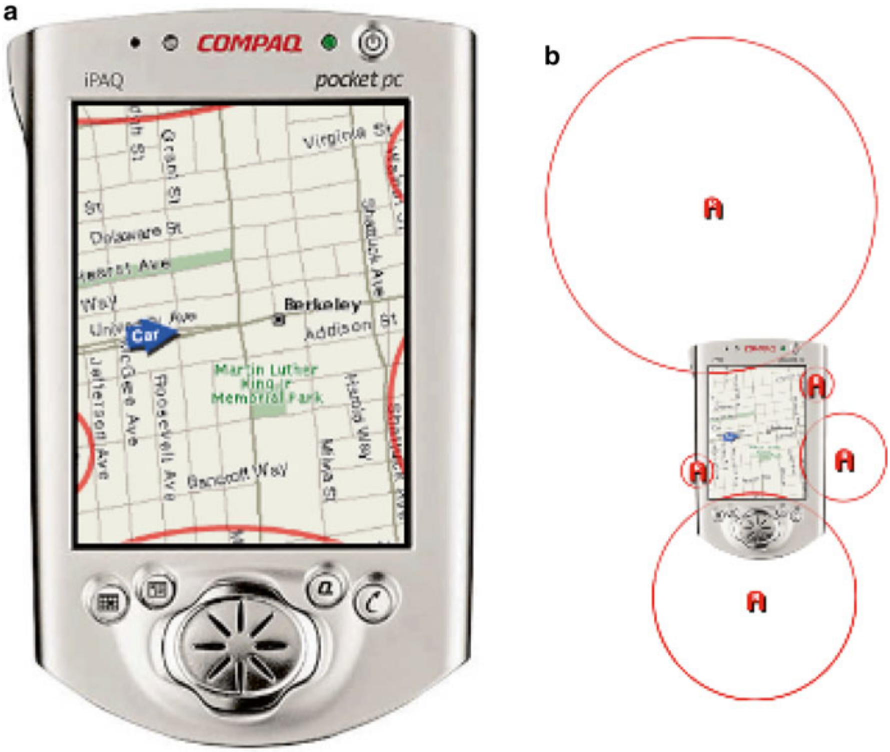


Fig. 4.34 (**a**) A map displayed on a small hand-held device. *Red circular arcs* permit an estimation of their centres relative to the displayed map, and (**b**) the location of items of interest (*Courtesy Patrick Baudisch*)

A reminder that presentation and representation are usually interdependent is provided by a creative focus+context design (Baudisch and Rosenholtz 2003) in which contextual information is reflected into the focus region, with the consequence that this information need not (at least at first) be sought outside that region. Figure 4.34a shows a handheld device displaying a street map in some detail. Figure 4.34b shows where items of interest (e.g., restaurants, churches) *would* be located if the map were to extend beyond the boundaries of the small display. To bring that context information within the hand-held display a red circle (a 'halo') is imagined to be centered on each item, and be of sufficient radius to intersect the map display. The result is shown in Fig. 4.34a: the user is aware, by estimating the location of the centre of each circular arc, roughly where an item of interest is to be found relative to the displayed map.

4.2.6.2 Large Displays Supporting Collaborative Use

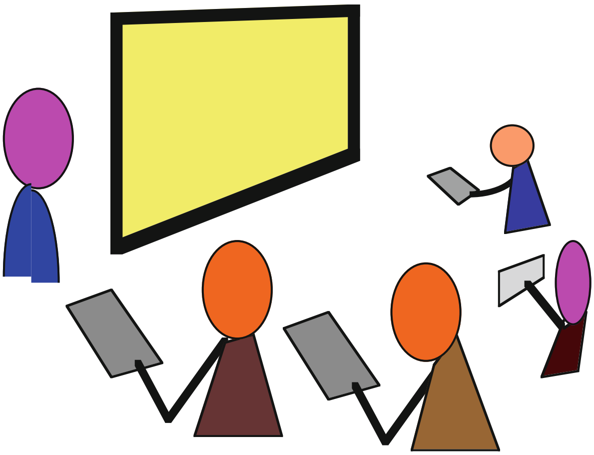
Much attention has been paid to the problems associated with small displays: but in recent years displays of considerable size have become available and affordable, some reaching the size of a very large wall. One immediate consequence is the potential to support *collaborative* working. Instead of 'looking over the shoulder' at a laptop display to merely share a view – and awkwardly so – a group of users collaborating in the performance of a complex task can share displayed data in a very flexible and powerful manner. Examples include the wall-size display at NASA mission control (Fig. 4.35) and vehicular traffic monitoring at a UK Highways Agency control room (Fig. 4.36). At a more modest size but, most importantly, exploiting the potential of collaborative working, is a display (Fig. 4.37) that supports a seminar involving a professor and his graduate students (Suppers and Apperley 2014). We examine this last application in order to distil some concepts relevant to the opportunities offered by large displays.

In the scenario sketched in Fig. 4.37 a professor is leading a seminar involving some graduate students. The professor will have prepared viewable material to trigger a useful discussion. Equally, each of the graduate students will have prepared for the occasion by generating sketches and other material on their personal iPads or similar devices. The seminar is thereby enhanced immensely in many ways: by the ability to *transfer* material from a student's device to the main display and vice versa; by the ability to *annotate* material already on the main display or transferred to it; by the possibility to copy original or annotated material from one owner to another; and

Fig. 4.35 NASA mission control room

Fig. 4.36 Vehicular traffic monitoring at the UK Highways Agency

Fig. 4.37 A seminar led by a professor. Each student can upload a contribution from their iPad to the main display for class discussion



by the ability to modify/edit someone else's material (Suppers and Apperley 2014). All these potential activities obviously raise the issue of protocols that say what can be done by whom and to what material. The dialogue can indeed become quite complex, and typical of collaborative working. Other issues requiring attention arise from the properties of the human visual system, as outlined in Sect. 4.1.

4.2.7 *Zoom: Geometric and Semantic*

4.2.7.1 Geometric Zoom

In the everyday scenario in which a television camera zooms in to a scene to provide a close-up view of a building or person (Fig. 4.38) we accept that, within the resolution of the camera and our TV display, we are simply going to see a magnified view of a fraction of that scene. This graphical transformation is called **geometric zoom** and can, of course, include both 'in' and 'out' zooming. In this trade-off between scene coverage and object magnification the image of an object changes only in size. Consideration of the acuity of the human eye does not occur on a case-by-case basis: decisions about the resolution of both cameras and displays are influenced by technical and economic factors as well as human factors and may remain in place for decades.

Fig. 4.38 Geometric zoom in the context of an transportation documentary: three frames selected from a continuous action

Data Density

We begin to take account of the human visual system on a case-by-case basis in the situation illustrated in Fig. 4.39. The figure shows four views of successively smaller parts of the UK. In (a) we have a map of the UK; in (b) a view of Yorkshire, one of the counties of the UK; in (c) a map of Hull, a city within Yorkshire; and, in (d), a detailed street map of that part of Hull of particular interest (e.g., to a traveller seeking a specific hotel). Even if the UK map (a) could be printed or displayed at infinite resolution it would serve little purpose: for example, the acuity of the human eye in the foveal region is such that a person can locate, within a square centimetre, not many more than about 100 points (Tufte 1983). So there is a limit to the amount of information that can be gleaned from a given area of display, *whatever is depicted in that display*. Thus, each of the four separate maps shown in Fig. 4.39 will generally exhibit a broadly similar **data density** (to use Tufte's terminology) and, within a general (and difficult to quantify) limit on such density, will be individually designed to serve a viewer's perceptual ability and cognitive needs. If the maps shown in Fig. 4.39 are to be individually printed or made available for display there is no consideration of a continuous geometric zoom: each map has to be individually designed for visual clarity and intended use. This approach is not new, as evidenced by maps ranging from 400 years ago to the present-day Ordnance Survey

Fig. 4.39 Maps showing successively smaller geographical areas and correspondingly greater detail (© *OpenStreetMap contributors*)

maps of the UK. Over this period of time the general level of data density in maps has not appreciably changed.

'Zoomable' Digital Maps

Although the concept of continuous geometric zoom does not arise in connection with printed maps there is, nevertheless, considerable interest in a digital map presentation supporting a zooming facility that can (a) allow the selection, on an essentially continuous basis, of a magnified or reduced geographical region of interest, and (b) can present information appropriate to that region while acknowledging acceptable limits on data density. The solution adopted by many sources of maps is algorithmic. For any currently displayed map (e.g., Fig. 4.40, left) a 'zoom-in' command – however issued – causes both the necessary contraction of the mapped area and the addition of streets, street names and other details appropriate to the requested level of zoom (Fig. 4.40, middle and right).

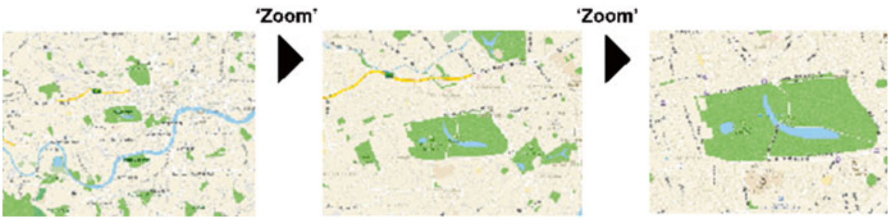
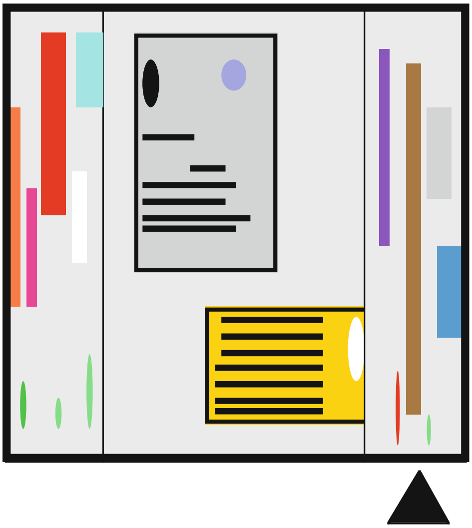


Fig. 4.40 The result of zooming in to an area close to the Royal Albert Hall in London. (**a**) The starting map (*left*). (**b**) The map resulting from a zoom-in action showing a reduced geographical area but more detail of streets and street names (*right*). (**c**) A further zoom showing even more detail (© *OpenStreetMap contributors*)

4.2.7.2 Semantic Zoom

The example of Fig. 4.40 serves to introduce the concept of **semantic zoom** which is very different from geometric zoom. With semantic zoom, objects – or, more generally, representations of data – are now not constrained to change only

Fig. 4.41 The arrangement of a bifocal display provides an example of semantic zoom. Some – but not all – features of a document change as its representation moves between the focus and context regions



their size. They can change in colour, shape, presence and texture, and they can offer a new selection and/or structure of represented data, all with the sole purpose of conveying, in available – and often very limited – display space, useful meaning to a user.

We have, in fact, already encountered an example of semantic zoom during our discussion of the bifocal display (Fig. 4.41, previously Fig. 4.30). Imagine a scrolling action that takes a document from the focus region across the (usually invisible) boundary to a context region. There is often little space available in the context region, so the document is transformed in a number of ways. First, its horizontal width is severely reduced in order to accommodate a number of similar items in the small context region. Since, as a result, text and similar detail would thereby be compressed and unreadable, it is removed. Third, its colour may be chosen to reflect the originator of a document or email (red, for example, for the user's manager). Even with these changes, the user is aware, perhaps initially via peripheral vision, that an email from their manager has been received. If a linear representation of time has been adopted in the context region the email's time of arrival can also be estimated. It may well be the case that vertical position also conveys meaning. However, as pointed out earlier, some aspects of a document's representation in the context region should not change: if discontinuity and its consequential cognitive dissonance are to be avoided when a document moves from the focus to the context region, its height and vertical position should remain unchanged. In the illustration of Fig. 4.41 we have two levels of zoom.

Semantic zoom can be applied to a wide range of applications. In the DateLens calendar (Bederson et al. 2004) designed for the limited area of a hand-held display, there are four levels of zoom (Fig. 4.42), each carefully designed to convey the

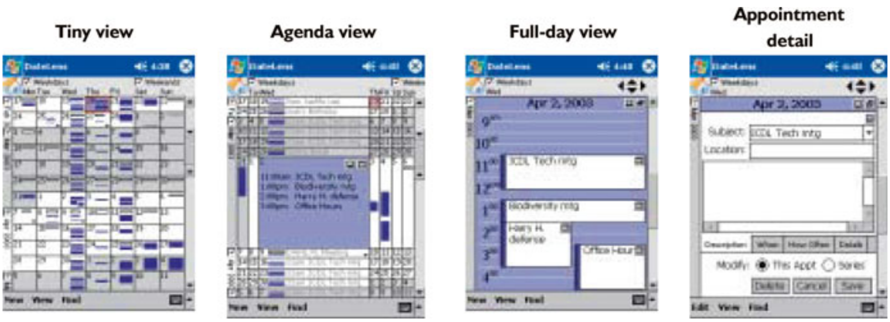
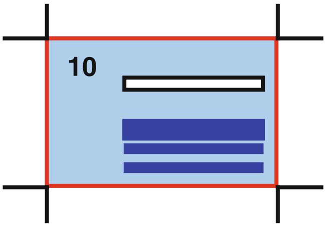


Fig. 4.42 An illustration of semantic zoom. The DateLens calendar (Bederson et al. 2003, 2004) offers four views, ranging from the 'Tiny' view on the *left* to the 'appointment detail' on the *right*. Interaction causes a zoom-in or zoom-out action

Fig. 4.43 Representation of one day in the 'Tiny' version of the DateLens calendar (Bederson et al. 2003). Six attributes of a day are encoded in the very small available space



meaning deemed appropriate to representative tasks being carried out using the calendar. The 'tiny' view (Fig. 4.42, left) provides minimal but useful information regarding each of many days, (as clarified in Fig. 4.43), whereas the 'appointment detail' view (Fig. 4.42, right) provides information about just one of a number of activities within a specific day. With such semantic zoom the four views provide a useful progression appropriate to a wide variety of tasks.

4.3 Temporal Considerations

Imagine walking into a bookshop and noticing what appears to be an attractive book. You might well pick it up and riffle (Fig. 4.44) quite rapidly through its pages. In the course of about 5 s you could have riffled through more than 50 pages, in so doing acquiring some feeling for its content, the use of colour, the presence or otherwise of equations and the attractiveness of the layout and text. Or the book could have been an art book you selected from your bookshelf in order to show a friend the Mona Lisa, in which case fast riffling would have enabled you to find the relevant image very quickly.[7]

[7] If it's a Mondrian you're looking for you might be able to riffle faster!

Fig. 4.44 The rapid riffling of the pages of a book to gain some appreciation of its content

4.3.1 Rapid Serial Visual Presentation

The activity you have just engaged in is called Rapid Serial Visual Presentation (RSVP). It is certainly **rapid** (ten pages per second, for example), and **serial** in the sense that individual pages become visible one after the other; and the content is **presented visually**.

The effect just described can, of course, be simulated computationally. But why should we be interested in doing so? Fundamentally, our interest in RSVP arises from the fact that something **useful** (the identification of a sought after image, for example) can be achieved extremely **rapidly** (in as little as 100 ms). But not only that: experiments show that with such rapid presentations **no conscious cognitive effort** is involved. It surely cannot be denied that a process that allows a useful result to be achieved rapidly and without conscious cognitive effort is truly remarkable, and deserves to be examined to determine its application potential. But first, let's review the experiment that established this remarkable phenomenon around 45 years ago.

4.3.1.1 Experimental Basis of RSVP

Potter and Levy (1969) conducted the experiment illustrated in Fig. 4.45. A subject is first shown a ('target') image and allowed to look at it for a few seconds. It could be a painting, a picture of a briefcase, or a car. The subject is then told that they will see, on a display screen, a collection of images presented one after the other at a fast rate. Their task is to say whether or not the target image was in the collection. Briefly, the

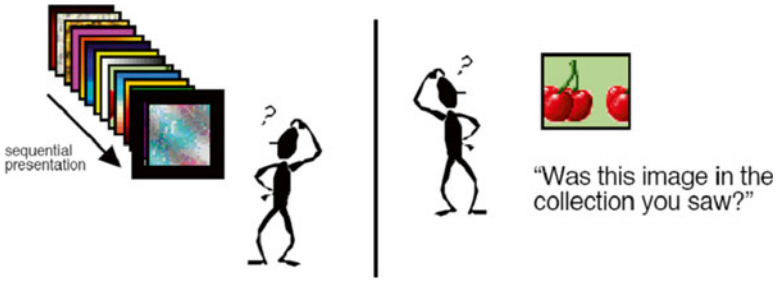


Fig. 4.45 A person is shown an image. A collection of images is then presented to the person at fast rates, typically up to 10 per second. The person is then asked to say whether the original image was present in the collection

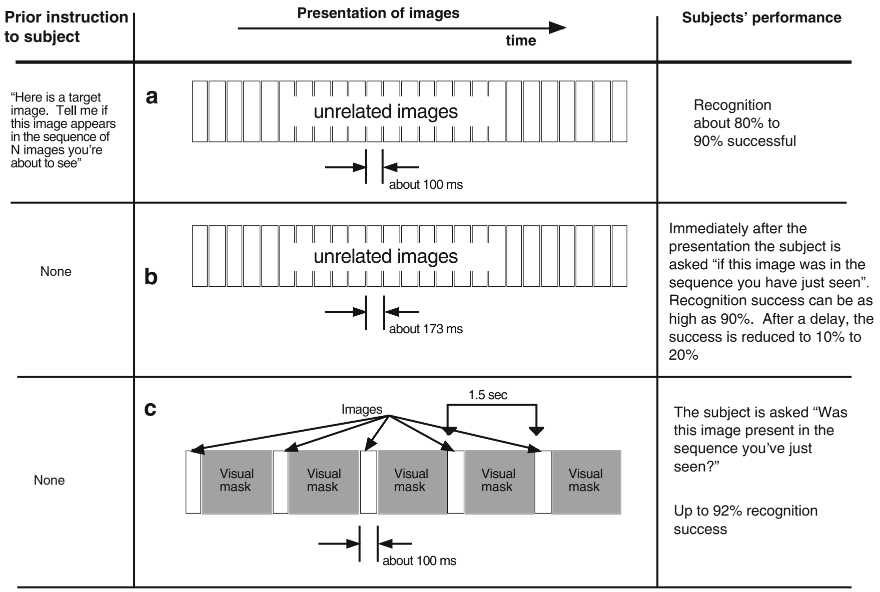


Fig. 4.46 Details of some experiments related to rapid serial visual presentation

experimenters found that recognition of the target was around 90 % successful until the rate of presentation increased above about ten images per second.[8] For later comparison with other, related experiments, this result is summarised in Fig. 4.46a. The phenomenon discovered by Potter and Levy is another example of **pre-attentive**

[8] Recently, Potter et al. (2014) conducted an experiment in which each image in a collection of 6 or 12 was visible for only 13 ms and with no interval between them, and participants had to detect a picture specified by a name (e.g., smiling couple) that was given either just before or just after the sequence. Successful identification occurred for even those small display periods.

processing already discussed in Sect. 4.1. Soon we shall examine how it can be beneficially exploited.[9]

4.3.2 Fleeting Memory

An obvious question is triggered by the experiment summarised in Figs. 4.45 and 4.46a: "Will the subject be able to *remember* the images they have seen?" The brief answer is 'No' unless their memory is tested within about 5 s of the end of the presentation. This result is summarised in Fig. 4.46b: the subject is given no instruction before the presentation of a collection of images, and at the end is asked "Was *this* image in the collection?" According to Potter et al. (2002), recognition success can be as high as 90 %. However, if more than about 7 s elapse before that question is put to the subject, identification success falls to 10 or 20 %.

One's instinctive conclusion from this result may be that 100 ms visibility is insufficient for an image to be retained in memory. But one would be wrong! If the above experiment is repeated (Intraub 1980, 1984, 1999; Potter 1976) with each image visible for only 100 ms *but separated by a 'visual mask' lasting 1.5 s* as illustrated in Fig. 4.46c, the recognition of images contained within the collection is as high as 92 %. It would appear that time is needed for the consolidation of the image in short-term memory.[10,11]

4.3.3 Applications

The obvious potential of RSVP can be realised in a number of practical applications. Because we shall soon be describing many variants of RSVP we shall identify the form of presentation illustrated in Fig. 4.45 as **slide-show RSVP**. Here are four possible applications.[12]

1. On my desk-top I have a folder whose title has not, perhaps, been wisely chosen (Fig. 4.47). Rather than **open** the folder and then **click** successively on each item within it to gain some feeling for the anonymous folder's content, I would prefer

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[9] The importance of preattentive processing is reflected in Ware's (2004) comment that "an understanding of what is processed pre-attentively is probably the most important contribution that vision science can make to data visualization".

[10] RSVP is not limited to images. Some very interesting studies have been carried out with the RSVP of text, primarily with a view to speeding up reading and its associated comprehension (see, for example, Rubin and Turano 1992.

[11] For a more comprehensive discussion, and especially an introduction to Conceptual Short-term Memory (CSTM) see Potter (1999).

[12] For a wide range of RSVP applications see chapter 1 of Spence and Witkowski 2013.

Fig. 4.47 An unwise choice of folder title

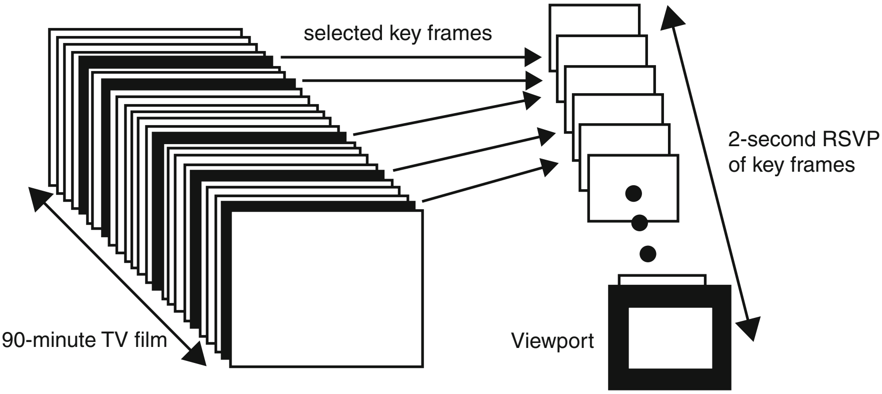

Fig. 4.48 To convey the gist of a video or film, carefully selected 'key frames' are presented in rapid succession for a short time

instead to undertake some action (a 'mouse riffle'?) that will cause a slide-show RSVP of the contents.

2. I want to watch a video, and notice the availability of one called *Flame*, a title that provides no clue as to its genre. I am, however, prepared to spend a few seconds – but no longer – to gain some insight into its content. One solution to the problem of acquiring the 'gist' of a video is (as already briefly explained in Sect. 4.1) to present, in slide-show mode, a fast sequence of 'key frames', each selected by a marketing specialist specifically to illustrate the nature of the video (Fig. 4.48). That this approach is viable was demonstrated by Tse et al. (1998) who showed that, within 2 s, 20 appropriately selected key frames were sufficient to convey the 'gist' of a video.
3. A news web page, of which a representative sketch is shown in Fig. 4.49a, typically contains a small number of 'major stories', each represented by an easily recognised generic image and possibly a very limited amount of text. The screen area of a tablet or mobile is, however, insufficient to display the entire page at a readable text size. A typical solution is to allow magnification and panning, for example by two-finger touch operation. An alternative (de Bruijn and Tong 2003), suggested by the potential of slide-show RSVP, is to present each 'major story' in sequence, *often at the same size as in the typical web page* (Fig. 4.49b). If a user can sequence through about ten of these 'major stories' at the rate of

Fig. 4.49 A solution to the 'key-hole problem'. News items conventionally displayed on a laptop display can each be presented, at roughly the same size, in sequence on a tablet display

around 2 per second they will be able to gain roughly the same feeling for available stories as they might when visually scanning a regular display. This example illustrates the potential offered by slide-show RSVP as an approach to the **keyhole problem**, by trading off space and time.

4. It is important to realise the limits to what slide-show RSVP can achieve. For an example we choose an application called Flipper which, in the words of its inventors (Sun and Guimbretiere 2005), "*carries the affordance of page flipping* [i.e., riffling] *to the digital world*". It is illustrated in Fig. 4.50. To support the finding of one's way through a document, it complements slide-show RSVP with scrolling. "Flipper combines speed dependent automatic zooming and rapid serial visual presentation to let users navigate their documents at a wide range of speeds".

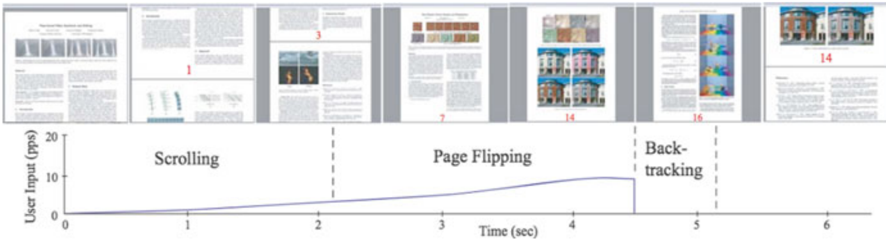

Fig. 4.50 In the examination of a textual document a speed-dependent mixture of slide-show RSVP and scrolling may facilitate search or browsing. Slide-show RSVP is complemented automatically by scrolling at lower rates

4.3.4 Assessment of Slide-Show RSVP

While slide-show RSVP offers considerable potential for some applications, it is not without its drawbacks in others. An obvious one is the consequence of blinking, which might well mask three or four consecutive images from view. Another is an inability to confirm the identification of an image of interest, since an image is only visible for a very short time. Yet another is the absence of any visible context that can often vastly enhance the understanding of and interaction with a collection of images. In view of these shortcomings of slide-show RSVP we now consider the considerable opportunity of presenting data in **both** space and time.

4.4 Presentation in Space and Time

Removal of the constraint imposed by slide-show RSVP – that images can only briefly be visible in a single location – provides a valuable degree of freedom when designing the manner in which a collection of images can rapidly be presented to view. Often there is adequate space available on a regular display so that consideration can be given to the relative allocation of space and time to a collection of images.

A very simple but powerful example (Wittenburg et al. 2003), and one that introduces a number of important concepts, is provided by the common activity of video fast-forwarding and rewind, an activity frequently undertaken by human beings above the age of three to locate a favourite sequence or to skip the commercials (Fig. 4.51). The major advantage of this simulated 3D presentation is that *temporal context has been translated to spatial context*. One can immediately notice where (and implicitly *when*) a change of scene has occurred, for example. Provided with an appropriate manual control of speed and direction,

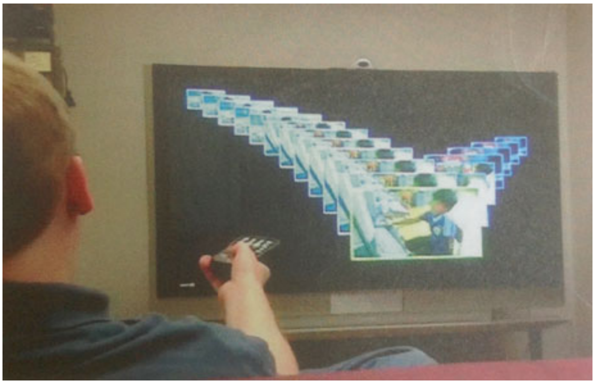

Fig. 4.51 An interactive visual interface supporting fast-forward and rewind. The context of a currently examined frame (at the '*front*') is visible and can be beneficial, for example, in identifying scene changes

the user can bring a new frame to the 'front' to be examined in detail (as with the Bifocal Display, see Sect. 4.2) or, perhaps additionally, view a sequence of images effectively in slide-show RSVP. The example also shows that the overlap of adjacent images, with consequent partial obscurement, need not always be a problem: there is obviously a trade-off between the partial obscurement of an image and the number of currently visible images. This technique for supporting fast-forward and rewind is preferable to the conventional facility that embodies slide-show mode.

Notwithstanding the attractive features exhibited by the fast-forward and rewind facility shown in Fig. 4.51, many questions regarding RSVP are still outstanding. Is there, for example, a limit to the number of images that can be provided on a display, and can they be located anywhere? How does a particular task influence the way in which RSVP should be exploited in both space and time? And how rapidly can a given collection of images be effectively presented to view? To answer some of these outstanding questions we now examine a few of the many forms that 'moving-mode RSVP' can assume. In so doing we shall discover how eye-gaze, and human visual processing in general, play a pivotal part in the effectiveness and acceptability of different RSVP modes.

4.4.1 Moving RSVP Modes

A variant of RSVP that has considerable application potential is Floating mode, illustrated in Fig. 4.52. It simulates what may be termed the 'motorway effect'. As one drives along a motorway, advertisements by the roadside appear to move towards and then past one: with floating-mode RSVP the user is obviously stationary and the images simply appear to move past.[13] For a user who, for example,

[13] In my lectures I introduce floating mode by the sequence: (1) walking around a department store to view products, (2) using an airport-style buggy to speed things up or, even better, (3) stand still and arrange for the contents of the department store to move past you.

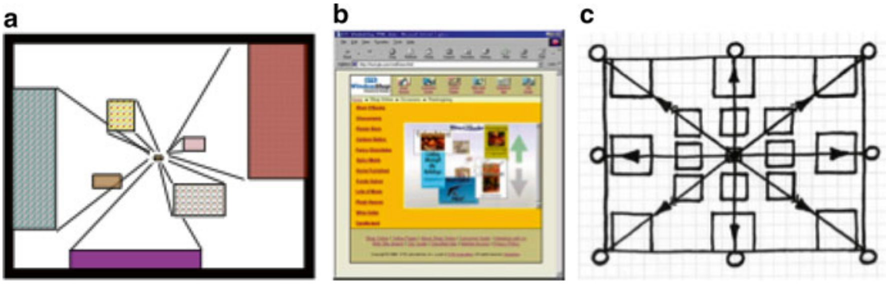

Fig. 4.52 Floating mode RSVP. (**a**) A diagrammatic sketch, (**b**) a screen shot from a working example, and (**c**) the notational description specifying, among other features, the location and nature of the image entry and exits and the trajectories followed

is uncertain what to buy his friend for Christmas, such a presentation can help to form a mental model of content and eventually lead to a choice, especially if the speed and direction of movement is under manual control. The speed of image movement would generally be chosen to allow time for an image identified preattentively as of interest to be attentively confirmed before disappearing.

It is obvious from Fig. 4.52b that a mere screen shot of a floating mode RSVP is insufficient to convey temporal details. For this reason we introduce a notation (Spence and Witkowski 2013), illustrated in the context of floating mode in Fig. 4.52c. First, a solid circle (●) shows where images (represented by empty frames), appear, and an empty circle (O) where they disappear from view (if the empty circle appears outside the display boundary the images gradually, rather than abruptly, disappear from view, a convention that also applies to image appearance). Second, a line with arrows indicates the trajectory followed by the centres of the images. Third, a 'right-angle symbol' (⌈) on each image frame indicates continuous rather than discrete image movement. Finally, frame locations can indicate the relative speed of movement. One remaining notational convention is introduced later.

A second moving mode of interest is Shot-mode, illustrated by a screen view and notational description in Fig. 4.53. Here, the presentation simulates images being 'shot', in a continuous stream, from a source that could be said to be 'on the horizon'. The rate at which the images appear – called the 'pace' of the presentation – is often higher than for the floating mode, but the two modes do share a number of features.

A very different mode is called the Collage mode and is illustrated in Fig. 4.54. It is strictly not a moving mode: what this figure does not show is the fact that each image appears in sequence in a random location. A cross is the notational indication that an image is stationary at that frame for a specified duration; in this special case an image *does not move thereafter*, even though it may be overlapped by a succeeding image. The effect is similar to that of watching someone throw a succession of books onto a table so that you can get some feeling for what is available.

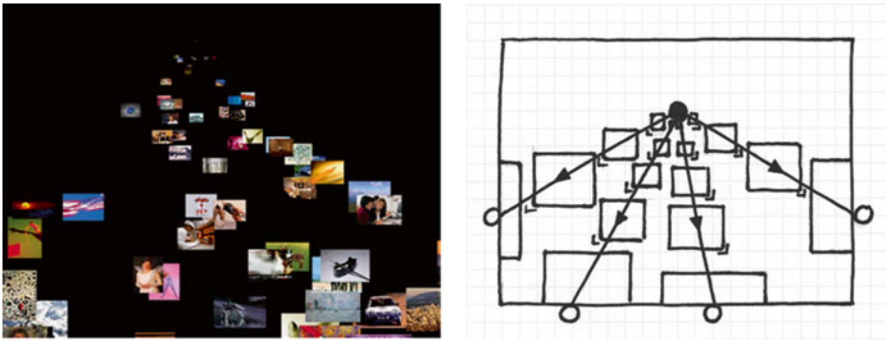

Fig. 4.53 Shot mode RSVP. A screen view (*left*) and a notational description. Images enter as if fired from a gun towards the *top*, and exit continuously at the lower edge

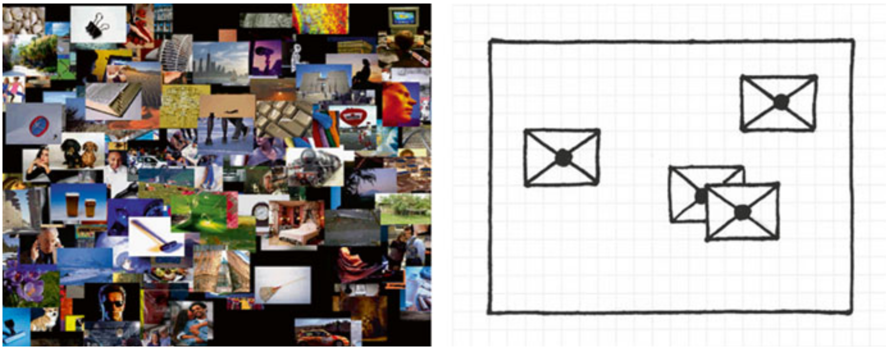

Fig. 4.54 Collage mode RSVP. A screen view (*left*) and a notational description. Images appear at random locations

Finally, we look at Stream mode RSVP (Fig. 4.55). Here, images enter the display in a continuous stream (indicated by a filled circle *outside* the display boundary) and move without stopping along a trajectory that leads to an exit point: an open circle outside the display boundary indicates that images disappear from view continuously.

There are, of course, many other forms of moving RSVP (Porta 2006), some of which we shall visit, and the reader can easily invent new ones. But to make use of them, what do we need to know? Which one is best? And for what task? More crucially, why should one mode be better, in some respect, than another? Perhaps more fundamentally for anyone intending to incorporate moving RSVP in a web page, "What are the features of a mode that determine its benefits?" Perhaps surprisingly, the answers to these and other questions are principally to be found in the way in which our eyes move when looking at an RSVP mode.

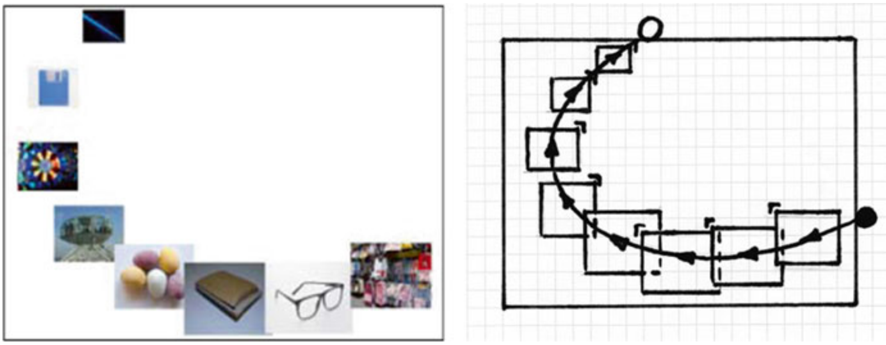

Fig. 4.55 Stream mode RSVP. A screen view (*left*) and a notational description. Images enter continuously *bottom right* and exit continuously *top left*

4.4.2 Eye Gaze

In Sect. 4.1 we saw how 'looking' at a scene was, in reality, quite a complex process. Typically, the movement of eye gaze is characterised by a sequence of fixations, each lasting on average around 200 ms, separated by very fast saccades, each of which lasts around 20 ms. What concerns us now, in connection with looking at an RSVP presentation, is exactly what happens during a saccade – perhaps surprisingly in view of its short duration.

If you move your gaze from one part of a room to another you will notice that you do not see the intervening scene moving continuously by. In fact, you are *blind* during that very short saccade, a phenomenon known as **saccadic blindness** (Chahine and Krekelberg 2009). It has, as we shall soon see, direct implications for the design of an RSVP application. Another interesting feature of a saccade is that it is ballistic – once begun it will end at a predetermined location.

4.4.2.1 Collage Mode RSVP

Let's examine the gaze behaviour that is typical of someone watching Collage RSVP. A recording of fixations and saccades over a substantial period of time might be difficult to interpret, so instead we use a representation (Fig. 4.56) called a **heat map**. Rather than temperature, the colours indicate instead the density of fixations accumulated over a period of 3.5 min. The heat map of Fig. 4.56 is commensurate with movement of gaze in a random fashion over the entire display, movement that would be consistent with gaze trying to follow the random nature of the location of successively appearing images. The question is, "does that matter?" It turns out that it would appear to do so, partly because the user experiences

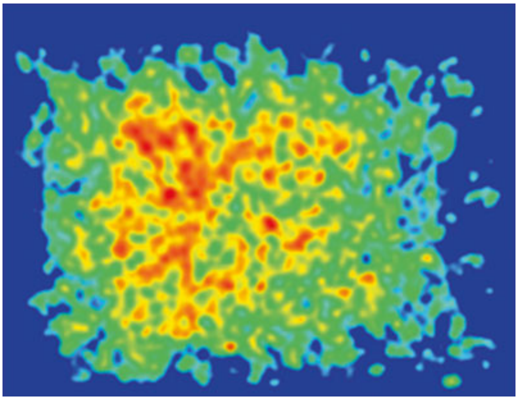

Fig. 4.56 A gaze heat map recorded during the use of Collage mode to identify target images

a great deal of fatigue, and partly because, if the user is searching for some form of target, the likelihood of finding it is less than for the other modes we shall examine. We shall leave a demonstration of these drawbacks until, for comparison, we have discussed the three remaining RSVP examples; Shot, Stream and Floating.

4.4.2.2 Shot Mode

A heat map derived from a single person attempting to find a given type of image (e.g., 'fish' or 'ship') using shot mode RSVP is shown in Fig. 4.57. What is happening here is that each image, when it first appears, is too small to be recognised, so the user realises that the point at which images become recognisable occurs somewhere further down the display from the point at which images enter. At this point, however, the images are spread out horizontally, so that gaze must travel to and fro sideways in a fairly well-defined region if image recognition is to be achieved: such primarily sideways travel is illustrated in Fig. 4.58 by the fixation tracks (blue) and saccades (yellow). Gaze will also have a downwards vertical movement if recognition is to be confirmed: the detailed trajectories of gaze (saccades removed for clarity) shown in Fig. 4.59 tend to support this explanation. Nevertheless, if total gaze travel is best minimised, we might expect shot mode to cause the user less fatigue and more recognition success than for the collage mode example shown in Fig. 4.56.

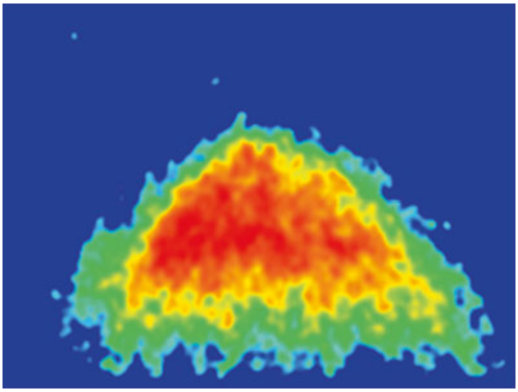

Fig. 4.57 A gaze heat map recorded during the use of shot mode RSVP to identify target images

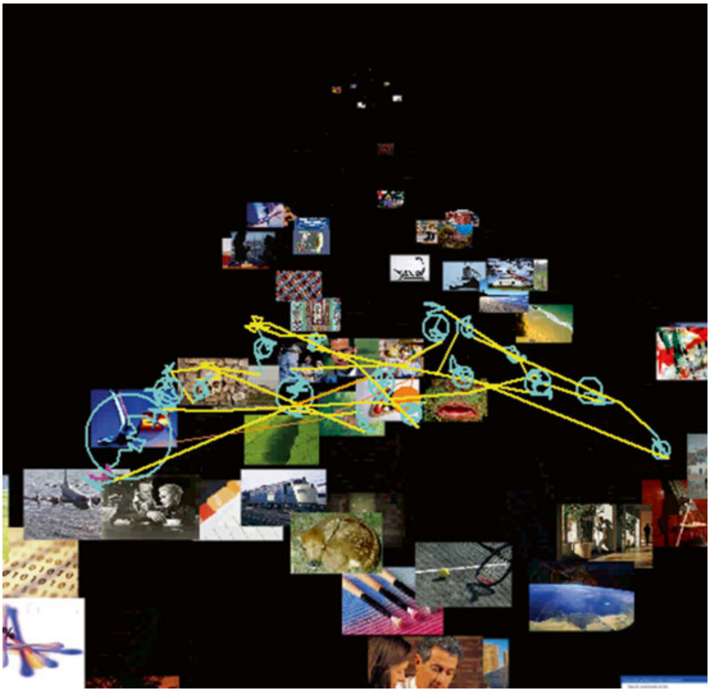

Fig. 4.58 Sideways movement of gaze is required in shot mode RSVP if target recognition is to succeed

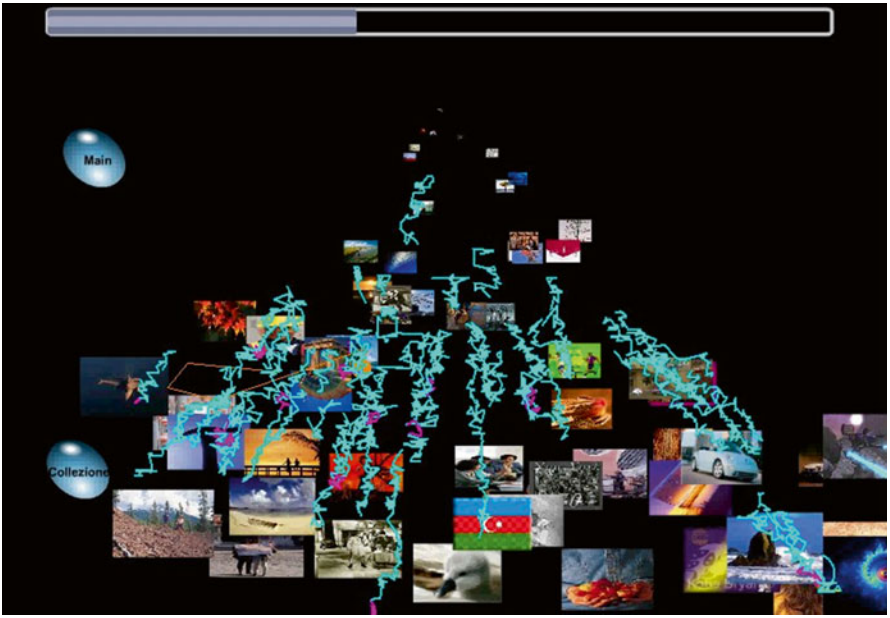

Fig. 4.59 *Blue* traces indicate gaze following the 'downward' trajectories of images in shot mode RSVP during a target recognition task. For clarity, saccades are not shown

4.4.2.3 Stream Mode

A recording of gaze movement (with saccadic tracks suppressed for clarity) for stream mode is shown in Fig. 4.60. Here we see a gaze behaviour ('nystagmus') that will be familiar to anyone who has looked out of the window of a fast moving train and attempted to 'keep up' with the scenery. It is not surprising that Cooper et al. (2006) found that a majority of users attempting to locate a specific image did not like doing so with the stream mode.

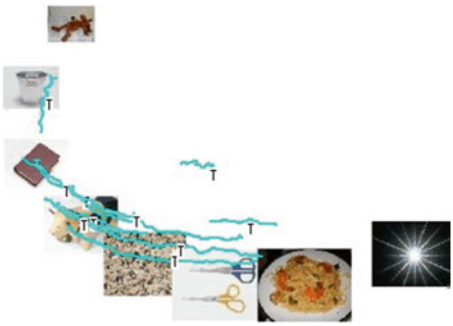

Fig. 4.60 A recording of eye gaze movements when stream mode RSVP was used to detect target images (saccades suppressed for clarity)

4.4.2.4 Floating Mode

With floating mode RSVP (first shown in Fig. 4.52), images first appear in the centre of the display, remain there in 'capture frame' for a short while – typically 100 ms – and then move along one of eight trajectories towards the outer edge of the display (Fig. 4.63) thereby making room for subsequently emerging images. In this way an image can remain visible for 2 or 3 s, usually sufficient to report its confirmation. A radically different heat map (Fig. 4.62) is associated with this mode: gaze tends to be concentrated at the centre, suggesting effective 'slide-show' viewing, but also along the eight trajectories that images follow towards the edges, presumably for the purposes of confirmation. From this heat map we might expect that the extent of gaze travel is much less than for shot and collage modes.

Fig. 4.61 A screen view of floating mode RSVP showing gaze trajectories (record of saccades suppressed for clarity)

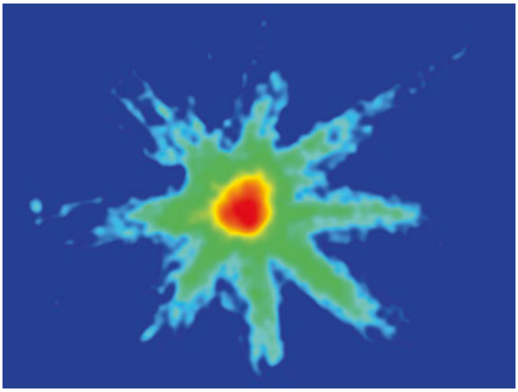

Fig. 4.62 A gaze heat map recorded during the use of floating mode RSVP to detect target images

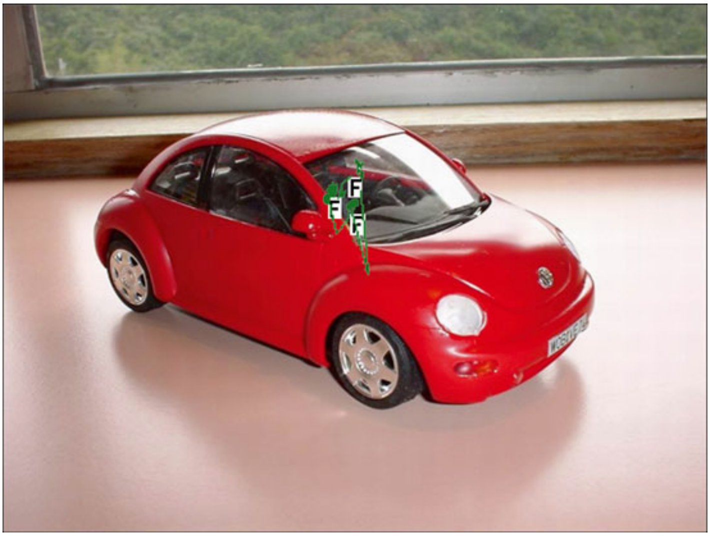

Fig. 4.63 A gaze record for a single subject viewing a collection of images in slide-show mode

4.4.2.5 Capture

Although it has not been confirmed experimentally it is generally acknowledged that, with a moving stream of images, it is usually beneficial to arrange for each image to be in capture mode as it passes through one particular location, as is the case for floating mode (at the centre) and also for the fast-forward and rewind example shown earlier (Fig. 4.51). One reason for a preference, at times, for treating the capture location as an effective slide-show mode may be suggested by the gaze record (Fig. 4.61) for a single subject viewing a collection of images in slide-show mode: here there is no reason why gaze should depart from a generally central location, and saccades (with accompanying saccadic blindness) are of minimal extent. At high values of pace image recognition is preattentive, compared with the attention involved in following an image along a trajectory.

4.4.2.6 Mode Comparison

It has been noted, in our discussion of the Collage, Shot and Floating modes, that there may be a causal connection between total gaze travel and both image recognition success and the fatigue experienced by a user. Strong evidence for this conclusion was in fact established by Corsato et al. (2008). For a number of modes including Collage, Shot and Floating they gave subjects the task of recognising as many images as possible in a collection of 2,000 which satisfied a given category description (e.g., “cat”), the sort of task that might be carried out by a graphic designer searching for suitable images to incorporate in a design: they would not be looking for a single ‘optimum’ image, but rather a small collection that merely satisfies the category requirement and which could later be examined at leisure. Figure 4.64 shows the experimental evidence obtained for the Collage, Shot and Floating modes for a collection of 2,000 images of which 40 satisfied the category requirement. The strong recommendation arising from the results shown in Fig. 4.64 is that a reduction in gaze travel might help both to reduce the fatigue experienced by the user and to enhance the success of image recognition. This empirical evidence provides one of the major guidelines available to the interaction designer intending to employ RSVP in an application.

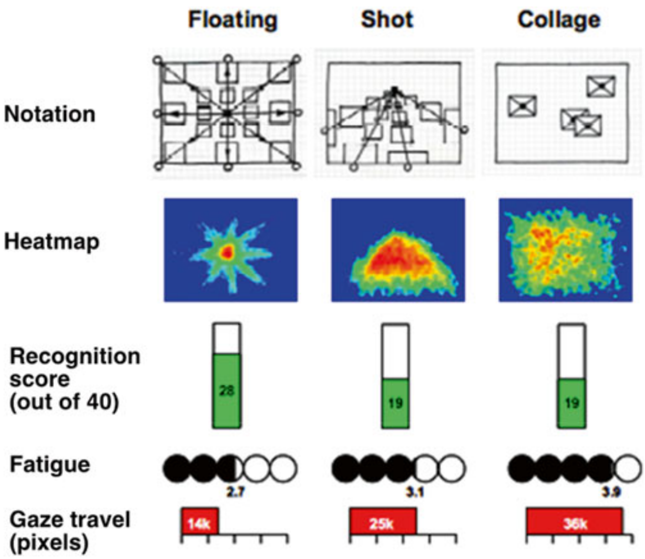

Fig. 4.64 A comparison of the target recognition performance associated with three RSVP modes

4.4.3 Design Considerations

Total gaze travel is only one of the parameters of which an interaction designer must take cognisance when designing for an application partially or wholly involving RSVP. Others are suggested by the 'soft boundaries' shown in Fig. 4.65 (Witkowski and Spence 2012): they are not precise limits but rather reminders of the consequences of moving towards and beyond them. For example, there will be an approximate upper limit on image speed dictated by the need for gaze to follow the images, a limit that has been empirically established at about 500 pixels per second. There will also be a lower limit to image speed set by consideration of the total time required for the presentation of a collection of images. Another soft boundary is associated with the fact that, as pace increases, overlap between adjacent images will occur unless image speed is sufficiently high. The only soft boundaries associated with approximate numerical values concern pace: if it is higher than 10 per second there may be insufficient time to recognise an image, whereas with a value lower than about 2 per second gaze behaviour and visual processing in general may depart significantly from that associated with RSVP. The area within the soft boundaries has been termed the Region of Acceptability merely to indicate the general direction in which the soft boundaries have less effect.

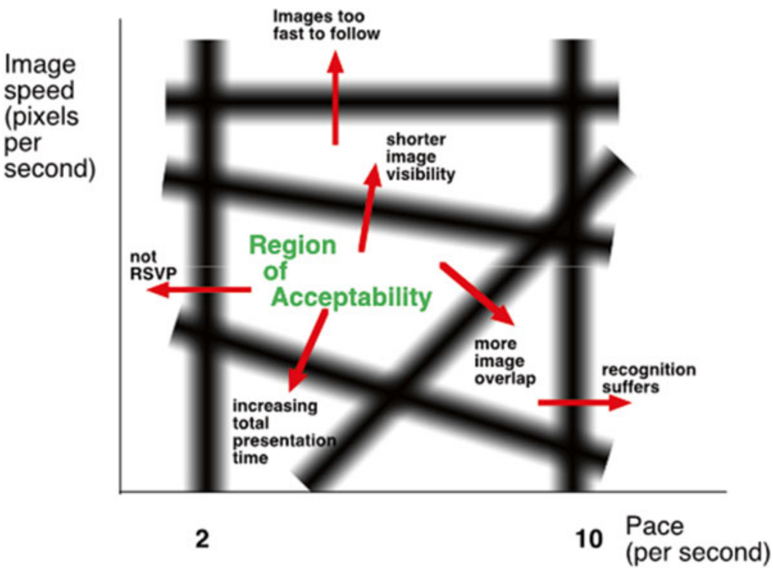

Fig. 4.65 Qualitative boundaries pertinent to the design of an RSVP application

4.4.3.1 Flexibility and Creativity

The principal interest in the RSVP modes described above – Floating, Collage, Shot and Stream – arose from the fact that they afforded a controlled experimental design leading to insight into important features of RSVP. There is no suggestion, therefore, that these modes are preferable in any respect for particular applications, though in some cases they may be found to be so. It is therefore important to discuss some RSVP applications that show how creative design can lead to useful products. In doing so we shall make the point that aesthetic requirements can, in many cases, exert a very strong influence over the visual and interactive features of an RSVP application. Below we look briefly at five examples.[14]

4.4.3.2 The Gist of a Video

It is often the case that someone wishing to watch a video will have a selection available, in which case there is an advantage in being able to acquire the gist of a few so that a good choice can quickly be made. Despite remarks made earlier about Collage mode, the SeeHere application (Wittenburg et al. 1999) employs it to good effect in rapidly providing a user with a feeling for a video's genre. For each video, eight representative key frames appear, one after the other, in the lower left quadrant of a display (Fig. 4.66), and jump, in a predicted temporal sequence, to the other quadrants, after which they disappear: thus, four are visible at any instant. A transparent title of the video appears centrally during the presentation. The positioning of each image has an element of randomness: when (say) an image is in the top-left corner, its *own* top-left corner is randomly positioned in the (invisible) top-left dashed yellow square. The designers were of the opinion that eight key frames displayed at four frames a second would give a viewer sufficient opportunity to acquire a high level gist of the video. Following the appearance of eight key frames, and separated by an empty background, the next eight key frames for another video would be similarly presented.

SeeHere offers an effective *integration* of temporal and spatial layout. What is more, the temporal and spatial characteristics are *predictable*, in contrast to the Collage example of Fig. 4.47. The positioning of each frame in a quadrant (the top left of a frame in the top left quadrant, for example) has an element of randomness that interjects, in the words of the designers, "a note of serendipity and visual appeal".

[14] More, together with an in depth discussion of RSVP, can be found in Spence and Witkowski 2013.

Fig. 4.66 The SeeHere application employs Collage mode to convey the gist of a video. *Yellow squares* are annotations that have been added to indicate where the corresponding corner of an image is randomly placed

4.4.3.3 Video on Demand

A prototype experimental interface for a 'video-on-demand' service is shown in Fig. 4.67 (Lam and Spence 1997). Each video is represented by a poster and the posters are stacked to form a three-tier 'bookshelf'. Cursor movement along the side of a stack causes posters to protrude one after the other, similar to the riffling of a book's pages, so that a number of posters can be viewed in rapid succession. The concept of the bifocal display is employed so that part of the bookshelf can be dragged to a central region, where static full views of the posters can be examined: moreover, clicking on a poster in this region causes an excerpt from the video to be played.

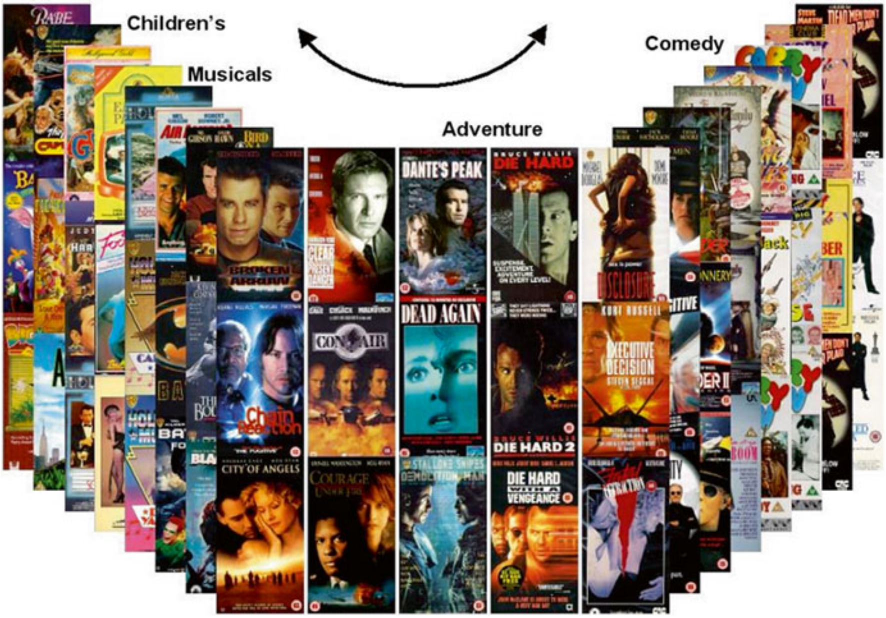

Fig. 4.67 A video store. Movement of a cursor along the 'walls' causes posters to pop out. The presentation is scrollable: when a poster is in full view in the central region a short movie can be played (Reprinted from Spence 2007)

4.4.3.4 Serendipity and Visual Appeal

Figure 4.68 illustrates a possible outline design for an interface whose purpose is to bring a variety of features of an hotel to the notice of a user. Instead of using the familiar scrolling slide show of 'pick-a-view' typical of hotel home pages, a collection of around 20 or 30 images flows along a winding trajectory at such a speed that any one image is visible for around 5 s. This ensures that plenty of time is available for a user to notice a potentially interesting image, check that it *is* of interest, and then halt the flow by some action. Perhaps by touch, an image might then be moved to a desired position along the trajectory. The images would move in a virtual loop, so that after disappearing at the bottom left-hand corner in a capture frame it would eventually reappear at the top. So that the user is aware of this arrangement one image might be designed to be very different from the rest, as shown by the largely black image containing the hotel name.

Fig. 4.68 Outline sketch of a homepage exploiting the technique of RSVP to bring a number of images relevant to an hotel to the attention of a user without requiring any action on the part of that user

4.4.3.5 Sketchbook

“Paper” is the name of an app (Fig. 4.69) available for the iPad. It directly simulates the riffling of the pages of a book, control of the riffling rate being achieved by finger movement on the display.

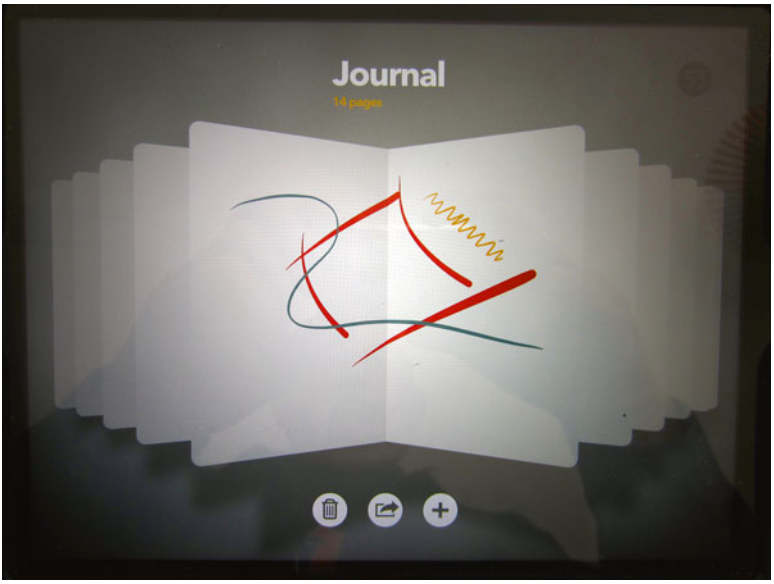

Fig. 4.69 Appearance of the PAPER53 app for an iPad. It allows the riffling of the pages of a sketchbook

4.4.3.6 Animation

In an entertaining and hugely informative though brief presentation, Hans Rosling (gapminder.com) shows the relation between lifespan and income for 200 countries over 200 years by means of a wall-sized display (Fig. 4.70), using animation. It could be debated as to whether such a presentation falls under the heading of RSVP, although the display, during fast animation, certainly changes at a pace exceeding 10 per second in what could be classified as slide-show mode. Debatable or not, the same gaze considerations apply to animations as for conventional RSVP applications.

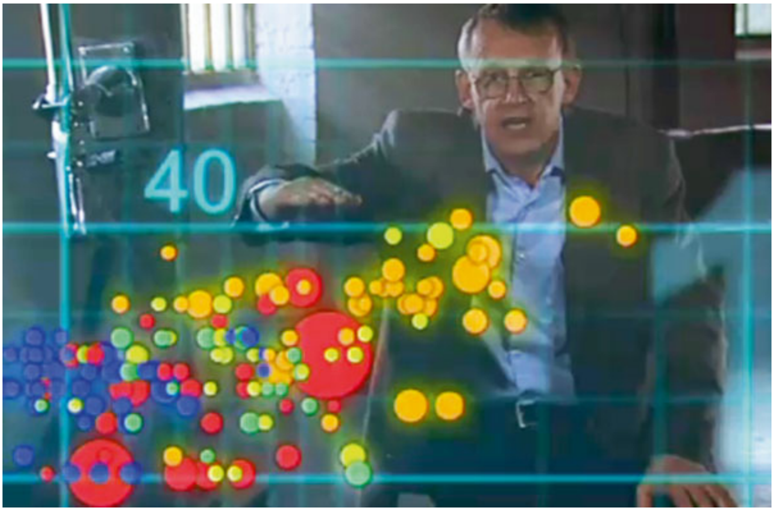

Fig. 4.70 A clip from a movie presentation by Professor Hans Rosling in which lifespan is plotted against income for a large number of countries, and animated to cover a period of 200 years from 1810 to 2009. Free material from www.gapminder.org

4.4.3.7 Attentional Blink

We briefly return to the properties of the human visual system to mention a feature that interaction designers should beware of. It is best summarised (Fig. 4.71) in the table format used previously. The phenomenon of Attentional Blink (Raymond et al. 1992; Kimron et al. 1999) can occur when a person is asked to identify the presence of two target images in a fast sequence. Following recognition of one of them, attention is not available to recognise, and report the presence of, the second target image for a period of between 200 and 500 ms.[15] For this reason there is a danger that a glimpse of a very attractive or familiar image may, for a significant period, hinder the subsequent search for a target image.

[15] If you wish to experience Attentional Blink access the website http://www.youtube.com/watch?v=MH6ZSfhdIuM

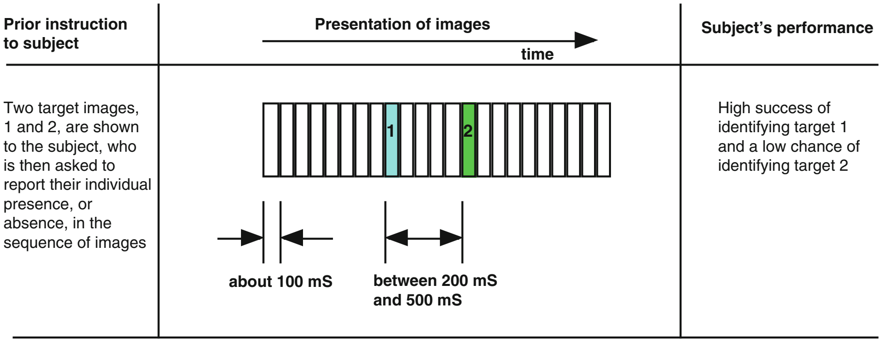

Fig. 4.71 The phenomenon of Attentional Blink

4.5 Representation of Presentation

A user will often be given a choice about the presentation mode to use in any given situation. Rather than describe presentation modes in the form of text it is often more convenient, especially for selection by interaction, to use symbols. Figure 4.68 presents a selection of such symbols (Fig. 4.72).

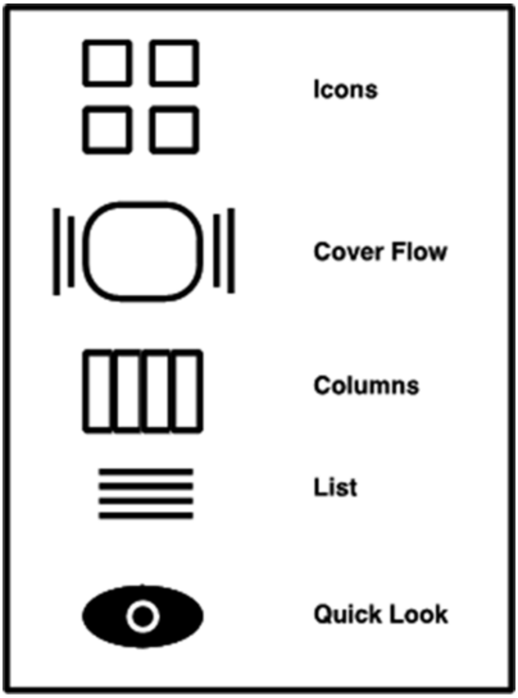

Fig. 4.72 Symbolic representations of presentation modes

Exercises

Exercise 4.1

For each of the following approaches to presentation write one sentence summarizing its essential features: (1) scrolling, (2) overview plus detail, (3) distortion, (4) degree of interest and (5) semantic zoom.

Exercise 4.2

Your hand-held tablet is fitted with a GPS facility and therefore 'knows where it is'. Sketch a design for a street map, with street names, which will draw a user's attention to, and suggest the approximate location of, places of interest (e.g., restaurants, petrol stations) over an area equal to nine times the area covered by the tablet's display.

Exercise 4.3

Explore the potential offered by the distortion principle for a person using a hand-held device to send text messages to additionally be aware of other items of interest such as text messages and recorded calls. Show how colour and position and any other encoding mechanism can be used to advantage. Justify the minimum size of icon in the distorted region.

Exercise 4.4

Identify a city of modest size that tourists or professionals may have to visit (e.g., Seattle, Oslo, Eindhoven, York). The local Visitor' Bureau wishes to make available, for travel and sightseeing planning, a printed representation of local transport and places of interest as well as major transportation links to destinations up to 50–200 miles away. Sketch a possible design.

Exercise 4.5

Figure 4.73 illustrates one approach to Exercise 4.4. The visitor is provided with the means to construct a 'Visitor's Cube' in which one face provides local detail of a city and the others provide context. Decide how continuity can be achieved along

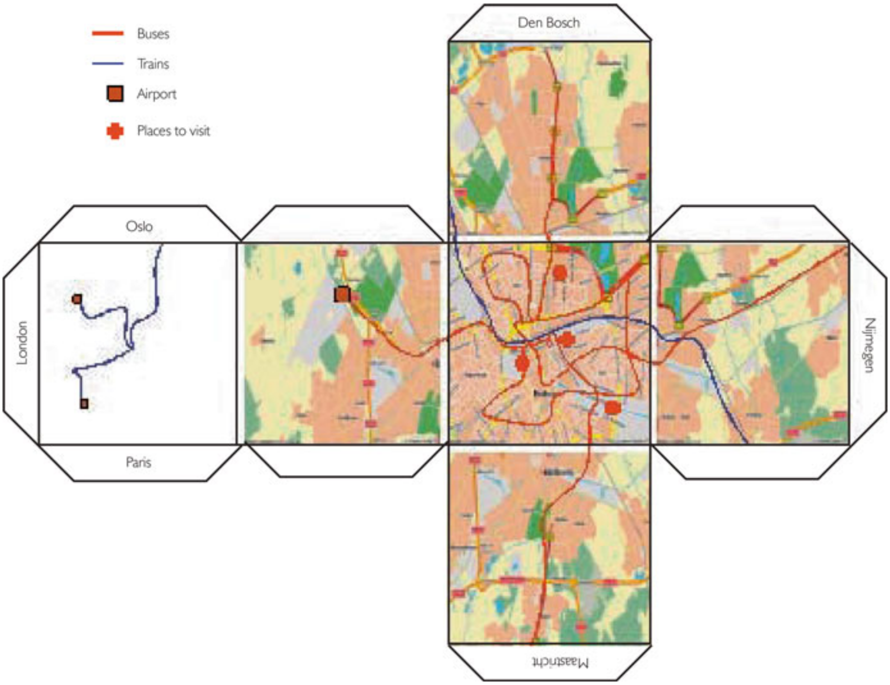

Fig. 4.73 A suggested design in response to Exercise 4.4 (*Courtesy Maurits Kaptein*)

the edges of such a construction and complete the design for the city you selected in Exercise 4.4. Critique your design.

Exercise 4.6

Propose a design for a facility suited to a hand-held tablet that will enable a user to review up to 500 photographs with a view to selecting one to show to a friend.

Exercise 4.7

A particular treemap is so extensive that it cannot usefully be presented in its totality on the display of a hand-held tablet. Suggest how an interactive presentation might be designed to allow easy comprehension of the treemap.

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Chapter 5
Interaction

In the previous chapters we have encountered many examples of interaction, where a single user action such as a mouse click causes a change in what is visible, often to extremely beneficial effect. The intent behind the action can take many forms. It may be the familiar need to proceed from one web page to another (Fig. 5.1). Or it may be a simple rearrangement of crop treatment data (Fig. 3.35 of Chap. 3) that provides insight to an agricultural researcher. Similarly (Fig. 5.2) the success of the interface EZChooser already encountered in Chaps. 2 and 3 depends upon its interactive nature to support a user in their fluent exploration of cars available for purchase. Interaction is, of course, far from being a specialized operation: in millions of homes at this moment viewers are fast-forwarding a recorded programme in order to skip the commercials.

If interaction is so common and beneficial there must be strong interest in how it can best be designed. What, for example, is a good way of supporting TV fast-forward

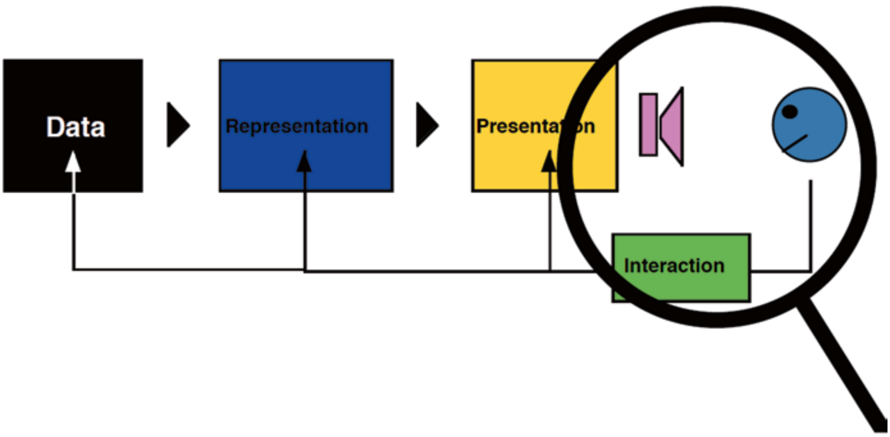


Fig. 5.1 The information visualization reference model, showing the focus of the present chapter

R. Spence, *Information Visualization*, DOI 10.1007/978-3-319-07341-5_5

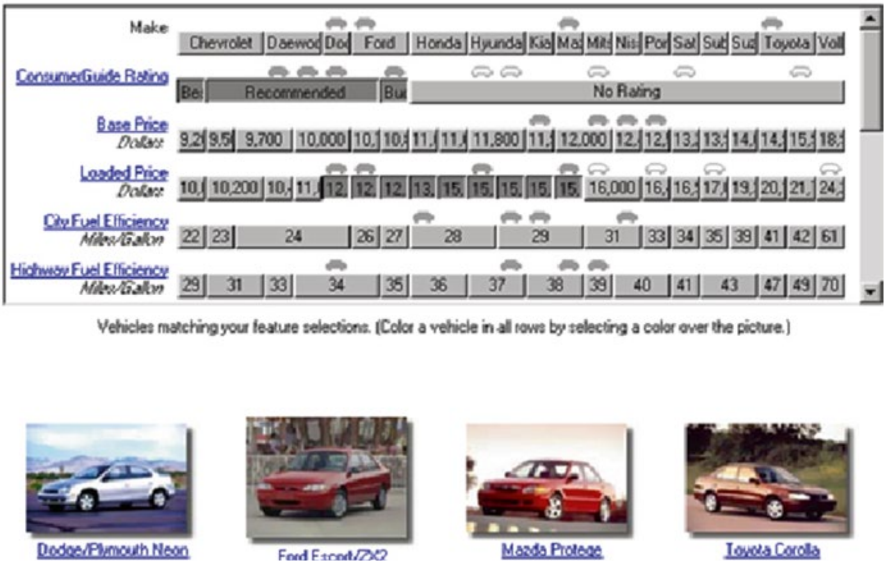


Fig. 5.2 The EZChooser interface (for detail and discussion see Chap. 2). Interactive choice of car attributes results in the identification of cars satisfying attribute limits (Courtesy Kent Wittenburg)

and rewind? How best can one help an engineer to quickly realize the benefit of making a change to the bridge he or she is designing? And how does one design a website to allow smooth and undemanding progress towards the page that provides the information being sought? Unfortunately there is no ‘science of interaction’, even though its discovery has been strongly encouraged (Thomas and Cook 2005) and researchers are still seeking answers. However, a framework that provides excellent support to interaction designers has existed for more than 25 years. It is called Norman’s Action Cycle (Norman 1988).

Before looking in detail at Norman’s Action Cycle it is important to point out that its relevance is far wider than information visualization: indeed, its power lies in its very generality. In the following section we therefore use a variety of everyday examples to introduce the concept. We then examine its specific relevance to information visualization.

5.1 Norman’s Action Cycle

Norman (1988) identified two gulfs existing between the human who has a goal to achieve and the ‘world’ which must be changed in some way if there is to be a chance of achieving that goal. The world that undergoes change may be a computer,

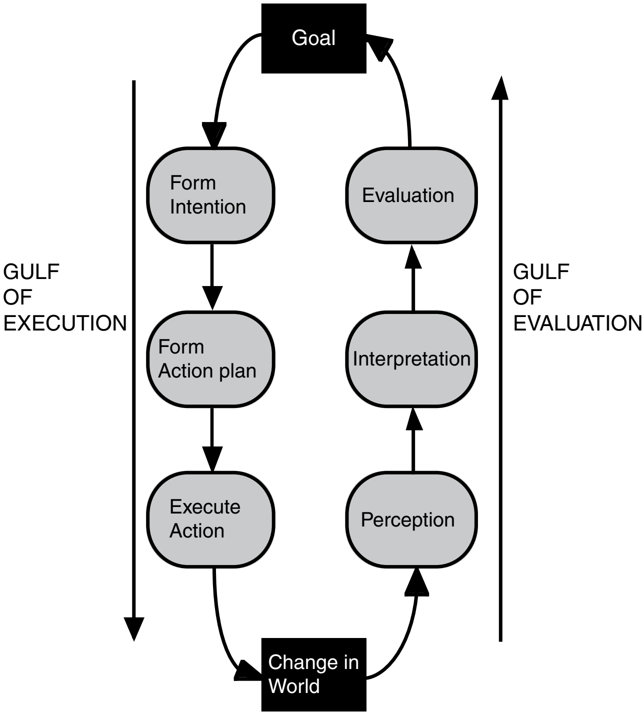


Fig. 5.3 Norman's Action Cycle relevant to the interactive achievement of a goal

but can equally well be a door, the state of a washing machine or the appearance (or otherwise!) of coffee from a coffee machine. Norman's Action Cycle (Fig. 5.3) is relevant to information visualization because the goal of the latter is the acquisition of a useful mental model and the 'world' that must be changed is some representation – visual, aural, tactile or olfactory – of data.[1]

The Gulf of Execution (Fig. 5.3) reflects the problem of knowing what to do to bring about a useful change in the world, while the Gulf of Evaluation reflects the problem of observing, interpreting and evaluating whether the change in the world has satisfied the goal. A helpful approach to an understanding of the Action Cycle is, first, to see how it relates to some familiar everyday things, and that is what we now do.

[1] Although the vast majority of interfaces represent data graphically the potential of aural, tactile and olfactory representation must not be overlooked.

5.1.1 The Goal

Norman's Action Cycle is relevant to a wide range of goal types. Buying a train ticket, washing clothes and browsing a web page are just a few examples. Others specifically illustrated below include making a record of a wedding, walking through a door (yes, even *that* can be difficult – read on!), making some toast and crossing a road.

5.1.2 The Gulf of Execution

5.1.2.1 Formulating an Intention

Having identified a goal the next stage is that of **formulating an intention**. To obtain a pictorial record of a wedding many options are possible: you can sign a contract with 'Hello' magazine, hire a photographer, use a personal camera or get a friend to sketch the proceedings. But the ready availability of your personal camera (already present, in fact, as a component of your mobile) may help you to form the intention of using the mobile to record the wedding. A second example is provided by the toaster shown in Fig. 5.4. In the (usual) absence of any toast between the two transparent uprights there is nothing to suggest that it *is* a toaster,[2] so its design does not support the formulation of an intention. A third example is drawn from the main railway station in Berlin (Fig. 5.5). A passenger wishing to change platform levels and looking in vain for helpful signage notices a transparent vertical circular shaft and reasons (correctly) that it probably contains a passenger lift. As Norman points out

Fig. 5.4 A device for making toast

[2] Residual crumbs may of course help!

Fig. 5.5 A circular passenger lift shaft linking platform levels in the Hauptbahnhof, Berlin

(his page 46), a goal does not state precisely *what* to do: the goal has to be translated into an intention, of which – as we have seen – there could be more than one.

5.1.2.2 Formulating an Action Plan

The stage that follows, that of **formulating an action plan** ("what do I have to do?") is often the most difficult. One example of a lack of support for this stage of Norman's Cycle is provided by a camera that became available many years ago (see the sketch of Fig. 5.6, showing the lens and the viewfinder). The use of that camera and the subsequent development of photographic films often showed (Fig. 5.7) many cases in which every image was an out-of-focus face. What had happened? As a result of the camera's design the user had mistaken the lens for the viewfinder.

Another very familiar device that often fails to support the formulation of an action plan is the common door. Doors have, of course, been around for centuries, but remarkably still cause problems! Take, for example, the door shown in Fig. 5.8. Attached to it is a user's manual – admittedly a simple one – telling me that I must push the door in order to open it even though there's a handle that suggests pulling.

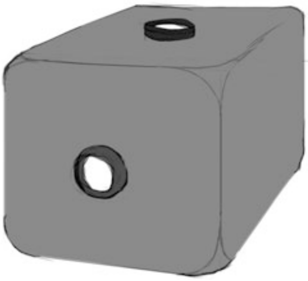


Fig. 5.6 Sketch of a camera, showing the lens and viewfinder

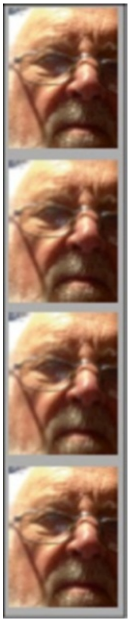


Fig. 5.7 (opposite) The frequent result of using the camera sketched in Fig. 5.5

But why should I need instruction on how to get through a door, something I do many times a day? By contrast the door in Fig. 5.9 is a much better design and requires no user manual, because it is clear that the door must be pushed: it is commonly accepted that the plate indicates that the door should be pushed, and in any case there is no way in which the door can be pulled towards one. So the door of Fig. 5.9 supports the formulation of an action plan.

There is an important concept here, called **affordance**. We say that the door of Fig. 5.9 "affords opening by pushing". That is the *actual* affordance. If I *deduce* that one pushes the door to open it, that is the "*perceived* affordance". Clearly, *the ideal situation is where the actual and perceived affordances are identical*, and that should be the goal of an interaction designer. Norman (1988), in an entertaining way, provides many examples of the problems caused when the perceived and actual affordances are not identical. Other examples, often amusing and sometimes almost unbelievable, can be found at baddesign.com. The fact that the formulation of an action plan is one of the most difficult stages to support is reflected in the title of a relevant and very useful book: "Don't make me Think" (Krug 2005).

Fig. 5.8 Why should one need instructions about how to pass through this door?

Fig. 5.9 The affordance offered by this door, that of 'opening by pushing', is clear

5.1.2.3 Execution

Having formulated an action plan, that plan has to be **executed**. With the door of Fig. 5.9 the execution merely involves pushing the door at the side where the flat panel is located. But with some interfaces execution is not well supported. The shower control of Fig. 5.10 may not at first be considered unusual, until one realises that turning a smooth circular (or near circular) knob with soapy hands can be difficult. Another example of an interface badly designed with respect to

Fig. 5.10 Turning a circular or near circular shower control with soapy hands is not easy

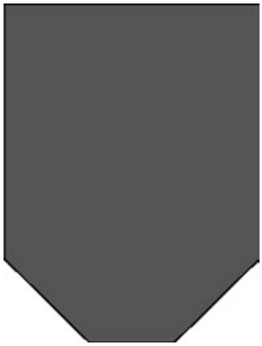


Fig. 5.11 A toilet paper dispenser for which the execution stage (acquiring paper) can be difficult

execution is the toilet paper dispenser shown in Fig. 5.11. If the paper wound around the (hidden!) cylinder protrudes from the dispenser, it is easy to grasp the end and pull. However, if the paper does not protrude, a hand has to be inserted into the device, fingers activated in an exploratory manner to find the paper end (always assuming there *is* some paper there…) and then pull the end, *very* carefully and without tearing it, to be visible.

To summarise, we have seen that there can be considerable cognitive complexity associated with the gulf of execution: it is the goal of whoever designs an interactive system to minimize that complexity.

5.1.2.4 Change in the World

Execution of a plan will generally (but not always!) cause some **change** to take place: for a coffee machine a cup might appear and/or coffee grinding may commence. With a digital camera an image is hopefully stored within a memory. In a lawn-mower an electrical connection is closed after a start button is pressed. But we need to be *aware* of these changes: and that is why we need the concept of the Gulf of Evaluation.

5.1.3 The Gulf of Evaluation

5.1.3.1 Perception

Some aspect of the change must be **perceived** by the user if confidence in the action plan is to be maintained. If, for example, pressure of a 'final' button on a coffee machine results in complete silence, the user will understandably be mystified, and may (with unexpected consequences) start pressing other available buttons to see if anything can be *made* to happen. By contrast, a grinding noise might be interpreted as indicating that fresh coffee is being ground. The aroma of freshly ground coffee is another useful indicator, whereas the sound of galloping horses would not be.

An example of a complete absence of 'confirmatory feedback' is to be found in Eindhoven in The Netherlands. A pedestrian wishing to cross the road safely can apparently register their presence and intention by touching a pad (Fig. 5.12). However, there is no perceivable response to suggest that the action has been reg-

Fig. 5.12 Applying pressure to this button results in no immediately noticeable result

istered: indeed, one could be forgiven for wondering if the ‘touch pad’ is even connected to anything? Maybe *nothing* affects the traffic light timing! Maybe it’s a placebo . . .

There is a special situation in which a user attempts to perform an action *that cannot be performed*. In many applications either nothing happens, in which case the user is perplexed, or an error message appears which is often impossible to understand and/or not easy to act upon. A very supportive technique is to be found in the iPad. If, for example, a user tries to scroll beyond the end of a collection of photos, the photos that are currently visible ‘bounce’ and return to their original position, thereby clearly indicating that the intended scrolling was not possible.

5.1.3.2 Interpretation

Perception and interpretation are very closely linked. The author thought he had taken 36 pictures at a wedding, reassured to a considerable extent by the sound of a shutter being operated. It turned out that the camera made the same shutter sound whether or not there was a film in the camera: no pictures had been taken. Another example of where a mere sound *alone* may be insufficient was provided by a parking garage ticket machine. It had its internal coin collection box situated *just* behind the chute from which rejected coins are dispensed, with the consequence that the perceived sound could easily be misinterpreted. Similarly the lighting of an external lift call button can reasonably be interpreted as confirming that the call has been registered, whereas the absence or failure of such a light can cause consternation. A more amusing example was provided by a psychologist who checked into a hotel, was given his room key and was pointed towards the elevator, whereupon he pushed the button located between the elevator doors. At that moment all the lights in the hotel foyer were extinguished. The psychologist quickly interpreted the situation and correctly deduced that the button was not the correct one to press (being a good psychologist he then sat down in the foyer to conduct a study of perceived and actual affordance!).

5.1.3.3 Evaluation

It is important to point out that the Evaluation stage of Norman’s Action Cycle does *not* refer to an assessment of the entire artefact. Rather, this is the stage at which the user checks to see if the executed action has led to a change that satisfies the goal. Has, for example, the machine dispensed the desired coffee or has hot chocolate appeared? On pushing the door purportedly leading to the café has it refused to open? On pushing the button at the pedestrian crossing, has this hastened the traffic light change? (one may never know, of course). Sometimes evaluation can take a few days, as with the processing of photographic film at a chemists, but fortunately within milliseconds when using a digital camera. For a final example we return to the toaster of Fig. 5.4, shown again as Fig. 5.13. Although its

Fig. 5.13 The toaster's transparency supports evaluation

design may not easily support the formulation of an intention in the mind of someone wanting to make toast, it does support the stage of evaluation, since the state of the toast is easily seen (Fig. 5.14).

As with the gulf of execution, the gulf of evaluation also possesses a degree of cognitive complexity that should be minimised by appropriate design.

5.1.4 The Following Sections

The examples employed above to illustrate Norman's Action Cycle were purposely chosen for their everyday familiarity. In the following sections we employ the Action Cycle specifically to see how we can support those kinds of activity directly related to information visualization.

5.2 Interaction for Information Visualization

Having introduced Norman's Action Cycle by means of everyday artefacts we now focus on its specific relevance to the support of information visualization. For our first illustration we examine, in detail, an interactive artefact invented in 1992 to see – admittedly with the enormous benefit of hindsight – how Norman's Action Cycle might support its enhancement. First, though, a cautionary note. The suggested *individual* enhancements that follow are for illustration: a final design would need to assess their *combined* effect.

5.2.1 A Goal

As discussed in Chap. 1, a very frequently encountered task is that of finding somewhere to live, perhaps as a result of having one's job moved to a different location. Finding a house involves many goals, but one that can be supported by information visualization (Fig. 5.14) is that of finding houses that are available for purchase with the money available and under other constraints such as the number of bedrooms required.

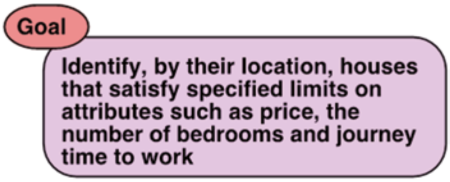


Fig. 5.14 A simple goal associated with a search for a new house

5.2.2 Formation of an Intention

As pointed out in Chap. 1 such a goal can be approached in many ways: by driving through the area of interest to see what houses are for sale; by looking in the windows of estate-agents; by scanning the appropriate pages in local and national newspapers; or by visiting relevant websites. So the initial intention of the prospective house purchaser will vary from one person to another. For purposes of illustration let us suppose that it is the intention of the purchaser to use the Dynamic Queries Interface (Fig. 5.15) to discover houses that satisfy requirements on various attributes such as price and the number of bedrooms.[3]

The Dynamic Queries Interface (Williamson and Shneiderman 1992; Ahlberg 1996) is shown in simplified form in Fig. 5.15 Briefly, interactively placed limits on attribute values identify houses that satisfy those limits, houses that are then represented by red dots on a map. The interface rightly caused a great deal of interest at the time (1992), principally because it allowed "What if?" questions to be *explored manually and dynamically*: in other words, if an attribute limit is changed, the effect is shown *immediately*, thereby encouraging and supporting exploration.

The idea is simple, like most good ideas. A geographical area of interest to the purchaser is first chosen. Each house available for purchase in that area is characterised by a number of attributes: for simplicity of illustration we consider just three, though in practice there will be many. The sliders on the right of Fig. 5.15, each associated with a house attribute, allow the user to place acceptable limits – in

[3] The Dynamic Queries interface is selected from among a number of other interactive software systems.

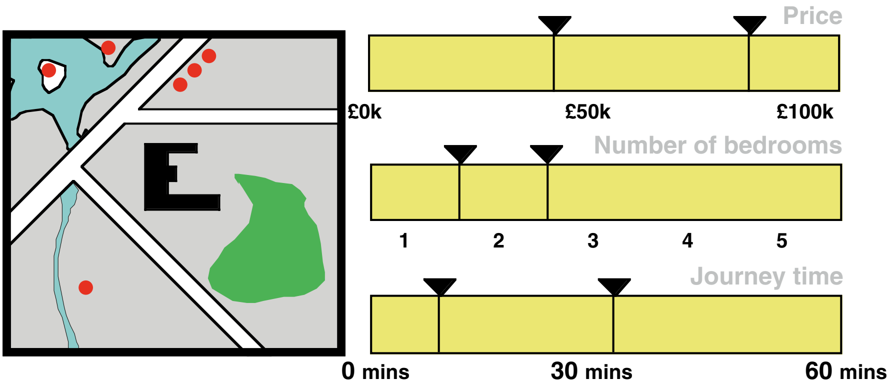


Fig. 5.15 The dynamic queries interface created to support a search for a house with specified attributes

this simple case – on **Price**, **Number of Bedrooms** and **Journey Time** to work. The limits placed by the user *together* identify a subset of the available houses, each of which is then immediately represented on the map by a red dot: no significant computation is required. Such an interface allows the user to gain some idea of the influence of attribute limits on house availability by varying those limits one at a time and observing the consequences on the map.

5.2.3 Alteration of the Goal

For many reasons it would be unusual for a decision to be made regarding house purchase following the initial positioning of the attribute limits. First, because people are naturally curious and want to explore to see what's available ("what if Granny could lend us £10,000?") and, second, because requirements are rarely initially precise: if a buyer says that they require a dining room at least 30 ft long they will almost certainly still at least consider one that is 29.5 ft long, especially if this restriction is compensated by accompanying advantages. And there is always the feeling that if a limit were relaxed by a very small amount, some really good bargains would present themselves on the map. In brief, then, users normally intend to *explore*.[4] If this is the case, the goal can usefully be broadened (Fig. 5.16) to additionally acquire a broader and hopefully more useful understanding. Let us see how we can support this broader goal, but keeping the intention (to employ the Dynamic Queries interface) unchanged.

[4] 'Exploration' can imply a variety of activities including explanation, confirmation and the acquisition of evidence to confirm an hypothesis about the data being visualized.

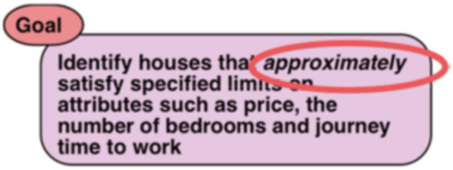


Fig. 5.16 Extension of the goal to include 'near misses'

5.2.4 Formation of an Action Plan

The acquisition of an understanding of the relation between house attributes and house availability is not as easy as it might at first seem. Only one attribute limit can be changed at a time and its consequence on the map noted before another attribute limit is changed. If, as is likely, there are (say) ten house attributes instead of three, there are many combinations of attribute value changes of which some – but at first the user does not know which – may be beneficial. The appropriate action plan, therefore, is not clear.

Norman's Action Cycle requires us, as interaction designers, to ask whether we can modify the interface to make it easier to formulate an action plan. The answer is 'yes', in a number of ways. For example, we can recall from our consideration of the Attribute Explorer (Sect. 3.5.4) how useful 'near miss' information can be: what is more, it is computationally straightforward to generate and display. The Dynamic Query interface can therefore be modified for the Price slider (and others) as illustrated in Fig. 5.17 which shows that two houses lie only just above the upper limit on Price and that one house lies just below the lower limit. A corresponding indication can also be provided on the map (Fig. 5.18). Awareness of near-miss information

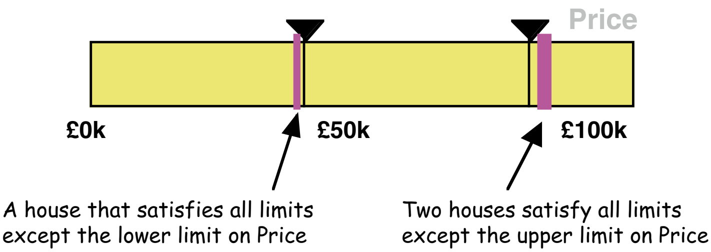


Fig. 5.17 The representation of available houses that fail a requirement by a negligible amount

can usefully influence the user's plan of action. It could be useful to arrange, for example, that a mouseover of a near miss house on the map could identify, by brushing, the corresponding bar(s) on the slider(s), and vice versa.

The above short discussion of the formation of an action plan actually conceals a complex composite of many interrelated potential interactions a user can take in

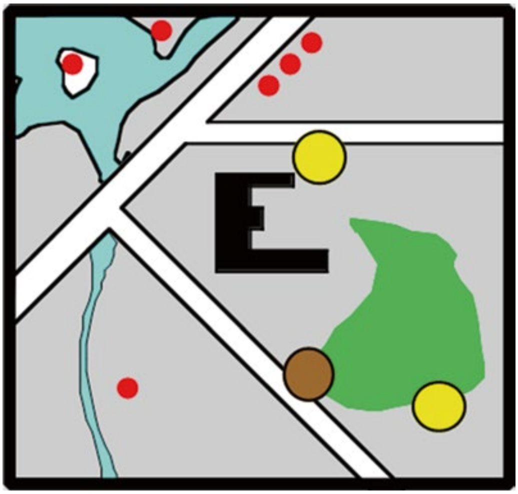


Fig. 5.18 The location of 'near-miss' houses on the map

response to their perception and understanding of a range of vital information, and in the context of many levels of representation. In what follows we try to indicate how the corresponding demand for good interaction design might be addressed.

5.2.4.1 See and Go

Before considering another way of supporting the formation of an action plan we diverge for a moment because the simple modification shown in Fig. 5.17 illustrates an important general concept. The original Dynamic Query interface offered a "**Go and See**" approach (Rao 1999): one had to "*go*" to a new upper limit on (say) Price in order to "*see*", from the map, its effect on house availability. The sensitivity information represented in Fig. 5.17 offers the option of '*seeing*' a possibly beneficial opportunity before deciding, *if necessary*, to '*go*' and examine it in detail, a much more effective approach ("**See and Go**"). The benefit of sensitivity information is enhanced if the examination of 'near misses' can be as incremental and continuous as possible. The 'near miss' sensitivity information supports interactive visualization. The sensitivity information represented in Fig. 5.17 is discrete. One alternative (Eick 1994) is shown in Fig. 5.19 which indicates the density of available houses (for current values of all other attribute limits), and thereby also facilitates a 'See and Go' approach.

Yet more support can be given to the user planning an exploration of the housing market by the technique shown in Fig. 5.20. The white coding identifies a region where any movement of that attribute's limit will have no effect whatsoever, in contrast to movement in the yellow region. Again, in this way, sensitivity information provides immensely helpful support to the user in their formation of an action plan.

Fig. 5.19 An alternative representation of houses that satisfy all limits except those on price

Fig. 5.20 Movement of a limit within the white region has no effect on house selection

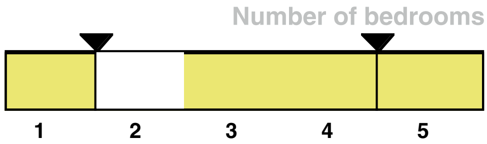
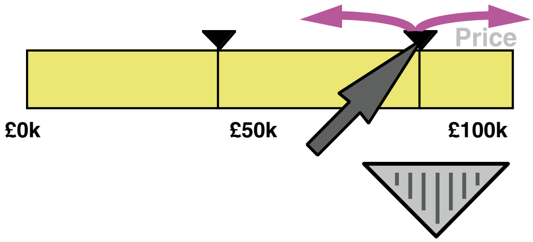


Fig. 5.21 (*top*) Mouseover leads to an indication of affordance: (*bottom*) an alternative design of the *arrow*



Adjustment of an attribute's limits – by a mouse-down on the limit 'arrow' followed by a mouse drag – might apparently present few problems for a user. But will the user *know* that that action is the one that will adjust a limit? The arrows shown in Fig. 5.13 may be found ambiguous by some: will, for example, simple clicking on an arrow make it move? Or must it be dragged? One possible redesign is shown in Fig. 5.21, where mouse-over provides a potentially helpful arrow representation. An alternative is to use the convention that a 'ribbed' device can be adjusted (Fig. 5.21 bottom) by mouse-down and drag.

5.2.5 Trade-Offs, Correlations and Overviews

Before progressing further down the Gulf of Execution we can potentially enhance the Dynamic Queries interface by drawing upon a technique originally mentioned in the context of the Attribute Explorer. It was indicated in Fig. 3.42 that a *range* of one attribute could be moved from side to side of the associated scale and the effect represented on the other sliders: an application of the concept of brushing. The same technique can be added to the Dynamic Queries interface so that any general relations between Price, Number of bedrooms, Journey time and map location can easily be explored. Figure 5.22 shows one possibility. A mousedown between two limits identifies the range (of Price in this case) to be varied manually, while red diamonds indicate (by position) the population average and (by shape) the variance of the houses within the range on other scales. Such brushing can also be extended to the map, so that areas of low and high house prices can easily be identified. Introduction of this facility has now broadened the goal to have the new coverage shown in Fig. 5.23.

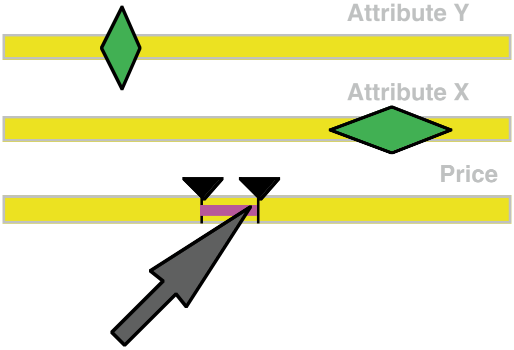


Fig. 5.22 Manual exploratory movement of a range of price will alter the average and variance of acceptable houses on other attribute scales

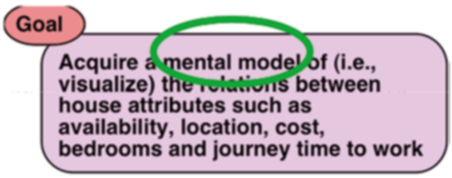


Fig. 5.23 A more general goal: the acquisition of a mental model

5.2.5.1 Execution

Once the means of adjusting a limit is understood, it would seem that no more attention need be given to the design of the manner in which limits are adjusted. On the contrary: if a user has to make sure that the mouse cursor remains on the limit arrow (which itself is constrained to move along the slider) they will not be able to pay full attention to what is happening on the map. The solution to this problem, now adopted quite universally, is to allow the cursor to move away from the slider once

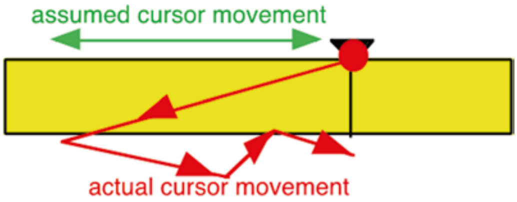


Fig. 5.24 Irrespective of the actual movement of the cursor it is assumed that movement occurs along the slider

mouse-down has occurred (Fig. 5.24), or even to put a limit arrow under the control of a joystick to which no attention at all need be paid.

5.2.5.2 Change

The action of changing an attribute limit may lead to change *or it may not*. However, the user will only be aware of this situation through the stages of Perception and Interpretation.

5.2.5.3 Perception

Except when a limit change has no effect on the houses identified as being available for purchase, corresponding red dots on the map will either appear or disappear. At first this would not appear to present any problem until we recall, from Chap. 3, the phenomenon of Change Blindness. A red dot may appear and simply not be noticed, thereby diminishing the value of the Dynamic Queries interface. Its disappearance may also not be noticed. Simple changes to the design of the interface are possible to ameliorate these effects. For example if, when a red dot appears, it initially – for say 1 s – appears as a much larger red dot, it would be more likely to attract attention (Fig. 5.25). The disappearance of a red dot could also be coded to attract attention.

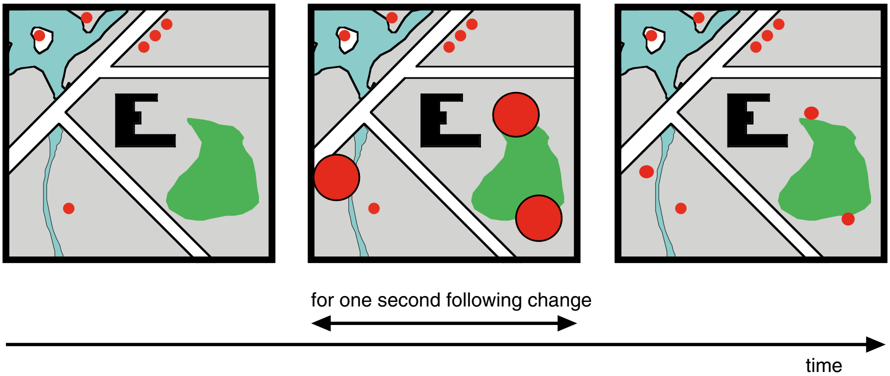


Fig. 5.25 The appearance of a red house may not be noticed due to change blindness. To ameliorate this effect a momentary enlargement of the new *red dot* may be helpful

5.2.6 Interpretation

The user notices a newly appearing red dot and interprets it as meaning that the attribute value change that immediately preceded its appearance was the cause. There might seem little room here for improvement, provided the delay between stimulus and response is not too long (e.g., <400 ms). But since the goal of the user is to form a mental model of available houses and their relation to attribute limits, some indicator (Fig. 5.26) showing (a) the number (50) of available houses ('the size of the universe'), (b) a qualitative indication (red bar) of how many now satisfy the current attribute limits and (c) a temporary (e.g. 1 s) arrow-like indication of the direction of change would be extremely supportive.

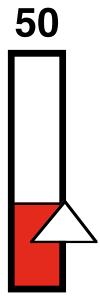


Fig. 5.26 Representation of the number of houses available, the number satisfying the limits, and whether the last limit change resulted in more or fewer of the latter number

5.2.7 Evaluation

It is at the evaluation stage where the prospective house purchaser assesses the benefit, to his or her mental model, of the attribute limit change just executed. The benefit could lie anywhere on a continuum ranging from completely absent to extremely valuable (and even serendipitous). What the interaction designer must be concerned with is rendering that benefit easy to evaluate. With regard to layout, it could help if sliders could be moved closer to the map in order to bring both closer together and hopefully into the foveal rather than the parafoveal or peripheral retinal region. With regard to responsiveness there should be little problem, since database look-up is essentially all that is involved. If the user varies an attribute limit *dynamically* in order to gain some insight into the effect of limit change, then ensuring a minimal delay between that change and the appearance of red dots can help, since a time delay above a certain value (of about 1 s) can significantly affect the success of dynamic interaction (Goodman and Spence 1978).

5.2.8 *Summary*

Hopefully, the above examination of the Dynamic Queries concept in the context of Norman's Action Cycle has demonstrated that the latter can usefully be applied in a systematic manner to an interface concerned with the goal of information visualization. A cautionary note was sounded earlier – and should be repeated – to the effect that all the potential enhancements discussed above are *individual* and considered in *isolation*. In any real design intended for implementation their value *in combination* must be assessed. The fact that the enhancements discussed above are only a few of many possible ones will become apparent when the exercises are attempted.

5.2.9 *Assessment in Context*

As pointed out earlier in Sect. 5.1, the evaluation stage just commented upon refers to *the effect of the change just executed*, and *not* to the value or otherwise of the modified Dynamic Queries interface. The potential of the Dynamic Queries concept is principally as a component of a much more powerful system, and it is within that context that the concept will eventually be evaluated. For example, the interaction designer working for a client whose business it is to sell houses will be aware that a prospective buyer is buying a *home* rather than just a *house* and, as discussed in Chap. 1, is therefore additionally concerned with such attributes as traffic noise, the incidence of crime, *per capita* income, school availability and cultural activities. Thus, the goal to be supported may be broadened significantly and realistically (Fig. 5.27) to include awareness of environmental and cultural matters, and supported by representations similar to those illustrated in Figs. 1.14 and 1.15. The assessment of such a visualization tool is both important and challenging.

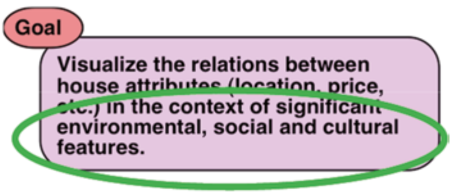


Fig. 5.27 A new goal reflecting the difference between a house and a home

5.2.10 *Design Freedom*

The potential enhancements to the Dynamic Queries interface discussed above have been chosen for illustration, and represent only a few of the many that might be considered by an interaction designer. The exercises that follow are designed to elicit many other user requirements and the manner in which they might be supported at appropriate stages of Norman's Action Cycle.

5.3 Interaction for Navigation

An important task that normally involves extensive interaction is that of navigating a discrete information space. Typical examples such as the purchase of a book or a hotel reservation involve a sequence of transitions from one web location to another, hopefully – though not necessarily – terminating at a location that satisfies the goal of a user.

Each step in that sequence of transitions can support one or both of two requirements. One requirement is to move 'closer' to what is currently considered to be a desirable location. We can refer to such movement as 'goal-directed pursuit' or, simply, *pursuit*. Another reason for making a transition is *exploration*, to form a mental map of – that is, to visualize – an appropriate region of discrete information space. It is for the latter reason that navigation is relevant to this book. Both reasons may of course apply to a given movement that might take the user closer to a target location *and* enhance their mental model (Fig. 5.28). Since reference to such a mental model can support decisions regarding subsequent (exploratory and/or pursuit) movements in that space, we consider the needs of both exploration and pursuit together when discussing how we can support a user interactively involved in the task of navigation.

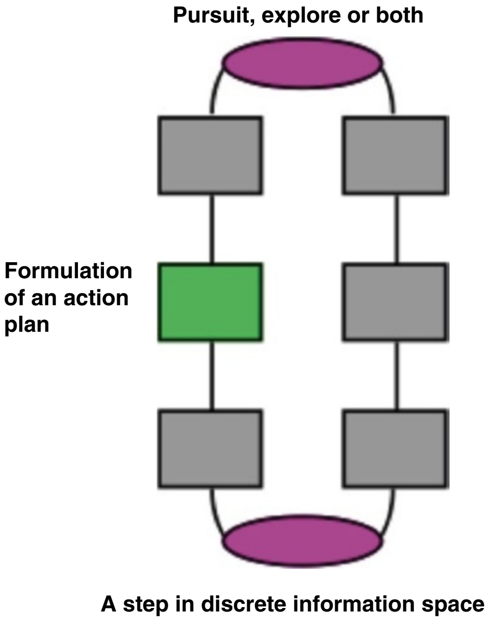


Fig. 5.28 In the navigation of discrete information space the goal may be a combination of pursuit and exploration. One of the major problems is the formulation of an action plan, indicated on the *left* of the representation of Norman's Action Cycle

Fig. 5.29 Navigation problems can arise in a department store

5.3.1 Getting Lost

In the early days of discrete information spaces it was quickly realized that a major problem faced by a user was that of 'getting lost', a term carried over from similar problems in the physical world. Physical examples abound, from becoming lost in the wilderness or at sea, to that of failing to find one's way in a department store (Fig. 5.29). That problem is still with us today: indeed, navigation in discrete information space shares many concepts with navigation in the real world, and similar questions occur to the person existing in either world. Thus, either when looking at a web page, or lost in the countryside or at sea, the following questions frequently occur:

Where am I?
Am I where I want to be?
Where can I go?
How do I get there?
What lies beyond?
Where can I *most usefully* go? (I can only go to one place at a time)
Where have I been? (I may want to go back)

Consideration of Norman's Action Cycle introduced in Sect. 5.1 can lead to the design of an interface that provides useful answers to these questions as well as supporting explanations, thereby facilitating efficient and effective movement through information space. While all stages of the Action Cycle are relevant to interaction for navigation, by far the most challenging problems arise when formulating an action plan (Fig. 5.28). We therefore first focus on two questions directly related to this stage of the Action Cycle: "Where can I go?" and "How do I get there?"[5]

[5] At the considerable risk of introducing humour into an academic publication I cannot resist mention of Douglas Adams' additional question "and will there be anywhere to park when I get there?"

5.3.2 *Formulation of an Action Plan*

We shall assume that a user has a goal (e.g., to organise travel to London), has formulated an intention (e.g., to book tickets online) and has arrived at a web page either as a result of a sequence of steps in information space or of having been 'parachuted in' by a search engine. That location may of course satisfy the requirements of the user, in which case no further transitions in information space are needed. If it does not, the user will wish to move to another location, hopefully leading eventually to a useful one. They must therefore form an action plan, partly from knowledge of where they can go and how they can get there.

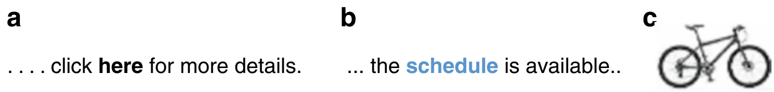


Fig. 5.30 Some encodings of available destinations in discrete information space and the actions needed to get there

An answer to the question "where can I go" can be provided in many ways. A very explicit indication (Fig. 5.30a) is sometimes provided, with an explanation that may vary from helpful to ambiguous. Conventionally, text – often blue and often underlined (Fig. 5.30b) – provides an indication of the destination of available transitions. Particularly in sales webpages, a picture of a product (Fig. 5.30c) may imply that a mouse-click (for example) on that picture – rather than on any accompanying text – will lead to more detail about the product.

Having become aware of possible destinations, the user needs to know what action to take ("How do I get there?"). The example of Fig. 5.30a is very clear about this, and so is the example of Fig. 5.30b now that the convention illustrated there (click on blue – and possibly underlined – text) is understood virtually universally. Where the picture of a product or person must be clicked (Fig. 5.30c) to move to a new destination the required interaction is less explicit. However, it is often the case that mouse-over will indicate that the picture is sensitive to interaction.

5.3.3 *Clarity and Ambiguity*

Available destinations in discrete information space may be indicated either explicitly or implicitly. In the menu shown in Fig. 5.31 it is clear what destinations are available. By contrast Fig. 5.32 shows an all too common situation with respect to ambiguity – do 'gifts' include books and music? In the example of Fig. 5.33 we also encounter some uncertainty: we are shown only categories, with the implication that we are seeing the top level of a hierarchy of choices. Here there is immediately

Fig. 5.31 A choice of three destinations in information space, with little ambiguity (*Courtesy of Springer Science+Business Media*)

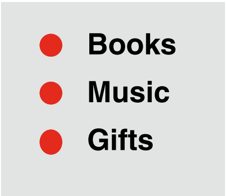


Fig. 5.32 Ambiguity regarding the content of available destinations in discrete information space. Does ‘Gifts’ include books and music?

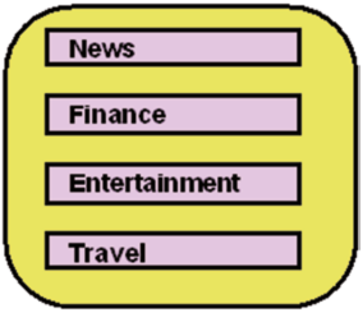


Fig. 5.33 The top level of a menu system, with some ambiguity about details of the next level down

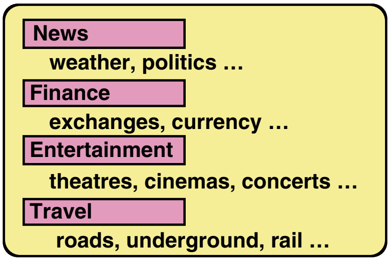


Fig. 5.34 Removal of some of the ambiguity present in Fig. 5.33 by the presentation of residue

a question of interpretation – we may not be sure, for example, what will happen if we select ‘Entertainment’. However, if examples of the menu options that will be encountered at the next level can be provided, as shown in Fig. 5.34, the user can make a more informed choice. Such ‘look ahead’ information is called ‘residue’ (Furnas 1997). **Residue** can be defined as ‘an indication of distant content’.

5.3.4 Menu Structure

Not surprisingly, much research has been undertaken regarding the ‘best’ structure for a menu. For example, with a well-structured information space there may be a choice of ‘Tall & Thin’ (Fig. 5.35a) or ‘Flat & Fat’ (Fig. 5.35b), as well as many intermediate variations, all of which have their advantages and disadvantages (see, for example, Norman and Chin 1988). The apparent advantage of a tall and thin menu structure (Fig. 5.35a) is that only a binary choice is required at each level. Unfortunately the accompanying and often serious disadvantage is that there may be many levels, with the attendant problem, illustrated in Fig. 5.35a, of associating a category label at a high level with the intended target possibly many levels below

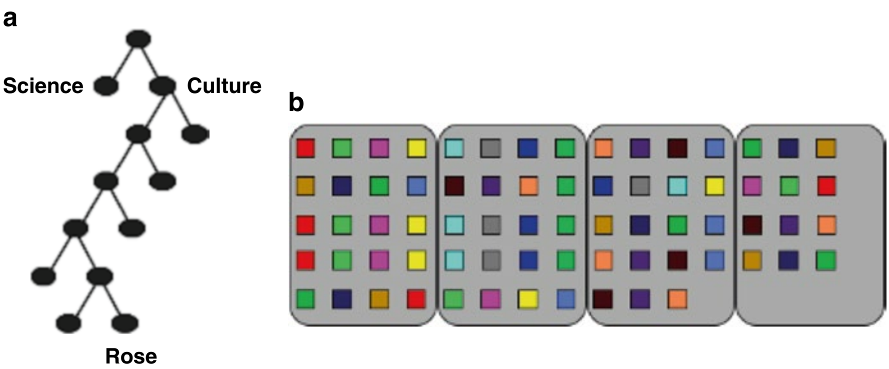


Fig. 5.35 Diagrammatic representations of (**a**) a ‘tall & thin’ menu structure and (**b**) a ‘flat & fat’ structure

(Snowberry et al. 1983, 1985). The ‘Fat and Flat’ menu structure, typified by the top level of an iPad, (Fig. 5.35b) has the advantage that all known destinations are represented at that level. The possible disadvantage that visual search is needed to locate a desired icon is often ameliorated by the frequency of the menu’s use (Field and Apperley 1990) and a consequently good mental model of the location of most icons, usually supported by their distinctive design.

5.3.5 *Sensitivity*

The concept of sensitivity can be helpful in design to support navigation, since it provides a conceptual mechanism for bringing together answers to the two key questions “Where can I go?” and “How do I get there?”

Sensitivity (**S**) is defined as the combination of two concepts, **SM** and **SI**. SM denotes a single movement in discrete information space (e.g., from one web page to another) and SI the interaction needed to effect that movement (e.g., a click on a word). Two examples, one from the physical world and the other from information space, will illustrate the concept of sensitivity (Fig. 5.36). With the door (a), the label ‘Café’ encodes SM because movement through the door leads to a café. The flat plate on the door, suggestive of its affordance (push to open), encodes SI. For the web page (b) the title ‘Britain’, for example, encodes an SM which is movement to another page dealing with holidays in Britain. Its grey background encodes the corresponding SI, indicating that a click on that area will cause transition to a page about holidays in Britain. Well designed, such encoding can help to answer the question “where can I go?” There are, of course, many ways in which a user can interact with an SI encoding – glance, touch, speech and gesture as well as the ubiquitous mouse – and consideration must be given to making clear the type of interaction required even though, in many cases (e.g., the iPad), the required interaction will have been quickly learned.

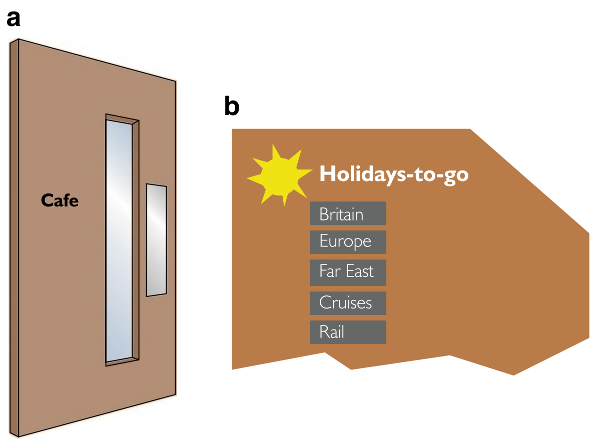


Fig. 5.36 Examples of SM and SI. (**a**) The label ‘Café’ encodes SM and the flat plate encodes the interaction SI. (**b**) The titles “Britain’, ‘Europe’ etc. encode SM and the *grey rectangles* containing text encode the relevant SIs

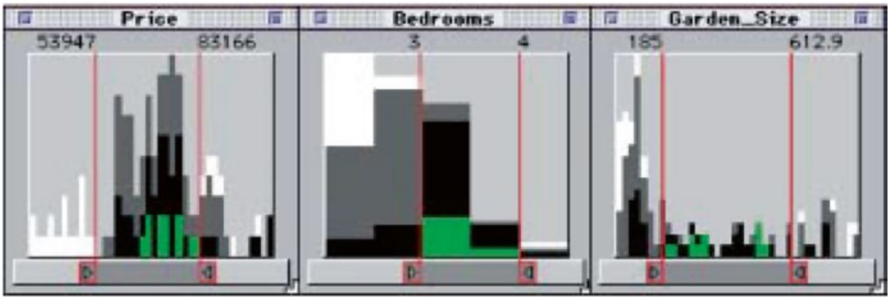


Fig. 5.37 In the attribute explorer colour encodes the number of attribute limits satisfied. *Green* denotes houses satisfying all limits while *black* encodes houses that fail only one limit. Thus a *black* house encodes the SM transition from a house failing one limit to one failing none. The corresponding SI is the movement of the relevant limit

The two components of sensitivity – SM and SI – are offered merely as useful concepts to keep in mind during the design of a web page.[6]

The concept of sensitivity is more general than might be suggested by the examples of Fig. 5.36 (Spence 2004). Let's revisit the Attribute Explorer, encountered earlier in Chap. 3 (Fig. 5.37). Black encoding of the representation of a house indicates that only one limit is failed, and that change to a green condition is possible. Change (SM) to a green house (satisfying all limits) can be achieved by executing a simple action (SI), that of moving the relevant failed limit to include the black house. Similarly, in the EZChooser (Wittenburg et al. 2001) introduced in Chap. 2, outline car icons (Fig. 5.38)

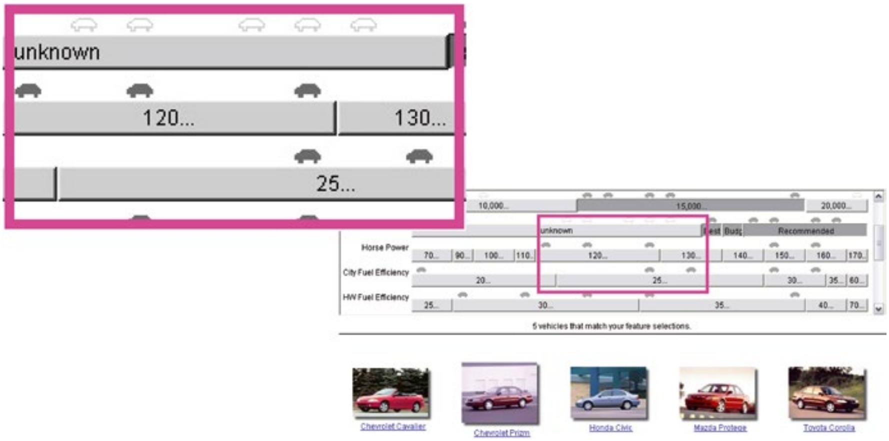


Fig. 5.38 'Outline' (i.e., unfilled) car icons denote cars that would satisfy requirements on all selected attribute ranges (highlighted *grey* in the example) if the range below them were additionally selected (*Courtesy Kent Wittenburg*)

[6] A more comprehensive source of guidance in the form of incisive critiques of 50 Home pages is provided by Nielsen and Tahir (2002) and is recommended reading for anyone who has designed or is designing a web page.

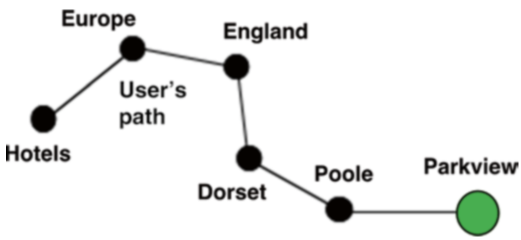
provide sensitivity information. The icon depicting the outline of a car (denoting one that satisfies all but one requirement) indicates that it can become (SM) a filled car icon (representing a car that satisfies all requirements) if the attribute range with which it is associated is enabled (SI).[7]

5.3.6 *Breadcrumbs*

Visible SM and SI encodings are not always freshly encountered. For example, immediate past movement in a discrete information space is often summarised at a current location by a representation referred to as **breadcrumbs**. An example is shown in Fig. 5.39: a user started from a website having to do with hotels and, by a sequence of actions, refined their selection of web pages until terminating at the page associated with the hotel 'Parkview' situated in the city of Poole in the English county of Dorset. Why is this representation (summarised diagrammatically in Fig. 5.40) useful? Mainly because experience and empirical evidence reveals that users often want to return to a previously visited location in discrete information space,[8] and that it will probably be one of the last six pages visited (Tauscher and Greenberg 1997). To facilitate such movement ('retreat') the

Fig. 5.39 A 'breadcrumb' summary of the transitions in discrete information space that led to the currently viewed web page (of the Parkview hotel in Poole). In this example text encodes both SM and SI

Fig. 5.40 Diagrammatic representation of a sequence of movements in discrete information space to the current location 'Parkview'



[7] In some circumstances sensitivity can take on a computable numerical value; in others it can be socially defined. See Spence (2004).

[8] Just as Hansel and Gretel planned to (but didn't) retrace their steps in the forest by laying down a trail of breadcrumbs.

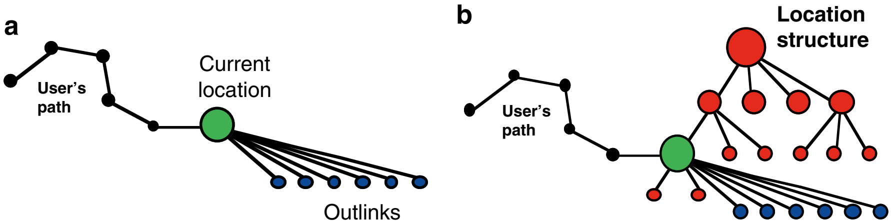


Fig. 5.41 (**a**) A reminder that retreat is not the only option at a location in information space (**b**) the concept of 'location breadcrumbs'

Fig. 5.42 Mechanisms to support selective retreat: (*left*) conventional url listing: (*centre*) miniature website images: (*right*) a space-saving solution in which images of recently visited pages are presented sequentially at a rate of about 2 per second (see the discussion of RSVP in Chap. 4)

breadcrumb summary of Fig. 5.39 can be designed to act as a menu, so a click on 'England' will take the user back to the page dealing with hotels in England. This breadcrumb menu will in general not be the only outlinks available, as Fig. 5.41a reminds us. Extensions of the breadcrumb concept can be useful. For example, even if the user first entered the sequence shown in Fig. 5.39 at the location 'Dorset' it might be helpful to offer 'earlier' (unvisited) locations for selection from the breadcrumb menu. And the idea of providing breadcrumbs identifying locations *not* already visited can be further extended, as illustrated in Fig. 5.41b, by the concept of 'location breadcrumbs'. If a user has 'entered' a site associated with, say, a corporation, it might be useful to offer 'virtual breadcrumbs' to facilitate movement around that site. Indeed, the concept of 'hierarchical breadcrumbs' would appear to be worth pursuing. It is useful to emphasise that breadcrumbs provide sensitivity information.

The mechanism (SI) used for retreat to an already visited location can take different forms. For a single-step retreat a simple BACK button will suffice. However, if retreat to other earlier locations is desired a variety of SI encodings is possible: Fig. 5.42 shows some.

5.3.7 *Scent*

In the discussion above we began by considering two questions asked by a user, and the associated concepts: "Where can I go?" and "How do I get there?" (sensitivity). In so doing we saw how answers to "What lies beyond?" (residue) can be provided as well as answers to the question "Where have I been?" (breadcrumbs). The representations discussed will also, to some extent, help to answer the question "Where am I?", though many visual aspects of a web page will help to characterise location and their provision falls within the expertise of the visual designer.

The only question we have not addressed is "Where can I most usefully go?" There may be many possible locations in information space just one step away from the current location, but only one can be chosen as a destination. The relevant concept in this case is 'Scent'; it was introduced by Pirolli and Card (1999) and Pirolli (2007) and can be defined as

> **Scent**: the perceived benefit associated with a movement in information space, evaluated following interpretation of one or more cues

Assessing scent by viewing a single location (e.g., a web page) is a challenging task for both user and interaction designer. For the user it involves consideration of the content of the entire page, familiarity with available destinations, awareness of any mental model that has been created during the entire session leading to that current page and consideration of the original goal and its possibly many adaptations. To make matters even more complicated, all these considerations may lack completion to some extent: a user will often, for example, choose not to examine all possible destinations, and a mental model is subject not only to deterioration with time and stress, but also to error.

From the above discussions we see that a considerable challenge is presented to the interaction designer who must address and balance a portfolio of concepts: sensitivity (including breadcrumbs), residue and scent.

5.3.7.1 Execution

In discussing Norman's Gulf of Execution in Sect. 5.1 we identified various considerations relevant to good support for the stage of execution, and those considerations are equally relevant to interaction design to support navigation. We would simply stress the many different means of execution now available – mouse, eye gaze, gesture, voice and touch, to name a few – and which must be evaluated appropriately for use in a particular application.

5.3.7.2 The Gulf of Evaluation

Our discussion so far has focused on one of the major Norman Stages relevant to navigation in discrete information spaces: the formulation of an Action Plan. We now briefly examine the Gulf of Evaluation.

5.3.8 *Visual Momentum*

In the vast majority of systems the 'change in the world' will be visual. Providing the user with a visual representation of the change presents a considerable challenge for the interaction designer, but a challenge that can be moderated by one concept, that of **visual momentum**. This concept will be familiar – in all but name – from the world of film. An essential member of any camera crew used to be known as 'the continuity girl' – the person concerned with scene transitions. The person who ensures, for example, that an actor's hairstyle doesn't suddenly change from one scene to the next (which may be filmed on different days) or that a gesture carries through from one shot to the following one. Translation of this principle to information visualization requires, for example, that the 'style' of a site's web page be maintained from one location to the next. It would confuse the user – and demand a significant update of a mental model – if, for example, menus took on different locations on a new page, or colour was used in a different way, or the design of a header were to be changed. Essentially, the momentum referred to is helping the user to align visual changes with those expectations arising from that user's mental model. When arriving at a new location in space the user should not have to jettison the original model and start building a new one; they should be able to direct cognitive effort largely to what is new and informative. This admittedly general guidance, encapsulated in the concept of visual momentum, will hopefully support the interaction designer: that person, just like the film director, needs the proverbial 'continuity girl'.

An illustration of the importance of visual momentum was provided in Chap. 3 in the discussion of the Cone Tree and, in particular, the transition from one state of the tree to the next in response to an interaction. If the change occurs instantaneously a user has considerable difficulty in reassessing what is seen whereas, if the change is animated to show the cones rotating appropriately, there is much less change needed to the user's mental model. As Stu Card stressed in a video demonstration of the Cone Tree, "without animation it takes several seconds to reassimilate the relationships between parts of a tree". He identified the underlying principle that the cognitive load is reduced because transitions are more easily interpreted by visual perception.

This same principle can be applied even when no physical metaphor is available. Artificial animation between two discrete views can often help provided that the starting and ending views are meaningful. A simple example is shown in Fig. 5.43 in which some economic measure of six countries (A–F) is represented by the area of a circle. In response to interaction (perhaps to look at records for a different year) representation **X** changes to representation **Y**. However, rather than arrange for an instantaneous change it might be preferable to arrange for the (wholly artificial and individually meaningless) sequence of representations **Z** to be presented, in the space of about 1 s, in an animated fashion.

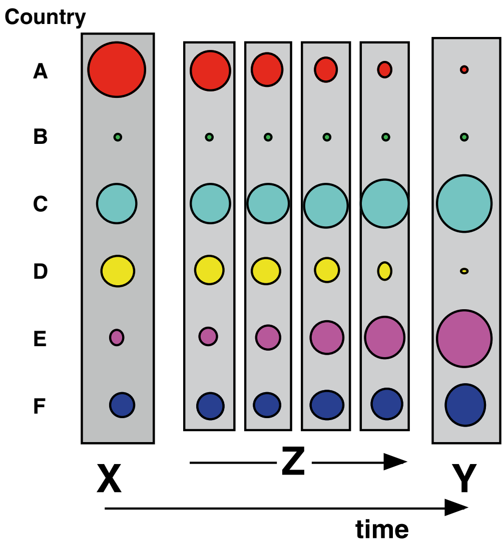


Fig. 5.43 The representation of an economic measure for six countries (**X**, *left*) changes to representation **Y** (extreme *right*). The animation sequence **Z** (*centre*) lasting about 1 s can enhance the user's mental model of the change from **X** to **Y**

5.4 Interaction with Models

5.4.1 Immediacy of Interest

People often wish to enhance their insight into some relationship as quickly as possible. A person wanting a loan needs to know without undue delay what the monthly payments will be over a chosen term; a prospective house buyer wants to understand how houses of different price ranges are distributed throughout an unfamiliar city; and someone planning to purchase a compact camera wants to get some 'feel' for the performance of what is available. These people do not want a "you-tell-me-what-you-want-and-I'll-tell-you-if-we've-got-it" interface: those take time to use and fail to provide an adequate mental model. An attractive alternative is a responsive "What if" interface that supports exploration, and one that is (Elmqvist et al. 2011) "engaging, compelling and even absorbing" as well as being "even playful."

5.4.2 Dynamic Exploration

Let's look at the above examples in turn. The person wanting a loan would prefer not to use an interface of the form shown in Fig. 5.44 for the reasons just advanced. The alternative sketched in Fig. 5.45 is much more supportive. Sliders allow the user to *explore incrementally and dynamically*: the selection of (say) an affordable monthly

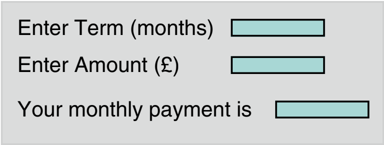


Fig. 5.44 An interface supporting an enquiry about a loan

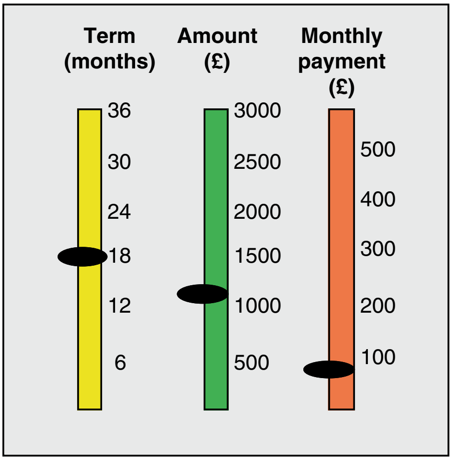


Fig. 5.45 An interface allowing a user to explore, dynamically, the inter-relations between features of a loan

payment would then allow the 'loan amount' pointer to be moved continuously and smoothly up and down and the consequences for the payment term noted from the corresponding movement of the indicator on the 'term' slider. Or the 'term' could be left at an acceptable value (i.e., locked) and the corresponding options for 'Amount' and 'Monthly payment' explored, again very flexibly. In view of the relationship between the three variables any one can be fixed in value while the others are explored, an approach not supported in Fig. 5.44. The principal benefit of the interface of Fig. 5.45 – the immediacy of response – is made possible either by a pre-existing table or a simple mathematical relation that requires minimal computation.

In a similar fashion the house buyer relocating to a new and unfamiliar city might seek some qualitative overview of the distribution of house prices, and may value an interface such as the one illustrated in Fig. 5.46. Here, manual (and typically smooth and continuous) variation of a price range along a price scale immediately causes corresponding areas of the city map to be coloured. Again, there is essentially no delay between the repositioning of the slider and the appearance of the appropriately coloured city area. Such *smooth and immediate interaction* allows the considerable benefits of dynamic exploration to be experienced.

Our third example concerns someone thinking of buying a compact digital camera. They will almost certainly have a number of priorities in mind, such as price, zoom, weight and resolution, and these may suggest the nature of an interface designed to support dynamic exploration. The sketch of Fig. 5.47 outlines just one

Fig. 5.46 Manual sweeping of a price range along a price scale highlights those areas of a city characterised by the corresponding range of prices. Response is immediate, so that dynamic exploration is supported

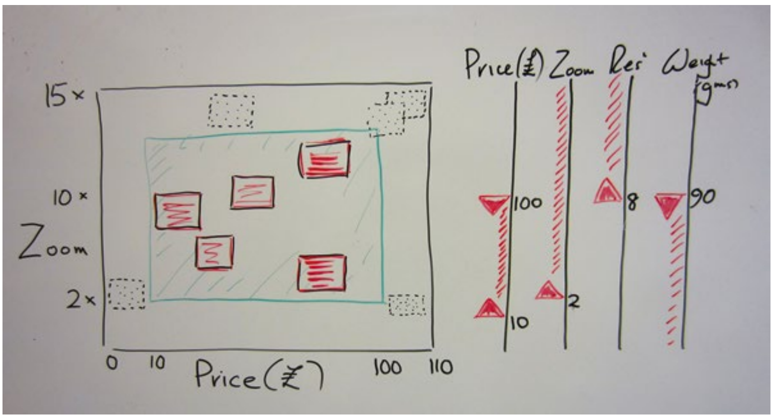


Fig. 5.47 An outline sketch to illustrate a possible approach to the support of dynamic exploration for someone interested in buying a compact digital camera

possibility. The user can select two properties to be the most important – here Price and Zoom – and assign them to the horizontal and vertical dimensions of a display. Sliders are used to determine the scales. If the maximum Price limit is £100 and the minimum is £10 the Price scale might automatically extend from zero to £110 to allow for 'near miss' information to be represented. The same approach applies to Zoom. Dynamic exploration can then take place: variation of the weight limit will control the appearance, on the display, of cameras satisfying the explored weight limit: the same facility is available for resolution (Megapixels). Recalling the value of sensitivity information (e.g., the Attribute Explorer), space is allocated beyond the limits of Price and Zoom to allow 'near-misses' to be brought to a user's attention. The camera representations on the display can of course encode other attributes of interest (e.g., shutter-lag, low light), and mouse-over could be designed to reveal additional attributes such as the manufacturer. Again, fluid interaction brings the benefits of dynamic exploration.

But a word of caution. Dynamic exploration that aids in the creation and adjustment of a useful mental model is not the only facility required by a user, who will eventually wish to *search* for a specific camera to buy. The boundary between dynamic exploration and search is a subtle one; both activities must be kept in mind when designing an interface.

It is difficult for the three static illustrations of Figs. 5.45, 5.46 and 5.47 to convey the enormous advantages associated with a dynamic and interactively responsive interface, but anyone who has actually used dynamic exploration will need little convincing of the immense benefits it can bring to the exploration of data. Studies by Ahlberg et al. (1992) and Li and North (2003) provide relevant discussion.

5.4.3 Availability of Data

A feature shared by the three illustrations just presented is the essentially *immediate* availability of data for display, thereby supporting the extremely beneficial activity of dynamic exploration. In many cases the data will already be available, often as a multi-dimensional array, though in some – such as the loans example of Fig. 5.45 – a mathematical model may be available that permits fast execution leading to the immediate display of data. The process of dynamic exploration is summarised in Fig. 5.48a and can be related to Norman's Action Cycle as indicated in Fig. 5.48b. Here, dynamic exploration is associated with a rapid traversal of the sequence 'execution-change-perception-interpretation-evaluation', avoiding cognitively demanding aspects of the Gulf of Execution. An obvious question is "how rapid should the response to interaction be?" Empirical evidence (Goodman and Spence 1978) suggests that a delay of up to 1 s might be tolerated.

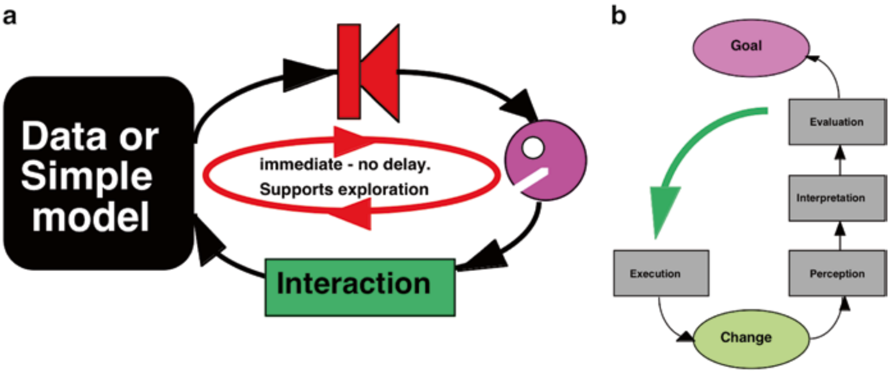


Fig. 5.48 (**a**) The process permitting dynamic exploration of a data set or simple model, (**b**) representation of dynamic exploration in the framework of Norman's Action Cycle

5.4.4 *Models*

In the three examples used above to illustrate dynamic exploration, the essentially immediate response upon which its benefit depends was made possible either through the prior existence of data (e.g., house price distribution in a city) or of an easily executed mathematical model (e.g., a relation between loan amount, term and monthly payment), as illustrated in parts A and B of Fig. 5.49.

In some fields simple models (B) are already available or can readily be derived, and can therefore be incorporated in dynamic exploration interfaces. An example relating diet, exercise and fitness is shown in Fig. 5.50. In this example of a Causal Explorer (Neufeld et al. 2008), a visually attractive display affords interactive and exploratory choice of diet and activity, with instant brushing into the obesity representation. Examples of readily available models can be found in many

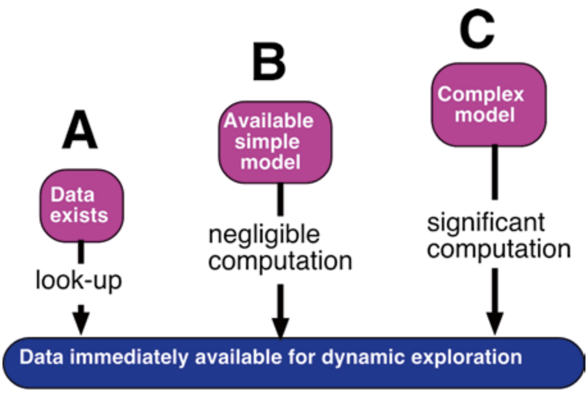


Fig. 5.49 Routes for the generation of data immediately available for dynamic exploration

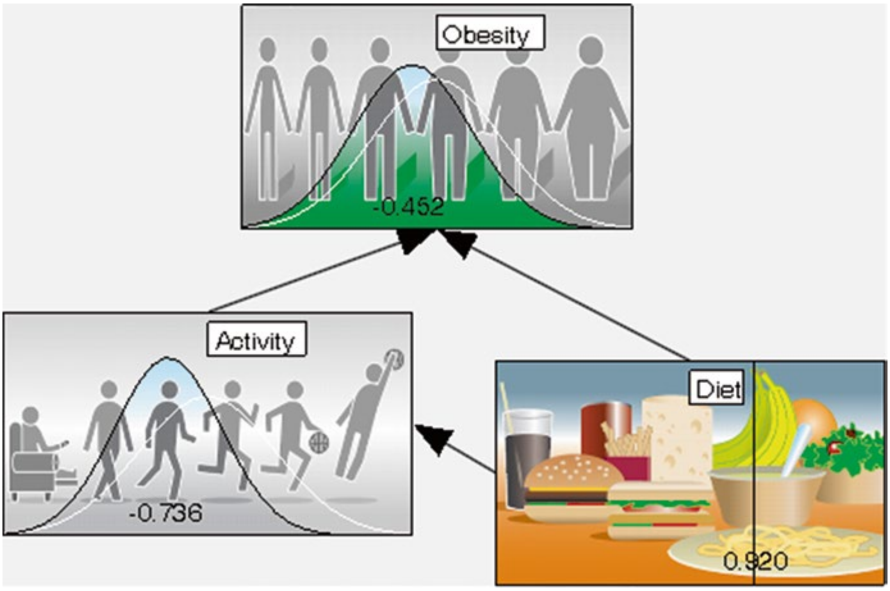


Fig. 5.50 The causal explorer allows a user to interactively explore the inter-relation between obesity, activity and diet (*Courtesy Eric Neufeld*)

fields: the Black-Scholes equation in finance (1973) and the Lotka-Volterra equations in biological systems are just two examples.

Unfortunately there are many important but complex fields – car engine design and typhoon prediction, for example – in which rapidly executed models are simply not available (see part C of Fig. 5.49). The associated challenge can be addressed in a variety of ways dependent upon contextual factors such as urgency and available resources. For time-critical situations, such as the need to explore and understand the likely behaviour of a typhoon, enormous computing resources may justifiably be employed. For car engine design, on the other hand, the degree of urgency may be less and it may be acceptable to undertake extensive simulations extending over many minutes or hours in order to accumulate the easily accessed data required for dynamic exploration (Part A of Fig. 5.49). This approach will always be helped by the discovery of more efficient simulation algorithms.[9] As with any model, a key and often subjective decision concerns the appropriate level of granularity.

To illustrate one of many possible approaches to the challenge identified by part C of Fig. 5.49 we choose an example that illustrates the surprising additional benefits that can accrue from dynamic exploration.

[9] There is always motivation to invent a new analysis algorithm that will speed up a simulation, as was the case for electronic circuits (Leung and Spence 1975).

5.4.5 The Design of a Light Bulb[10]

Electric lamps are mass-produced, so it is important that they be designed to be sufficiently robust to withstand transportation and handling. An example of a metallic support for the glowing filament within a bulb is shown in Fig. 5.51. The designer of that structure has to choose four of its dimensions (three of them are thicknesses and one is a radius of curvature). For convenience of reference we denote these dimensions as X_1 to X_4.

What criteria must be satisfied by the designer's choice of the four dimensions? The principal requirement is that certain stresses within the structure (shown as S_1 to S_4 in Fig. 5.51) be minimised, simply because high stress can be associated with fragility. But why should the choice of the four dimensions present any difficulty? Simply because, at the outset, the designer is likely to have little idea about how a specific choice of dimensions will influence the four stresses. It is precisely because dynamic exploration was expected to enhance the designer's visualization of that influence that the approach we now describe was undertaken.

At first it was not at all obvious how the relevant model shown in Fig. 5.48 might be obtained to allow dynamic exploration. The approach that was adopted is illustrated in Fig. 5.52. The first step was to calculate the four stresses for a small number of designs representing 16 combinations of X_1 to X_4 values, so chosen to cover a wide

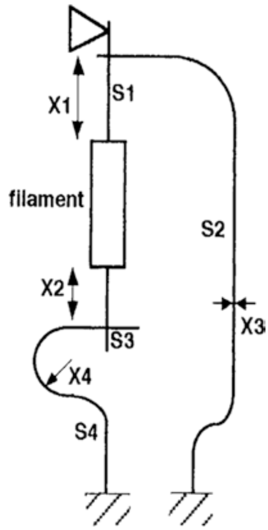


Fig. 5.51 The structural support for a filament inside an electric lamp

[10] The reader will be forgiven for expecting the discussion of a light bulb to be less than riveting. On the contrary, it illustrates an extremely powerful technique relevant to many fields. What may help is to keep in mind an example closer to your interests (e.g., finance, typhoon behaviour, aeronautical design) and thereby hopefully better appreciate the powerful tool of dynamic exploration.

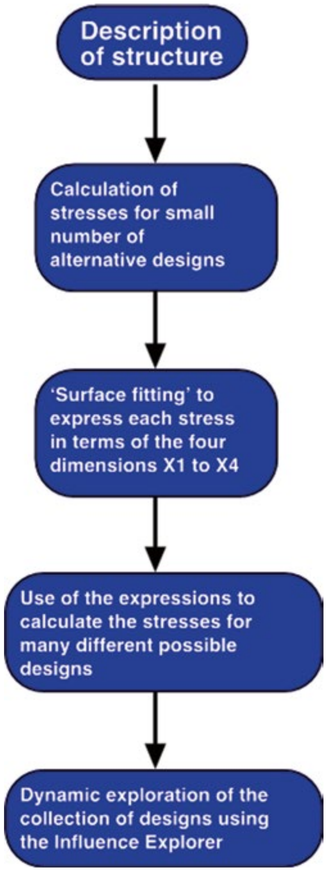


Fig. 5.52 Stages involved in the preparation of data immediately available for dynamic exploration to support the design of a light bulb

anticipated range of likely designs. Then, a surface-fitting procedure (Box and Draper 1987) was carried out to obtain a sufficiently accurate *continuous* approximation of each stress in terms of the four dimensions X_1 to X_4. For example, the stress S_4 was found to be related to the X values according to the equation:

$$S_4 = 60.4 + 23X_1 - 3.8X_2 + 631.2X_3 - 26.4X_4 - 79.7X_1X_3 \\ + 4.8X_2X_3 + 2.6X_1X_4 - 2.6X_1^2 - 278.2X_3^2 + 5.7X_1^2X_3$$

Such an equation, of course, provides absolutely no insight to the designer wishing to choose X values that will reduce S4. However, that expression for S4, together with similar expressions for S1, S2 and S3, *permits the efficient calculation of all stresses for a large number of designs* – i.e., combinations of X_1, X_2, X_3 and X_4 – ***thereby making dynamic exploration possible***.

But which designs should be simulated in this way? The approach employed by Su et al. (1996) was to randomly choose about 200 designs that, in the opinion

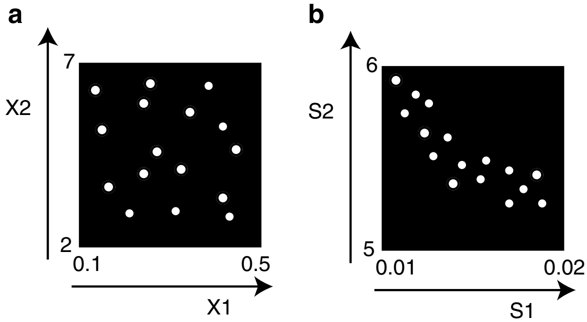


Fig. 5.53 (**a**) Designs (points in X_1~X_2 space) are randomly chosen to 'cover' the expected likely range of designs. (**b**) The corresponding values of S_1 and S_2 are calculated

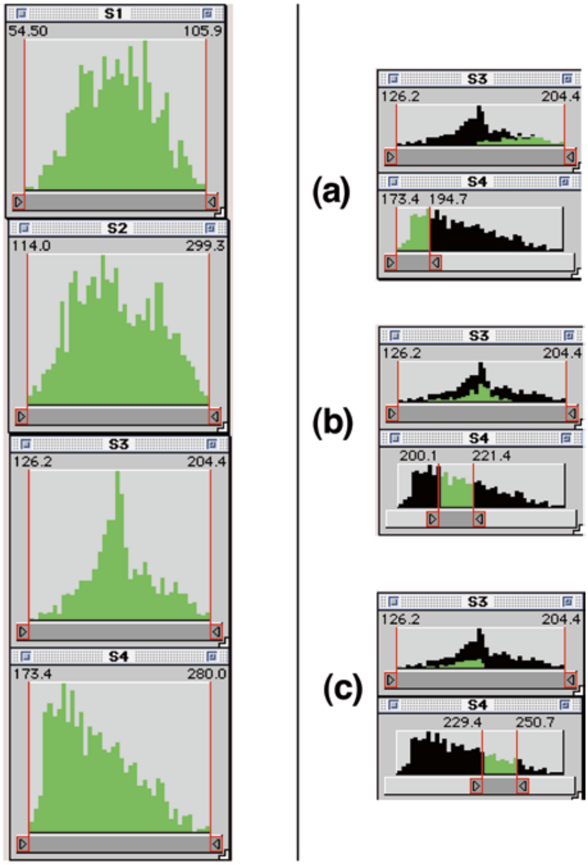


Fig. 5.54 (*left*) Histograms of stress for all lamp designs (*right*) the effect on S_3 of selected ranges of S_4

of the designer, might effectively 'cover' realistic ranges of X_1, X_2, X_3 and X_4: obviously a subjective choice based on the experience of the designer. The principle is illustrated in Fig. 5.53 for the much simpler case of just two X values and two S values. In this very simple case points in X-space (i.e., designs) are randomly generated and the corresponding values of S_1 and S_2 calculated. The designer would then simply be able to choose which stress results (i.e., points in S_1~S_2 space) are acceptable and trace the corresponding designs to X_1~X_2 space. But the 'curse of dimensionality' renders this approach impossible if we are representing designs and corresponding stress results each in a 4-dimensional space (and bear in mind that many realistic designs are described in a much higher dimensional space). Instead we represent the dimensions X_1 to X_4 and the stresses S_1 to S_4 in histograms.

We first look at the stress histograms (Fig. 5.54 left), remembering that each design will contribute a component to all four histograms. Now suppose that the designer interactively selects, from the 200 or so designs, those with small values of S_4 (Fig. 5.54 right (a, lower)), and immediately notices that they correspond to high values of S_3 (a, upper). Aware that any relation between two stresses can be of vital importance, the designer now moves the selected range of S_4 towards the centre of the range (b) and then to the high end of the range (c), readily confirming from simple observation that there is indeed a trade-off so that, for example, the *simultaneous* achievement of low values of both S_3 and S_4 is unlikely. In the same exploration a general and significant correlation between S_4 and S_2 was also discovered.

5.4.6 The Influence Explorer

While knowledge of the S_4~S_3 and S_4~S_2 relations is extremely valuable, considerable additional insight can be gained by the designer from three extensions to the histogram presentations. First, concurrent presentation of both S and X histograms, as shown in Fig. 5.55, can allow interrelations between stresses (S) and dimensions (X) to be explored dynamically. Second, the positioning of limits on stresses and dimensions (as illustrated in Fig. 5.55) leads to their brushing to all histograms and can refine the process of exploration to take account of realistic requirements. Third, the provision of sensitivity information, as illustrated by coloured aspects of the histograms (in the same way as for the Attribute Explorer) provides the designer with some idea of the success of the design: a 'black lamp' fails one of the stress limits. Because the interface shown in Fig. 5.55 can allow three influences to be explored (stress~stress, stress~dimension and dimension~stress) it is called the Influence Explorer (Tweedie et al. 1996).

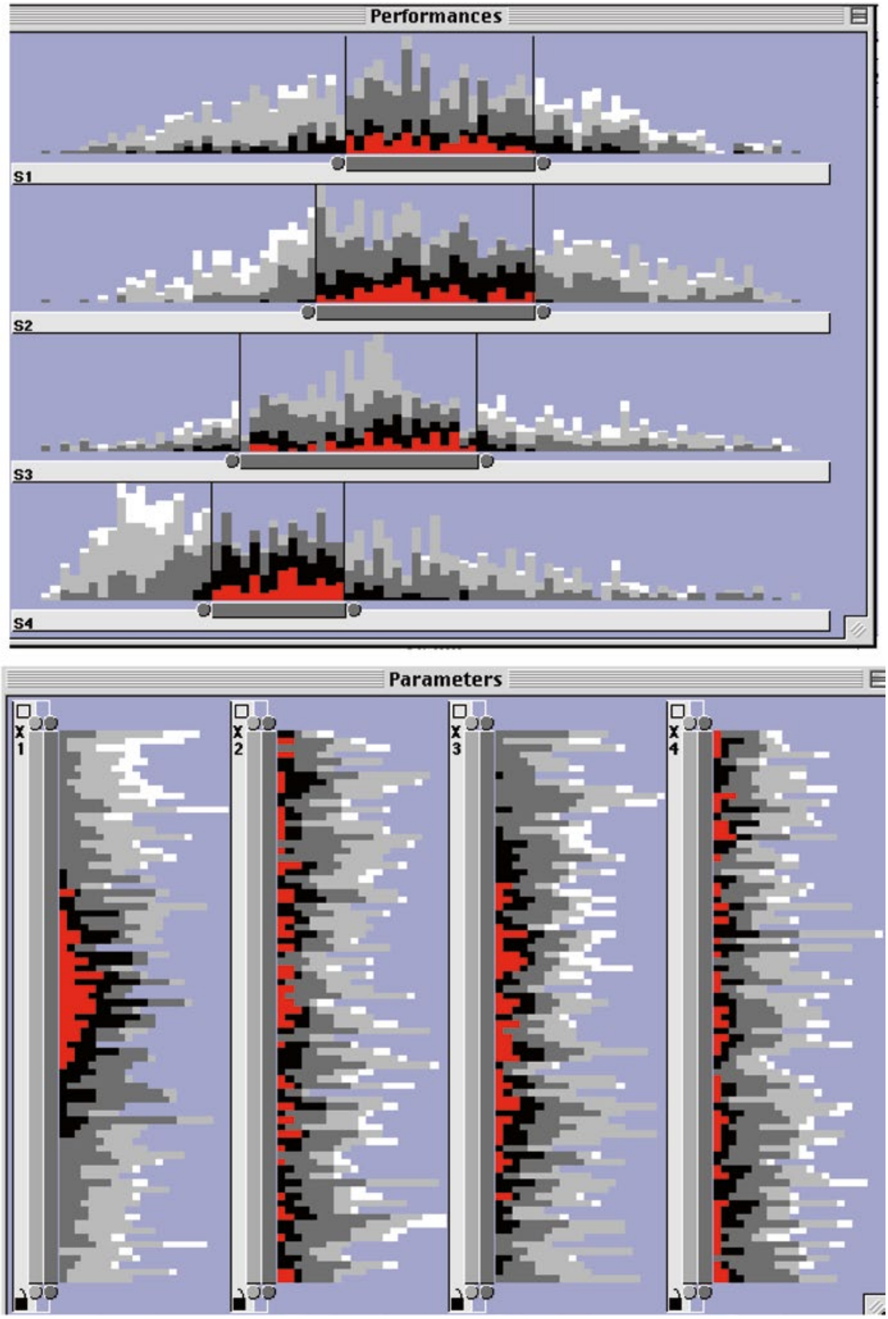


Fig. 5.55 Histograms of the dimensions (X_1–X_4, *right*) and stresses (S_1–S_4, *left*) for 200 designs of the lamp structure of Fig. 5.50. Thus, each design is represented once on all eight histograms. In this example exploratory limits have been placed on the stresses, thereby defining – as for the Attribute Explorer – designs that satisfy all stress limits: these are coded red in the stress histograms but also in the X histograms. We see, for example, that for the stress limits chosen, values of X_1 in the mid-range would be worth exploring

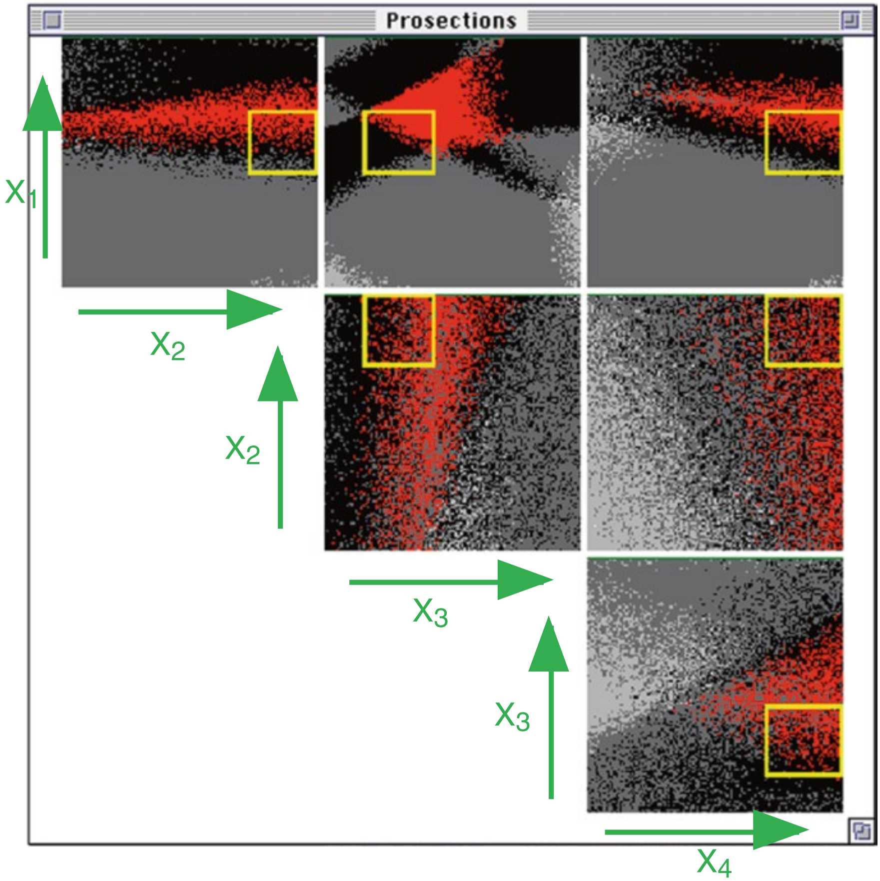
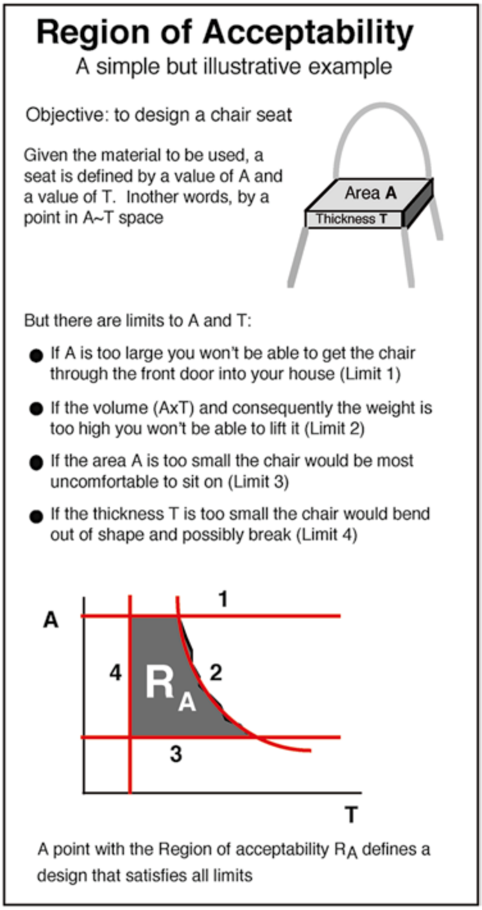


Fig. 5.56 A prosection matrix associated with the design of the lamp described in Fig. 5.51

5.4.7 Alternative Representations of Derived Data

Mindful of the many possible representations of data (Chap. 3) it is natural to ask how the data describing the 200 light bulbs might best be represented to provide a user with insight. For the lamp design task discussed above the interactive representation embodied in the Influence Explorer is certainly a useful one. But there is another, called the Prosection Matrix (Furnas and Buja 1994; Tweedie and Spence 1998) that can offer additional benefits to the designer. It is illustrated for the lamp design task in Fig. 5.56.

Each of the six ‘tiles’ of the Prosection Matrix is associated with two variables, in this case two of the four dimensions X_1, X_2, X_3 and X_4. The value of the Prosection Matrix resides in the fact that (1) a single design is represented in each tile by a



A simple example to clarify the concept of a Region of Acceptability in parameter space

single point, and (2) that acceptable designs – meeting all limits on the four stresses – are coded red. The lamp designer's principal task is therefore to place the intended design, described by a collection of 6 points defined by the values of X_1, X_2, X_3 and X_4, within the red regions which, together, define the Region of Acceptability (see box). The value of the Prosection Matrix may not at first be obvious until it is realised that a designer typically has no idea where the red (acceptable) regions might be.

But the Prosection Matrix is especially relevant to design for two additional reasons. First, the boundaries of the red (acceptable) regions are defined – in the lamp example chosen for illustration – by the limits imposed on the stresses S_1, S_2, S_3 and S_4. Those limits can be *interactively* adjusted using separate sliders to see what, if any, effect they have on the extent of the Region of Acceptability: they may have no effect, but they may have considerable effect, and perhaps usefully enlarge the Region of Acceptability. Second, the Prosection Matrix representation facilitates consideration of an inevitable problem associated with design for mass production, whether one is designing lamps or wristwatches: the fact that *all manufactured dimensions have tolerances*. In other words, one cannot be certain of the dimensions of a manufactured product within certain limits. Tolerances are easily represented in the Prosection Matrix: in each sector a design is now not represented by a point, but rather by a rectangle (see Fig. 5.56) within which all points representing a mass-produced product must lie. The designer's task is then to adjust the position of these rectangles in such a way that they lie wholly with the red regions – but with the considerable advantage that the adjustment can be interactive and exploratory. If that is not possible either a manufacturing yield of less than 100 % must be accepted or an exploration undertaken to see if limits (e.g., of S_1, S_2, S_3 and S_4) can be acceptably relaxed in order to change the shape and extent of the Region of Acceptability. The fluid interaction offered by the Prosection Matrix supports not only dynamic exploration but also a smooth transition to the design of an artefact, in this case the lamp structure.

5.5 Involuntary Interaction

Despite the enormous benefits that can accrue from interaction, there are times when it can be viewed as hard work. Just the formulation of an action plan can be extremely challenging if the interaction has not been well designed. It's therefore not unreasonable to ask whether there are alternatives to the achievement of a goal that can *avoid* the Gulf of Execution altogether and yet still provide a valuable experience for a user. The answer is 'yes'. As we recall, The Gulf of Evaluation is often not as challenging as that of Execution (Fig. 5.57): it can be undertaken *on its own* very quickly and sometimes achieved with no conscious cognitive effort (Potter 1999). We shall now see how this property can be exploited.

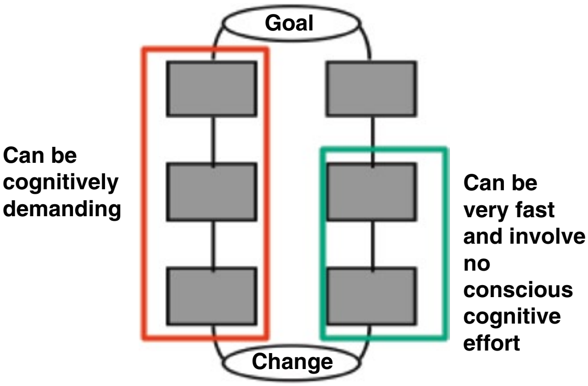


Fig. 5.57 The gulf of execution can often be demanding of the user, while the first two stages of the gulf of evaluation can be fast and involve little or no conscious cognitive effort

5.5.1 Involuntary Browsing

People have many goals. Some are stated explicitly ("I've got to buy a new washing machine") but others are latent. A familiar example of a latent goal is trying to remember the name of someone you met at a party. Another is an interest in playing games of chess. Yet another is the birthday present that you must buy sometime in the next 2 days. Usually, these goals will not be constantly articulated, but they are always 'in the mind'.

The relevance of a latent goal to Norman's Action Cycle arises from the nature of the 'change in the world'. One thing that is constantly changing, at a rate of about 4 or 5 times each second, is the image on one's retina (Fig. 5.58). Each of those images is very rapidly processed by the human visual system, through the stages of perception, interpretation and evaluation. Its relevance to a latent goal is quickly (preattentively) assessed. In the absence of any relevance the image will quickly be forgotten. However, if that retinal image is apparently[11] relevant to a latent goal the user will become aware of that fact.

For example (Fig. 5.59), imagine entering a library. Every 200 ms or so a different view of that library will appear on your retina. The floor might be of little interest, and so might the stranger sitting at the table. But your gaze might at some point alight on the poster containing an icon representing a chess piece.[12] If you have a latent interest in chess you will almost certainly become consciously aware of that poster. The continual process in which retinal images are assessed against latent goals in this way is known as Involuntary Browsing.[13] The attraction of Involuntary Browsing (Fig. 5.60) arises from the fact that it involves only the Gulf of Evaluation in Norman's Action Cycle. What action, if any, the user will take as a result of becoming aware of an image of interest will of course depend on many factors.

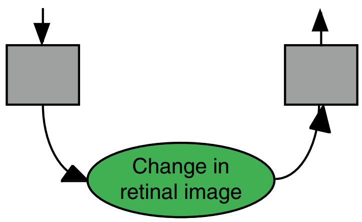


Fig. 5.58 Normal eye-gaze behaviour results in a constantly changing retinal image

[11] *Apparent* relevance can be invoked in other ways, for example by optical illusion or by disrupted attention engineered by a magician.

[12] The arrival of gaze at the chess piece following a saccade might well have occurred as a result of the salience of the chess image in parafoveal or peripheral region of the retina.

[13] The process of Involuntary Browsing is not without relevance to the phenomenon of serendipity, defined as "the faculty of making happy and unexpected discoveries by accident".

Fig. 5.59 A representation of a chess piece on a poster on a wall may, when glanced at, trigger an awareness of a latent goal

Fig. 5.60 Those stages of Norman's Action Cycle involved in involuntary browsing

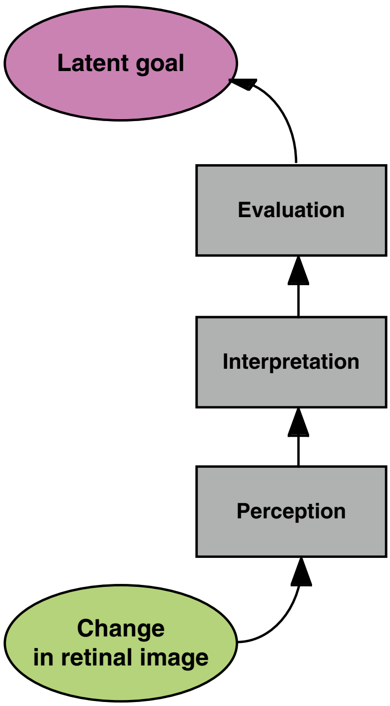


Fig. 5.61 A coffee table supporting involuntary browsing (©*Philips LIME design project 2000*)

How can Involuntary Browsing be usefully exploited? One example is shown in Fig. 5.61). It is a coffee table, but a coffee table with a difference. Part of each side of the table is an LCD display. Moving *very slowly* – and intentionally *unobtrusively* – around the periphery of the display is a stream of icons representing activities taking place within the locality (e.g., a village) in which the coffee shop is located. If an art group is meeting nearby next Wednesday a simple image depicting an artist's palette will be one of those icons. A small picture of a cat's face may be associated with a pet that a local resident has lost. If one of the people drinking coffee at the table notices the palette icon in view of their interest in art they can place their finger on the icon and 'push it' towards the centre of the display, whereupon it enlarges to provide detail of the art group's meeting. If it turns out to be of no interest the user need do nothing – the enlarged icon will simply fade away after a few seconds. If, on the other hand, the information *is* of interest, a further 'push' towards the container in which the user's token is placed will ensure that the information is transferred to their computer for later perusal. The design was motivated by a wish to enhance social cohesion within a local community (Stathis et al. 2006) but with minimal interference to the social intercourse for which coffee tables were intended.

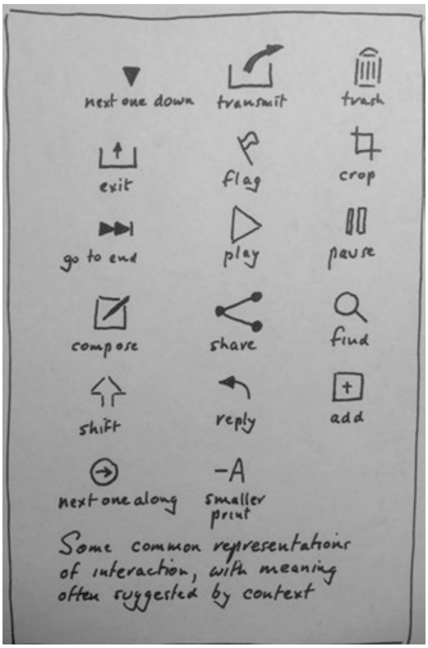
5.5.1.1 Salience

The designer of such a coffee table, and any similar system supporting unexpected and possibly serendipitous experiences, will understandably ask how close gaze must be to an item for that item to be interpreted as being relevant to a latent goal. For example, must the retinal image subtended by the icon lie wholly within the foveal region of the retina?

No, at first it need not. As discussed in Chap. 4, Sect. 4.1, covert attention taking place in the parafoveal and peripheral regions of the retina influences the choice of the location of the next fixation. Since, in general, there will be many visual items in these areas, the determining factor is that of *salience*. There are two aspects of an item within an image that will cause gaze to saccade towards it. One is the item's *proximity* to the current gaze position. The other is the perceived potential *relevance* of the item. Together they define the salience of the item. The more salient the item, the more likely it will be that gaze next moves to that item. One obvious conclusion is that the visual design of an item has considerable influence over whether gaze is attracted to it. Unfortunately, understanding of the concept of salience (Findlay and Gilchrist 2003) is insufficient to provide strong guidance to the interaction designer.

5.6 Representation of Interaction

To facilitate the efficient and effective use of interaction, icons have been developed to encode the interaction needed (i.e., SI, as in Sect. 5.3) to initiate a particular action. Some are sketched in the box below. The effectiveness of any icon will, of course, be influenced both by context, cultural issues and frequency of use.



Exercises

Exercise 5.1

Locate an interactive system or device (e.g., toaster, washing machine, ticket barrier, door, shower control) and identify the extent to which it supports each stage of Norman's Cycle of Action. Illustrate with sketches or photographs where appropriate.

Exercise 5.2

Devise, in outline, an interactive home-finding system interface in which an object representing a desirable house is moved around a map on which houses that approximate to the desirable house are displayed.

Exercise 5.3

Examine the result of Exercise 5.2 in detail and determine the extent to which it supports each of the stages of Norman's Action Cycle. If the support is not satisfactory modify the design appropriately.

Exercise 5.4

Choose any home page on the web and critique its design with particular attention to the extent to which it supports navigation and exploration. (For examples of informative critiques see Nielsen and Tahir (2002)).

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Chapter 6
Design

6.1 A Very Personal View

The literature on interaction design is vast. So it may appear both presumptuous and lazy of me to devote only a few pages to this topic. But remember that this book is targeted, not at experts in the field of information visualization and interaction design, but at readers enjoying their first concentrated exposure to the subject and, in all probability, completing their introductory course by undertaking a short project – one of the best ways of gaining an understanding of interaction design for information visualization. So what I present in this chapter is a very *personal* account of the guidance for project/design work that I offer to my students in London, Eindhoven and Funchal.[1] I'm aware that other teachers of information visualization will adopt different approaches, and I would indeed be very pleased to hear from them as well as from professional interaction/visual designers. In the narrative that follows I'm addressing my remarks directly to 'you', my students.

6.2 An Attitude

Creative design may appear quite foreign if you have just emerged from one of the many traditional academic disciplines such as physics, mathematics and psychology, although it was almost certainly a feature of your kindergarten and primary years. There is a very different ethos associated with creative design: you will be collaborating with others in a small group; you will at first be generating ideas without first evaluating them, and some may at first be considered 'silly'; you will know that there are many possible outcomes of the task you have been given, not

[1] I concentrate on the design process and oral presentation. My students will have had years of instruction about report writing (e.g., Goodlad 1990): more discussion here would be unwelcome, and could never encapsulate the millions of words already written on the subject.

R. Spence, *Information Visualization*, DOI 10.1007/978-3-319-07341-5_6

just one; you will be making very large sketches, perhaps on walls or very large pieces of wallpaper, with very thick pens; you will use lots of Post-it stickers to remind yourselves of ideas; and your instructor will have little idea what the outcome of your design will be. And laptops will be conspicuous by their absence – huddling around someone's laptop, especially when that person is in charge of scrolling, is not the way to do imaginative and creative design.

6.3 A Commission

In real life the design of a system to support information visualization takes place in response to a commission from a client. If such a commission is available – and vetted by your instructor for its suitability for a student project of limited duration – that certainly lends credence to the design task. If not, I have found that most students, offered the freedom to formulate their own commissions, are very creative and able to define a project suited to the time available (typically an intensive 7 days). Some of the 'commissions' undertaken by my students are shown in Table 6.1: often, remarkably creative designs have emerged suited to consideration by industry, one example being the Connectivitree discussed in Sect. 3.7 of Chap. 3. It will be up to the individual instructor to indicate where, on a continuum between 'extremely visionary' (i.e., looking 10 or 15 years ahead) and 'designs implementable today', your project could lie.

In real life, the initial goal of a commission is a *design* – *not* an implementation. Why? Because a proposed design will usually be subjected to intense discussion and modification – and possibly rejection – by the client and/or yourself. If modified or rejected, any expensive implementation that might have been carried out would thereby be rendered virtually worthless. Indeed, in a typical student design project there is, in any case, no spare time available to think about implementation!

Table 6.1 Illustrative design commissions

A new approach to cookery instructions
TV channel browser
Interface to support shopping for car/camera/house
A news archive
Interactive interface for a garden centre

6.4 Idea Generation

The eventual quality and effectiveness of a design is influenced immensely by the first hour or so of project activity. From the very beginning it is essential to get ideas flowing, and one way of doing that is to use **brainstorming**.[2] Following an agreement as to the goal of the project, all members of the project group are invited

[2] Brainstorming and many other aspects of design are treated, for example, in Martin and Hanington 2012.

to voice – typically by a word or phrase – ideas that occur to them, with one or two people standing by a board to write those ideas down immediately they are offered. Especially at the start of a design project the aim is to externalise ideas – to move them from your internal thought processes where no one else can appreciate them, to some surface where your colleagues can see them and start thinking about them. A variant involves individual members of the project group writing down ideas on Post-its – one idea per Post-it – and sticking them onto a vertical surface visible to all, thereby supporting later collaborative critiquing, grouping and ordering. In this activity *all participants are equal*, and it is essential that there is no deference to the most animated person taking part. But it is essential that the accepted rules of brainstorming are obeyed. The session must be 'judgement free': none of the ideas that are voiced and written down must be questioned or ranked or judged in any way: at this stage there is no such thing as a silly idea.[3] There is a good reason for this rule – ideas that might be developed into a truly useful outcome might at first appear 'silly' or 'obviously irrelevant'. Thus 'wacky' or 'wild' ideas are encouraged, as well as lateral thinking. For the same reason, at this stage, quantity rather than quality is of prior importance: 'quantity can breed quality'.

A brainstorming session can be quite brisk, and might typically last for just 20 min, though the time to stop will usually be obvious. The ideas that are generated should preferably be recorded on a wall or very large pieces of paper so that, later, they are visible to all members of the group: that objective would, of course, be defeated if ideas were recorded on a laptop or notebook. Brainstorming is often referred to as a **divergent** activity in the sense that quantity and a lack of judgement are essential. For this reason the dynamics of the brainstorming session are relevant: pauses can easily and quite naturally cause transition to criticism and evaluation.

Group brainstorming is not the only way to generate ideas for later evaluation and development. Some individuals can be extremely creative on their own, so it may be a good idea to introduce a substantial pause following a group brainstorm so that the results of such individual idea generation can be added to the result of the group session. In any case brainstorming can be mentally exhausting and can often best be followed at the very least by a coffee break and even longer to allow any individually created ideas to emerge.

6.5 Who Is the User?

Early in the design process the relevant characteristics of the people who will use your design must be established. Will their interest be casual and poorly formulated, as with many visitors to a garden centre? Or well-formulated as a result of training, as with an ambulance driver? Interviews are a normal part of the design process, and

[3] During one presentation about a design to show a supermarket's produce to online customers three ideas were mentioned and developed, with a fourth merely classified as being silly and therefore discarded. I asked about the 'silly idea'. A very embarrassed student said that he had the idea of supermarket products 'falling from the ceiling'. Creative development of that idea could have explored the idea that gravity might be rearranged to pull the products *towards* the user and disappear over their head – in other words, the idea encapsulated in the Floating method of RSVP (Chap. 4).

Fig. 6.1 The users for whom your design is intended. Who are they? What do they want? Do they even *know* they want it? If so, do they know *precisely* what they want? How do they approach problems? How did they solve their problem before they had a tool such as the one you are designing?

benefit both from your well-prepared questions and your readiness to accept that some of your pre-conceived ideas may be inappropriate. The elicitation of useful evidence from potential users is not easy, and the advice of experienced designers is valuable. What will hopefully emerge is some understanding of the task that the user will be expected to undertake and the way they have formulated that task. If it transpires, for example, that most visitors to a garden centre do not really know what they want, a website might be designed with some degree of serendipity in mind. If, on the other hand, the visitors are likely to possess considerable horticultural expertise, a very different type of design might be indicated (Fig. 6.1).

6.6 Convergence

The **divergent** activity of brainstorming must be followed by a **convergent** activity in which the recorded ideas are considered, ordered, expanded, critiqued, modified and annotated in order to lead, eventually, to ideas that are considered worthwhile to take forward in some detail. However, there is no sharp transition between divergence and convergence as Greenberg et al. (2012) have pointed out (Fig. 6.2): new ideas can still be added to the 'pool' during convergence.

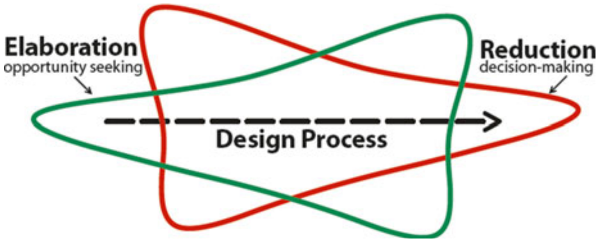

Fig. 6.2 Divergence typified by brainstorming is followed by Convergence in which ideas are grouped, considered, and evaluated in order eventually to lead to useful routes to follow in some detail (From Greenberg et al. (2012) *courtesy Morgan Kaufmann*)

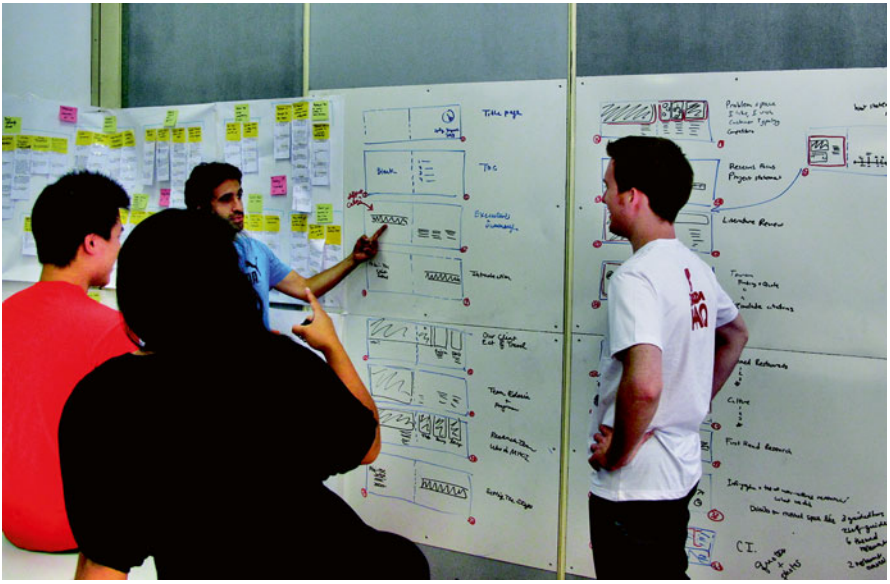

Fig. 6.3 Large surfaces support the fluent collaborative discussion of ideas and the externalization of new ones (*Courtesy Nuno Nunes*)

The first stages of convergence typically involve a number of activities. Some ideas may simply require clarification in order to be considered further. Groupings may be tentatively identified, in which case Post-its can usefully be brought together. And potential links can be indicated with string or by drawn lines. Affinity diagrams may emerge, emphasising relationships between concepts and data. Variants may be explored in a divergent manner: to take an example from RSVP in Chap. 4, the conversation might proceed as "Rapid? Why not *Slow* SVP? Serial? Why not Rapid *Parallel* Visual Presentation? Visual? Why reject *sound*? At this stage of the project guard against "yes but …" and encourage "yes, and …": useful detailed criticism can come later. A productive outcome can benefit from the liberal use of sketching, directly onto the wall or white board on which ideas are collected for all to see (Fig. 6.3).

6.7 Sketching

Why the emphasis on sketching? There are many reasons (Greenberg et al. 2012). You can think more openly and creatively about your ideas. You can instantly record many ideas without worrying about their neatness or completeness: indeed, interdisciplinary discussions leading to the design of a visualization tool (Craft and Cairns 2006) sometimes only need, at first, a table top, large sheets of paper and thick coloured pens (Fig. 6.4). If you are lucky enough to work in a room with specially treated walls you can quickly grab a pen and deposit your ideas on them immediately, otherwise sheets of wallpaper are often used for that purpose. You can invent and explore concepts by being able to record ideas quickly. You can add ideas later as they occur. Especially, you can easily discuss, critique and share ideas with others and facilitate their annotation and modification. A view of all the ideas on a wall can help in making decisions (not necessarily irrevocable) as to which to explore further and, when preparing a final report, can act as a valuable reminder. That is why laptops, fine pens and small pieces of paper are strongly discouraged at this stage. It has been said that “The Pen is mightier than the Pixel” (Baskinger 2008).

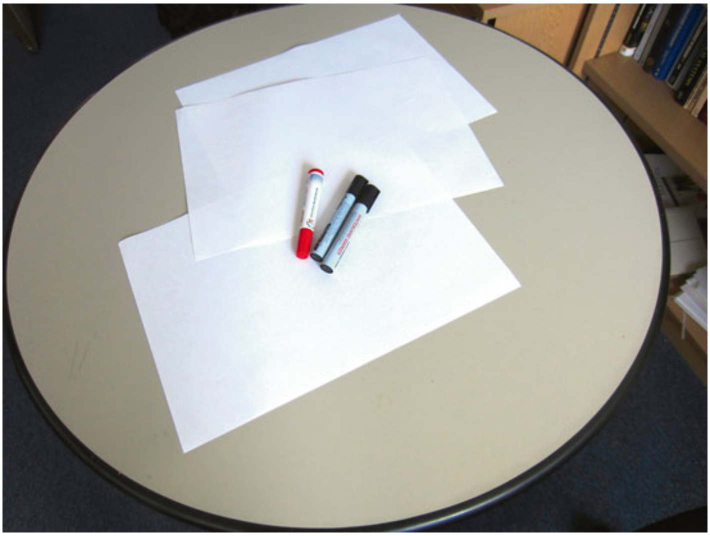

Fig. 6.4 Large sheets of paper and a collection of thick coloured pens are often all the tools needed for preliminary discussions of design ideas

6.8 Design

The clarification, expansion and evaluation of ideas may well take some time, so it is highly desirable to work in an environment (Fig. 6.5) where a record is maintained in full view. This activity will eventually lead to the identification of a small number of potentially promising approaches. The group may arrive at the view that one particular approach is so promising that it should be the one to be followed; otherwise some form of voting may be required. It may also be the case that each individual in the group will be asked to investigate a particular aspect of a proposed design in some detail and to return and discuss it later with other members of the group. The continuous clarification, expansion and evaluation of design ideas will draw upon the concepts learned from Chaps. 3, 4 and 5.

Fig. 6.5 Professional interaction designers during the design of an interface exploiting information visualization (*Courtesy Prof. Alison Black*)

6.9 Evaluation

How do you know that your design is a good one? You don't unless you test it on real people! It may well have some flaws that would have been difficult to anticipate but which render it irritating or even impossible to use. You will only find out how good (or bad) your design is by trying it out on real people – preferably by the sort of person who will use your design rather than your classmates. At some point during the gradual evolution of a design the evaluation technique of Paper Prototyping might be relevant, where a non-digital – and possibly rough and ready – implementation of an interface is rapidly constructed, perhaps in order to clarify ideas and/or to test the reactions of potential users. Another form of prototype, also valuable for presenting concepts to an audience, is a video simulation of a design technique. Bill Buxton (2007), for example, showed how, in about 30 min, a short video illustrating the bifocal display technique (see Chap. 4) could be put together. It has been said that if you test your design thoroughly on five or six people and encounter no obvious problems then you can be reasonably – but not overly! – confident in your design.

So, be aware that your client may well ask if you have evaluated your design, and that the answer 'No' would not be warmly received. They would not, however, expect the sort of evaluation that might be carried out by a researcher seeking statistically significant results and requiring testing by 20 or more subjects, but would be reassured that you had carried out the limited evaluation discussed above. However, be extremely cautious when stating that an interface is "easy to use". Such an expression is surprisingly often encountered in reports, and equally frequently dismissed unless backed up by evidence.

6.10 Oral Presentation to Client

For any commission for a client a crucial stage is that of the oral presentation: it will determine whether your design is accepted (or, for students, how they are assessed), whether it needs to be modified and, crucially, whether you will be considered for further commissions. Guidance regarding this important aspect of a project is most easily presented as a list of dos and don'ts:

- Ahead of time, consider the value of an animated sketch that would show your client the essence of your design without any implication that it has been implemented (Fig. 6.6).
- Prepare a 15 min oral presentation (or whatever duration your instructor specifies) and rehearse it as many times as necessary to keep it to 15 min and to make it effective. If you can, get an independent observer who will be critical to listen to your planned presentation.
- Be prepared for questions to be asked during the presentation and work out how to handle them.
- The first minute – even the first 15 s – of an oral presentation is crucial. Be absolutely clear about what you are going to tell your client, and don't – ever – use jargon that may be unfamiliar.
- Don't speak quickly: you are *not* having a conversation over coffee with someone familiar with your work. Rather you should be taking your audience through something they may well be unfamiliar with at a pace appropriate to their understanding of your material (listen to some of David Attenborough's television presentations and appreciate the value of pauses).
- You may feel more comfortable if you prepare a script, and refer to it during the many rehearsals, but try not to read from it during the presentation (watch any politician who reads from a script)
- Don't keep looking at the display if you are using Powerpoint, just refer to it.

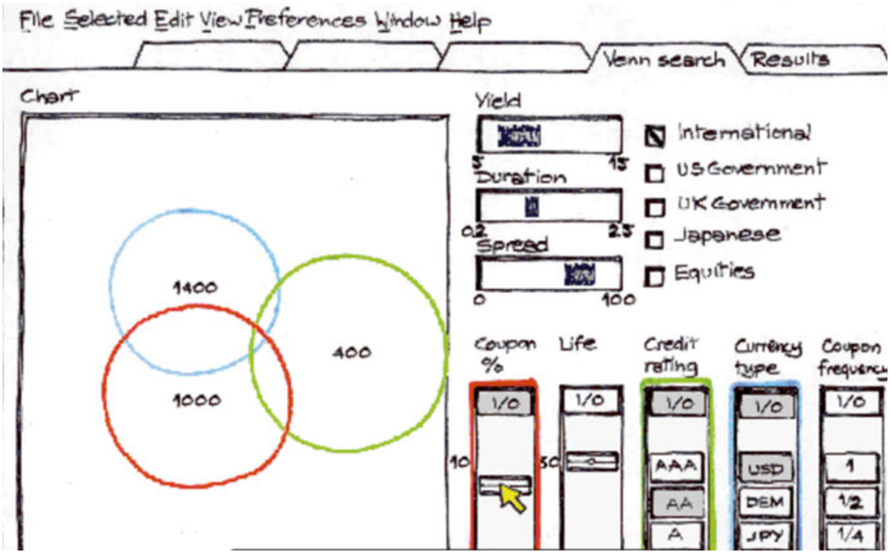

Fig. 6.6 A frame taken from a brief animated sketch demonstrating an idea for a financial interface (Courtesy Ron Bird)

- Don't read out loud what is on the screen – your audience is perfectly capable of reading for themselves and will have finished long before you do.
- Try not to present a new Powerpoint frame immediately full of detail: Powerpoint allows you to develop a diagram and text *step-by-step*, as you discuss the relevant concepts.
- Speak clearly – don't mumble and don't fade away at the end of a sentence. Some audience members may have hearing difficulties and be reluctant to ask you to speak up (and they may be major decision makers!).
- Find out who your audience is and prepare the presentation appropriately.
- Be prepared for questions. In fact, get friends to invent questions that you might have to answer. And beware of the audience member – often elderly and apparently asleep during most of your presentation – who asks the killer question beginning with "I'm not as familiar with your project as I should be, and this may well be a silly question, but …". Reputations and prospects can be shattered this way!
- Whoever in the group is currently speaking, make sure that *they* are in control of any Powerpoint presentation.
- Choose your opening slide carefully. Many older people who have long suffered torture by Powerpoint may cynically recoil at the familiar first slide that includes:
  - Introduction (what else would come first?)
  - Basic theory (Oh no … give me some results first!)
  - Results (I should hope so)
  - Conclusions (why else would you do the project?)
  - Future work (i.e., what you didn't have time to do?)

If you would feel uncomfortable not using such an overview as an introduction then use it by all means (but consider showing results *before* the theory?). But give some consideration to an alternative way to grab your audience's attention. For example, when describing a mobile interface for a developing country, by stating:

– "I'm illiterate (one second pause). And I want to send money to a friend (pause). But I do have a mobile. …

Exercises

The following 'exercises' are, in fact, intended as short projects to be undertaken by groups of three or four students over a period of about 5 days plus, perhaps, an additional day for the preparation of an oral presentation and a written report. Each project suggests a commission that a client might specify in greater or lesser detail and give to a group of consultants. The group may well have to add detail to the specification. What is expected from each group is a design proposal, and ***definitely not*** an implementation. The projects emphasize the application of information visualization concepts, but not to the exclusion of other issues: they place information visualization in context.

Project 6.1 Garden centre
Design a website for a garden centre.

Project 6.2 Search results
Design a new way of representing, and supporting interaction with, the results of a search engine such as Google.

Project 6.3 Art history
For the non-specialist visitor an art gallery wishes to mount an exhibit concerning a particular artist (e.g., Picasso). It would illustrate, for example, not only typical paintings but also the influence of contemporaries, the materials and techniques available and the reaction of the viewing public. Suggest how the exhibit might usefully be made interactive. Bear in mind the content of Sect. 3.7 ('Alternative canvasses').

Project 6.4 Calendar
Assume that a group charged with investigating alternative calendars has undertaken a brainstorming exercise and generated the idea presented in Chap. 7.1.11. Explore the possibilities further.

Project 6.5 History
See Project 3: in this case assume that a museum's goal is to allow an interested non-expert to gain some insight into the Second World War or any other chosen historical event.

Project 6.6 Cooking

Preparing a dinner party and at the same time entertaining guests is a stressful and potentially disastrous task. Devise a means of representing the ingredients, tools and processes in a static form (e.g., in a book or wall poster) to minimise the stress.

Project 6.7

Design an e-commerce website to support the purchase of one of the following (1) cameras (2) furniture (3) cars (4) mobiles (5) clothes.

Project 6.8 News

Design a news website either for local or global news.

Project 6.9 Email records

Most users of email possess records of received and sent emails stretching back over a long time. First, make a list of the tasks that the owner of such a record might want to undertake (aim for about ten) and the questions they might ask. Then, design an interactive representation of such records to support those tasks as well as others that occur during the design.

Project 6.10 Postgraduate study

Anyone contemplating postgraduate study must visit a large number of websites in order to come to some conclusion about universities to which a first approach might be made. Suggest a design for a website with that person in mind.

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Greenberg S, Carpendale S, Marquardt N, Buxton B (2012) Sketching user experiences. Morgan Kaufmann, San Francisco

Martin B, Hanington B (2012) Universal methods in design. Rockport, Beverly

Chapter 7
Case Studies

Design

A design is a moment in time. It draws upon the past and it influences the future.

Whatever is being designed – an interface, an aircraft or a financial investment – the design activity inevitably draws upon previous designs and experiences (both successful and unsuccessful); it attempts to exploit to the best the characteristics of available components; it acknowledges current and anticipated technology and human needs; and it is cognisant of market forces. As the design proceeds, pilot evaluation and use of the designed object or scheme suggest potentially beneficial modifications.

Design is therefore a *dynamic process*. The time constants of this process – and there are many – can vary enormously: decades for aircraft, months for domestic product design and, at an extreme, days for some innovative interfaces. The one constant feature in this scenario which cannot be changed is innate human performance.

The design of an information visualization tool – on its own or as part of a more extensive application – is very much a *craft activity*. The human designer – more often a collaboration of designers – draws upon known concepts and techniques as well as fresh ideas to produce an innovative result and in this sense does what engineering designers have been doing for hundreds of years. A crucial component of this activity is the designer's vision. Design is also a collaborative activity, involving prospective users where possible.[1]

What follows are five accounts of designs that have led to significant examples of information visualization tools and which emphasize the craft nature of design. Necessarily the designs draw upon principles and techniques from the wider context of human–computer interaction. The accounts are my own: I rejected the easy option of reprinting existing papers in favour of the freedom to emphasize what I think are the essentials of the design and the achievements of the designers, to

[1] A well-known designer is reputed to wear a badge with the message (for interaction designers), 'Remember, you are not the user.' Another badge says, 'You don't even *think* like a user.'

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introduce brevity and additional background where I think it appropriate, and to provide a consistency of presentation throughout the book. I have often used, verbatim, passages from the original paper which are already expressed with great clarity and which could suffer from rewriting, but in all cases I have obtained the permission to do so from the senior author. Their permission to use original figures is most gratefully acknowledged, but the reader should know that I have introduced figures of my own where I thought it might help comprehension. At the end of each case study an intentionally brief collection of relevant references is provided.

Readers who are familiar with major information visualization tools such as Spotfire and ADVIZOR may be surprised by the absence of any mention of them in this chapter. The reason is simple. Progression from the previous chapters to the present one involves a quantum leap from concepts and techniques to *the design for their use in the context of specific tasks and other constraints.* Justice could not be done to the further quantum leap to major commercial visualization tools involving a multitude of fresh contextual factors and requirements: indeed, it would be an insult to their designers to present a necessarily superficial account in the limited space that is available.

The case studies

The case studies which follow have been selected to encompass as wide a range of issues as possible. The first three, for example, address different available display areas: PDA (Sect. 7.1), conventional monitor (Sect. 7.2) and mobile (Sect. 7.3). The tasks are equally varied, from the online purchase of objects (Sect. 7.2) and calendar use (Sect. 7.1) to the selection of a news channel (Sect. 7.3). The data that is visualized by the user is also varied: from the communications generated by a military exercise (Sect. 7.4) to the details of a huge collection of newspaper articles (Sect. 7.5). Where possible I have implicitly addressed the topic of usability – worthy of a book in its own right – to show how this topic can be handled. The different sections discuss the following:

- PDA calendar (Sect. 7.1) describes an application exploiting *distortion* and *degree of interest* to good effect within the severe constraint imposed by the display area available on a PDA.
- The online purchase of objects (Sect. 7.2) provides an illustration of the representation of *hypervariate data* and the use of *interactive bargrams* to permit flexible exploration of available objects, as well as the effective use of *sensitivity cues* to facilitate a 'see-and-go' rather than a 'go-and-see' strategy.
- Mobile telephones impose a very severe constraint on available display area and provide a natural medium for exploration of the *slide-show mode* of image presentation in the context of searching for a relevant news channel (Sect. 7.3).
- The exploratory analysis of vast collections of communication data arising from a military exercise (Sect. 7.4) illustrates the potential of the *Attribute Explorer*, especially within the context of other tools, to support the acquisition of insight.
- In the last case study (Sect. 7.5) the InfoSky system adopts a Galaxy *metaphor* to address the problem of searching and browsing a large collection of newspaper articles, illustrating the value of well-designed *semantic zoom* as well as the power of *algorithms*.

7.1 Small Interactive Calendars

7.1.1 Planning Your Time

Human activity, whether personal or professional, is increasingly well planned and calendars are an excellent means of facilitating such planning. When can I schedule a dental appointment? When is a good weekend to go camping this spring? I've forgotten – what's the date of the CHI conference? A calendar is virtually essential to obtain reliable answers.

The combination of plentiful memory and interactive computational power enables calendars to become more powerful, while handheld devices such as PDAs have the potential to render them mobile and permit immediacy of use. But how? Calendars are conventionally not small, especially if one needs to look ahead by up to a year, but PDAs have very limited display area. By the skilful and innovative integration of available concepts and techniques, the power of the calendar was brought to the PDA display by Bederson, Clamage, Czerwinski and Robertson in 2002. The result was first named FishCal, reflecting the principal concept on which it is based, but is now known as DateLens.

The designers made one major decision: to handle the large amount of calendar data within a small display area by exploiting the concept of the Fisheye lens: hence the name FishCal. The approach is illustrated in Fig. 7.1 by views taken from their

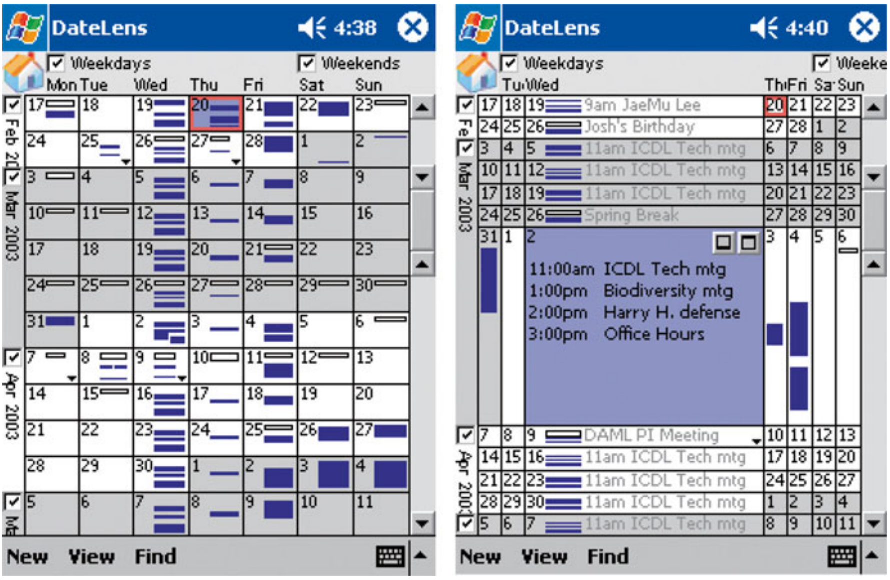

Fig. 7.1 Two views of the FishCal calendar, showing the use of distortion

design. On the left is a representation of 12 weeks showing 'overview' data (e.g. the extent to which a day is already scheduled) rather than detail. On the right is the result of a single tap on the date of 2 April: all days except that one are automatically distorted (but *not* removed) to allow the selected day to be (again automatically) assigned sufficient space for the time and nature of appointments to be visible and readable.

7.1.2 Design Philosophy

The designers acknowledged the part played by existing knowledge in influencing their design decisions:

> … much of the groundwork for this design was laid by earlier work,

a situation very common in the design of complex systems. But they rightly identified their achievement:

> …. while individual features of FishCal represent only variations of existing approaches, the primary contribution here is the integration of a host of techniques to create a novel application that is both usable and useful in an important domain.

7.1.3 Background

It is appropriate to examine earlier work that is relevant to the development of an interactive PDA calendar.

As the designers point out, the fisheye distortion technique which underlies the design of FishCal is the bifocal display (Spence and Apperley 1982) discussed in Chap. 4. Later, in 1986, Furnas proposed the 'degree-of-interest' concept which handles suppression to leave important data visible (also discussed in Chap. 4). A combination of distortion and suppression lies at the heart of FishCal.

The first proposal for a fisheye calendar appeared in Spence and Apperley's original 1982 paper proposing the concept of distortion and is shown in Fig. 7.2. A rudimentary illustration presented in 1980 (Imperial College) purely for concept demonstration, it exploited both X-distortion and Y-distortion, but its implementation was severely limited by available technology. Later, Furnas (1986) described a textual program in which clicking on an individual day caused the amount of space allocated to that day to be increased (Fig. 7.3). Impressive for its time, it did not support graphical representations or searching and it did not have widgets to control which and how many weeks to display. Furthermore it was not designed with small displays in mind. Later, Sutton and Spence (1988) described a means of suppressing detail to provide space by employing the metaphor of sliding tectonic plates: 'plates' containing the full detail of a day could be moved to provide more space for a particular day or collection of days (e.g. a week), as illustrated in Fig. 7.4.

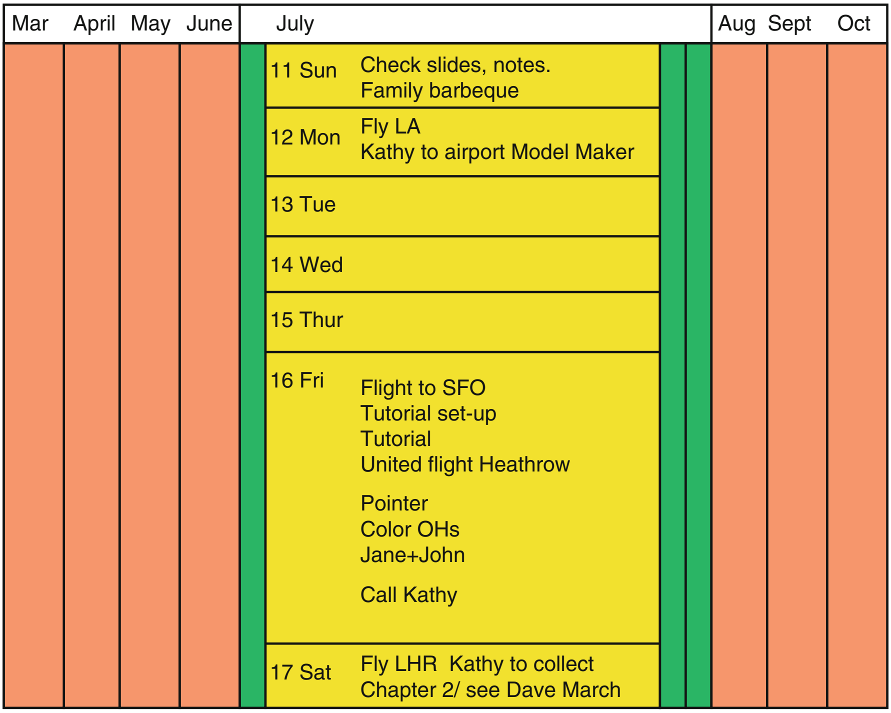

Fig. 7.2 The first bifocal calendar (1980)

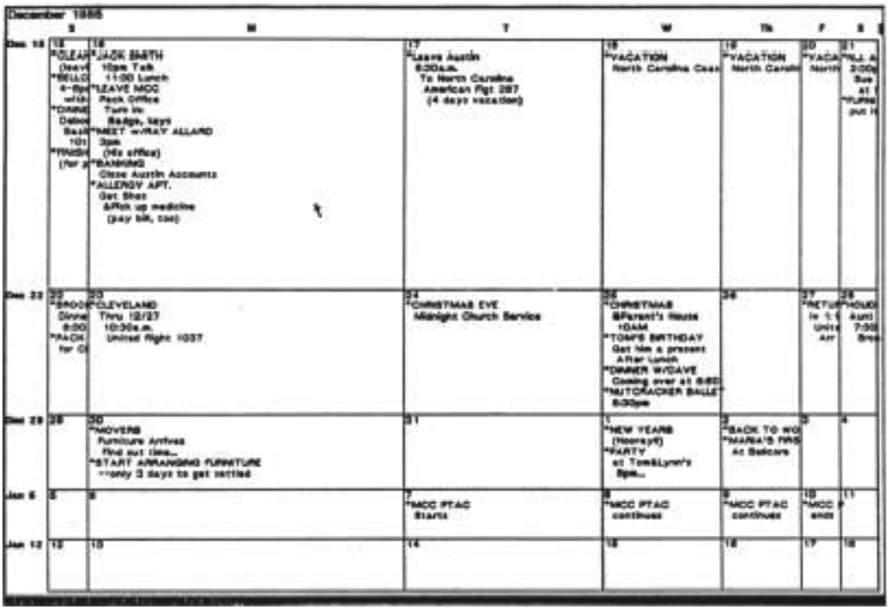

Fig. 7.3 Furnas's calendar (1986)

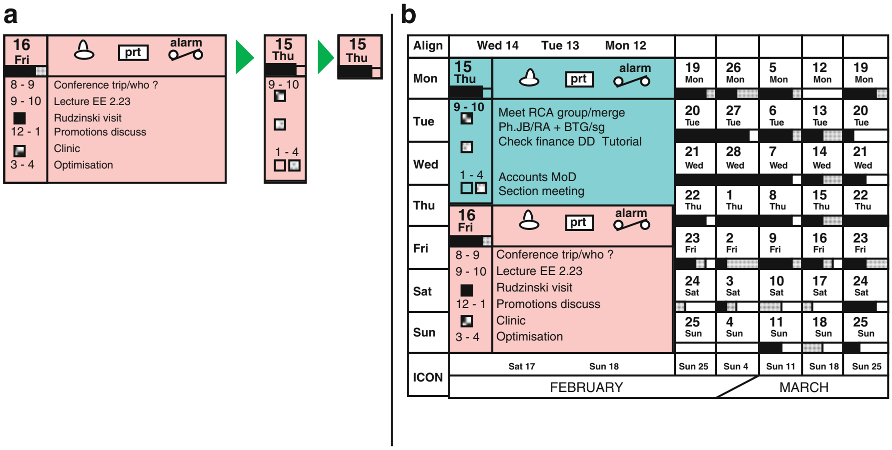

Fig. 7.4 The tectonic calendar (1988). (**a**) Successive suppression of detail by masking; (**b**) the resulting tectonic calendar

Since a calendar is essentially a collection of tables, the potential offered by the table lens (Rao and Card 1994) must be considered. However, it is principally designed to support one item per cell rather than the multiple items demanded by calendars. Other early work included the first visual representation of a calendar on a small display (Plaisant and Shneiderman 1992) and the cascade of calendar components due to Mackinlay et al. (1994) sketched in Fig. 7.5. The latter is not suitable for small display devices, though it does have a fisheye-like quality.

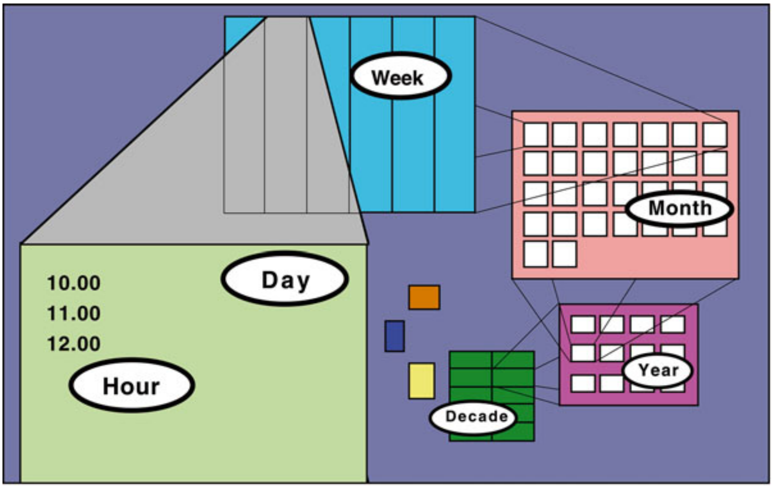

Fig. 7.5 The spiral calendar (1994)

7.1.4 Calendar Views

The designers of FishCal decided to provide four different views of the calendar called ‘Tiny’, ‘Agenda’, ‘Full day’ and ‘Appointment detail’ (Fig. 7.6). The names are virtually self-explanatory. For example, *Appointment detail* provides detail of a particular appointment within a day; *Full day* allows a conventional full-day view, with appointments shown at relevant times. The *Agenda* view shows an ordered textual list of appointments. If space is available times are shown and a larger font is employed. The *Tiny* view offers a graphical view of the day’s appointments, using colour to differentiate between different types of appointment.

7.1.5 Interactive Control

A simple and consistent scheme is employed to achieve transition between the four views and is shown in part in Fig. 7.6. Two buttons, always appropriately located, permit maximization and minimization, involving semantic zooming to achieve the desired view. Space limitations require a tapping action to move from *Tiny* to *Agenda* view.

The time span displayed by the calendar can also be adjusted with ease, simply by moving the bottom of the scrollbar thumb, as shown in Fig. 7.7. FishCal also

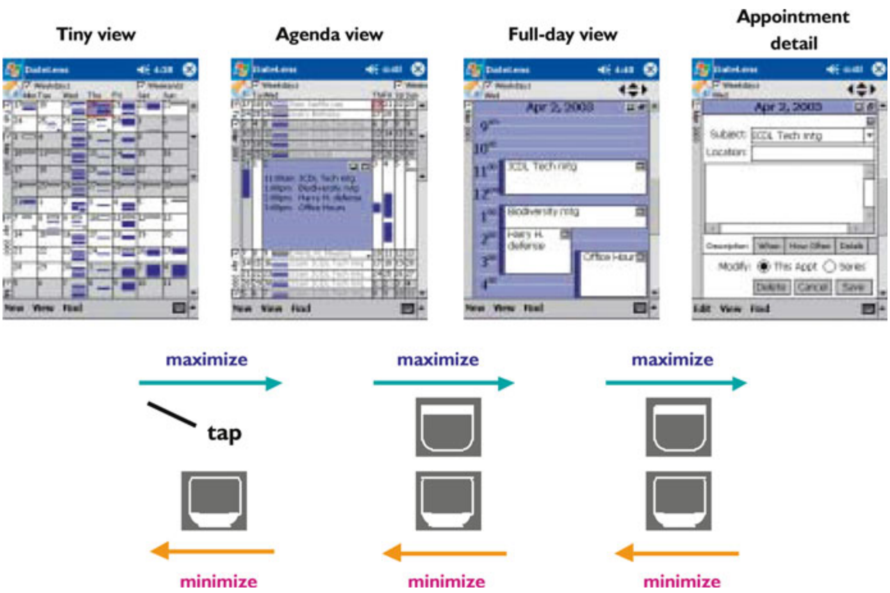

Fig. 7.6 The four views offered by the FishCal calendar and some of the interactions involved in transitions between them

exploits direct manipulation, for example by allowing a user to tap anywhere on a day to focus upon that day, simultaneously minimizing the area devoted to other days. Also, within a focused day (e.g. Fig. 7.1, right) a tap on the background causes a zoom-in to a full-day view.

The designers recognized the considerable value of animated transitions between calendar views. As they point out,

> [these animated transitions] may improve users' ability to maintain a sense of where they are.

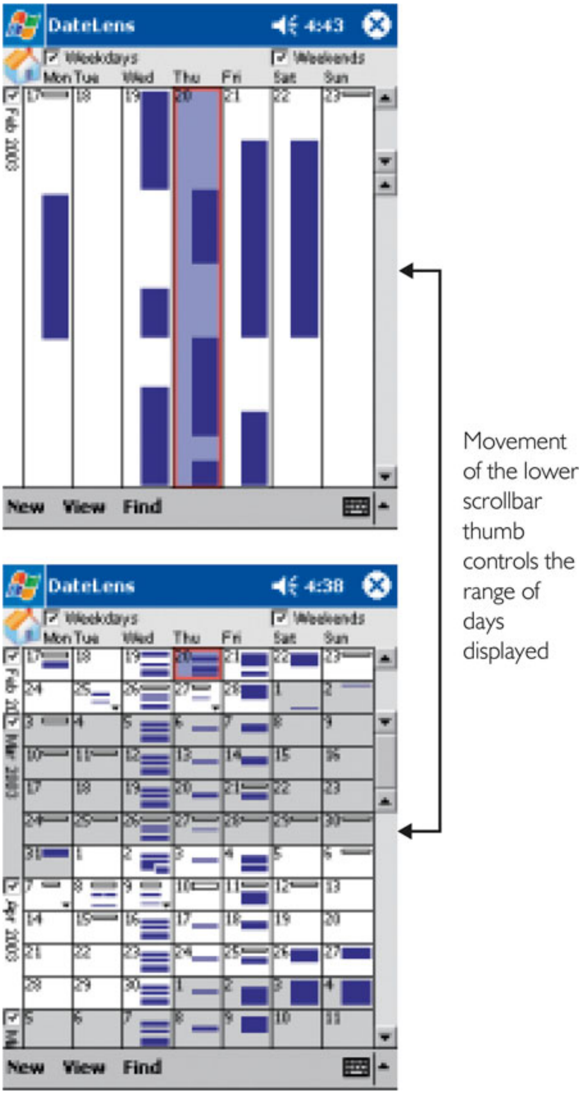

Fig. 7.7 Use of the scrollbar thumb control to adjust the visible time span

7.1.6 *Search*

As the designers remark, the activity of searching is important because it allows users to identify patterns and outliers within a large time span. A search in FishCal leads to the highlighting of all days that contain a matching appointment (Fig. 7.8).

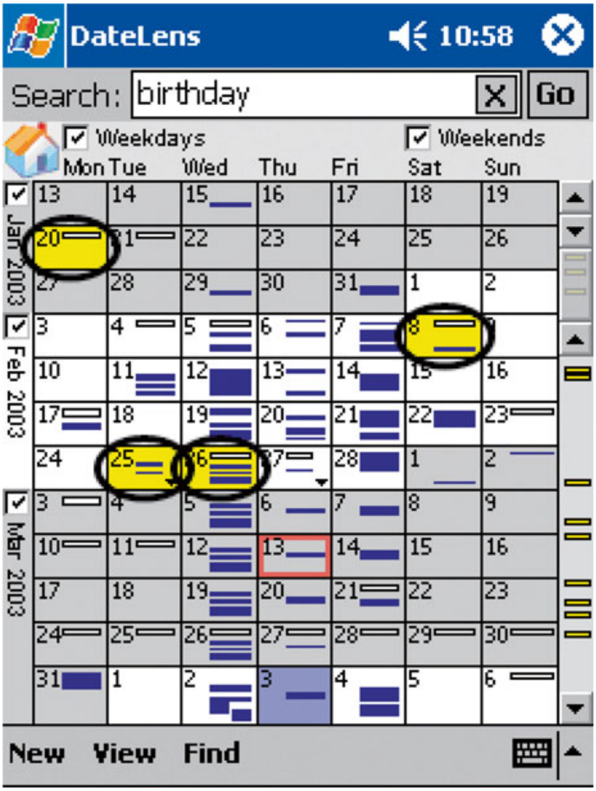

Fig. 7.8 The result of using the FishCal search facility

7.1.7 *Usability Study*

The designers of FishCal carried out a study to compare it with the then currently available user interface of Microsoft's Pocket PC 2002™ calendar. Because relevant software was not available on the Pocket PC to run FishCal satisfactorily, both calendars were run on a PC using a mouse and keyboard. In the 1,024×768 resolution display each calendar occupied a 240×320 pixel window (corresponding to standard Pocket PC resolution) centred on the display.

Six male and five female subjects, carefully chosen, were used to evaluate the new calendar. Following brief tutorials to acquaint the subjects with both calendars, each subject performed 11 tasks using each calendar. Necessarily, the order of calendar use and the task set for the calendar were counterbalanced to minimize the effects of training or the possibility of one task set being slightly more difficult than another. A limit of 2 min was set for the completion of each task, since this deadline seemed consistent with a user's expectations of being able to discover information from a calendar. Typical tasks were:

- Find the date of a specific calendar event.
- Find how many Mondays a particular month contains.
- View all birthdays for the next 3 months.
- Find free time to schedule an event.

7.1.8 Observations

What aspects of a new calendar are of principal interest and should be the concern of the calendar's designers? An obvious performance measure is the time needed to complete a task. Another is the success in completing a task. More subjective is the user's satisfaction and preference, though this was then transformed by the user to a quantitative value (1 = very difficult, 5 = very easy) for purposes of statistical analysis. Finally, in the course of observing the progress of any experiment, usability issues always arise and, indeed, point the way to potentially useful redesigns and research.

7.1.8.1 Task Completion Times

Statistical analysis revealed that tasks were performed faster using FishCal (49 s on average) than with Pocket PC (55.8 s on average), though the significance was borderline (Fig. 7.9). It was also found that as the tasks became more complex the FishCal time advantage increased.

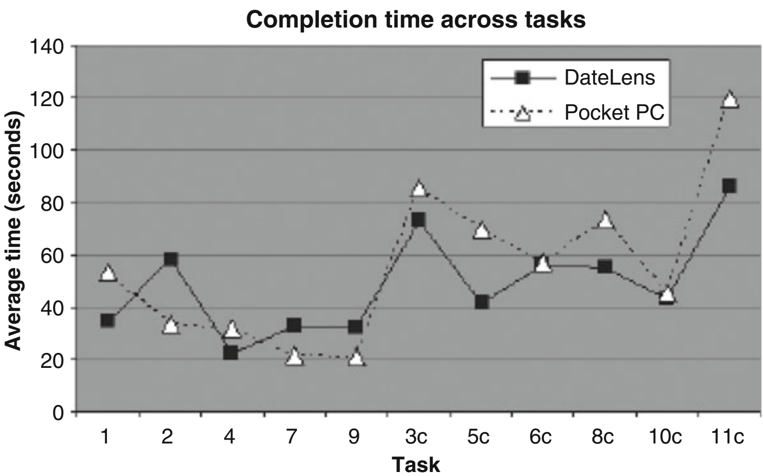

Fig. 7.9 Average task completion times for the two calendars (DateLens = FishCal)

7.1.8.2 Task Success

Tasks were completed successfully significantly more often using FishCal (on average, an 88.2 % success rate versus 76.3 % for the Pocket PC) (Fig. 7.10). The more difficult and ambiguous tasks were successfully completed more often with FishCal. This was primarily because the user had the ability to get all the information across a particular time span into one view in order to answer the question; the Pocket PC user was confined to predetermined views (day, week, month and year views).

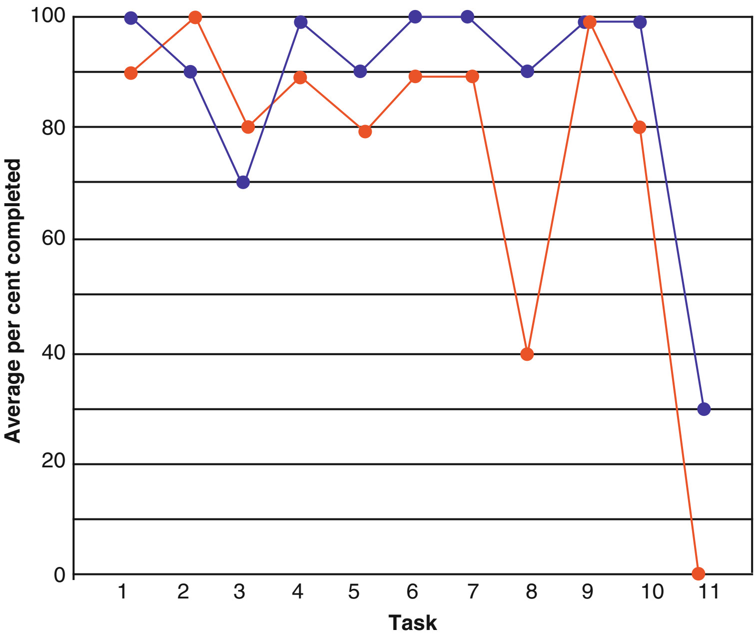

Fig. 7.10 The percentage of tasks completed by participants for each task (*blue* = FishCal, *red* = Pocket PC)

7.1.9 Satisfaction and Preference

FishCal was rated higher across a majority of tasks, especially the most difficult one (task 11 – how many conflicts are there for the next 3 months?). FishCal was rated higher than the Pocket PC in terms of task-by-task satisfaction, though the significance of this result was borderline.

7.1.10 Usability

The designers received good design feedback from participants suggesting how best to move towards redesign. For example, many users disliked the view of the calendar when more than 6 months were shown at once; they also wanted to see all 24 h of a day in the Full view rather than just the 9 am to 5 pm view provided in the prototype; and users expressed strong concerns about the readability of text and the desirability of setting their own default views. Users also wanted control of the day selected for the start of a week (Sunday or Monday).

It is rare to encounter a clear-cut expression of preference, or the reverse, for a thoroughly explored innovative interface, and the outcome of an overall satisfaction questionnaire and briefing completed by participants is no exception. Responses to the questionnaire revealed no significant differences, though users preferred the Pocket PC slightly more overall. Six of the eleven participants chose the Pocket PC calendar, one abstained, saying she wanted features of both calendars in the ideal calendar, and four participants chose FishCal. It was also clear that a frequent reason cited for choosing the Pocket PC calendar was the participants' familiarity with Outlook XP calendar.

Again, as with the development of many innovative interfaces, several areas of future work were identified. Inevitably users requested a long list of desirable features and these must be examined to see how they would affect users without jeopardizing ease of use for the novice. It was also recognized that studies must be carried out on hand-held devices using pens and touch-screens rather than the mice and keyboards that necessarily had to be employed in the reported studies.

The authors' conclusions are not unusual for an innovative development of the sort described here. They have certainly revived a useful application of fish-eye technology and in so doing have produced in FishCal a viable competitor to traditional calendar interfaces. However, as they remark, since the managing of one's calendar is so important, many users will be cautious about adopting non-traditional interfaces, so that a remaining challenge is to refine FishCal so that it is appreciated by a broad spectrum of users.

Overall, FishCal – now DateLens – represents a significant design achievement, especially in view of the remark by Kent Wittenburg that must surely be echoed by many designers:

> Achieving positive results for first-time users of novel visualization systems is rare.

7.1.11 Potential Developments

The last decade has seen the large majority of tablet-based calendars adopting a conventional format, making little use of the Bifocal Display or Degree-of-Interest concepts. Nevertheless, as well as looking back at past developments it is useful to look forward, albeit tentatively, at what might be. To provide material for student exercises we briefly discuss a concept that emerged from a recent brain-storming session and which intentionally provides more questions than answers.

The elements of a calendar could be mapped to the surface of a globe, as sketched in Fig. 7.11. To employ a geographic metaphor, 'lines of longitude' can separate successive years, with 'lines of latitude' separating months. One feature of the globe is that sight of its reverse is not essential, since it will be assumed that years continue both forwards and backwards (though not necessarily in a linear fashion), and that any one or a group of years can be brought to the front merely by single-finger stroking. If a particular year is of interest the appropriate lines of longitude can be moved apart, as in a bifocal display (Fig. 7.12), by two-finger expansion, and a similar action will magnify – and yield appropriate detail using the Degree-of-Interest technique - any required month (Fig. 7.12). There are many possible representations of each day of a month. Additional drilling down, and acknowledgement of the need for a rectangular format rather than a distorted shape, could be achieved by (reversible) morphing. The globe could, of course, be tilted to reveal an alternative view of individual years, and even 'unwrapped' (as with a Mercator or one of many other geographic projections).

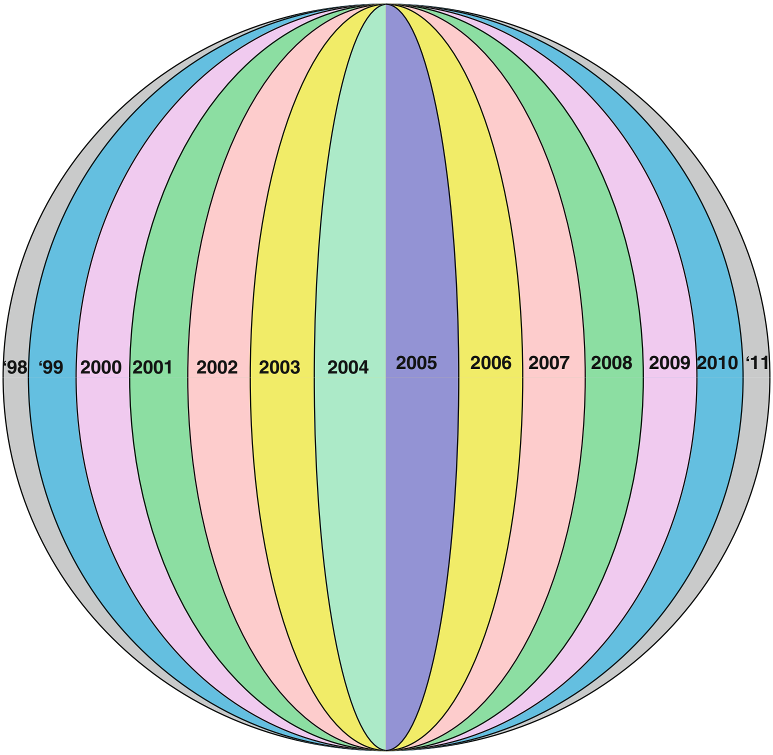

Fig. 7.11 A calendar mapped onto the surface of a globe

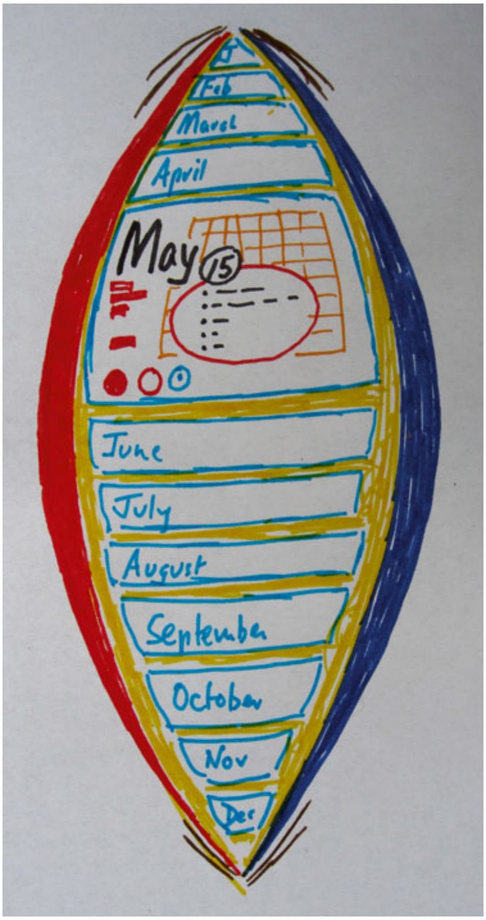

Fig. 7.12 Stretching horizontally and vertically to reveal a particular month in a selected year

The concept described in outline above may well have a visual and interaction appeal to users of a certain age and adventourous attitude who would welcome and accept unusual artefacts. The concept is intentionally left incomplete to stimulate discussion and development (See Exercise 6.4).

Principal References

URL: www.cs.umd.edu/hcil/datelens

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Supporting References

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7.2 Selecting One from Many

7.2.1 The Problem

The activity of selecting one object from many that are available is a common one. We go to the supermarket and select a cheese, to the department store to buy a tie, to the car showroom to select a new car and to the estate agent with a view to moving house. We have been doing these things without the help of computers, of course, for a very long time: the challenge now is to decide how best to offer an alternative by supporting these activities by computational means. In this case study we examine the development, by Wittenburg and his colleagues (2001), of a web-based application called EZChooser which facilitates the selection of one object from a collection of such objects on the basis of its attribute values. The success of EZChooser is primarily a result of the use of the *bargrams* introduced in Chap. 2, the provision of sensitivity cues, a recognition of the many and complex sub-tasks involved in the selection of an object and, consequentially, the importance of a mental model in the entire process of object selection.[2]

[2] Some material in this case study will constitute a repetition of material that has been presented in earlier chapters. This is intentional so that this case study can be read independently.

7.2.2 The Task

Wittenburg and his colleagues – we shall henceforth call them 'the developers' – begin by stating in very precise terms the task they propose to facilitate (Spence 2001, p. 73):

> Given a collection of objects, each described by the values associated with a set of attributes, find the most acceptable such object or, perhaps, a small number of candidate objects worthy of more detailed consideration.

As they point out, this generic task is applied very widely: to investment decisions, the choice of colleges, travel itineraries or real estate.

For many years database queries followed a rigidly prescribed procedure, but the severe limitations of these classic techniques are now well established. As the developers remark:

> Responses to queries all too often lead to zero hits, leading to complex follow-up dialogues. A fundamental issue is that in many decision contexts users may not be sure of what they are looking for before they start. Making a good choice may depend on the total set of choices available and how individual choices compare and interact across a number of dimensions (attributes). Users will improvise as a reaction to discovered knowledge (Suchman 1987) and, at best, classic querying provides only an indirect and tedious route towards formulating a mental model that can discover unanticipated solutions. For instance, in a car-buying context, if users discover the existence of a better warranty or gas mileage than they had previously supposed, they may be willing to extend their previously assumed price limit. Classic querying approaches will not easily reveal such information to a user.

Their comments are appropriately reflected by the inclusion of 'exploration' in the title of their paper. It is disappointing that many current online services appear to be unaware of what the developers state so cogently.

7.2.3 Existing Solutions

Before the creation of EZChooser, a number of approaches designed to overcome the limitations of classic techniques were available. *Tables,* for example, constitute a data format familiar to many people and may well be useful for examining options once a sufficiently small number have been distilled by a 'whittling-down' process. Indeed, after presenting EZChooser, the developers make a comparison with the use of tables. *Guides,* which ask the user a number of questions, have the drawback that a user cannot anticipate the consequences of taking a certain path. For example, in the travel domain, a user may not feel comfortable selecting departure and arrival times before knowing the corresponding consequences for the price of the ticket. A more recent development is the provision of *agent-based recommender systems* which gather preference information from the user and respond with a 'solution'. Often, the user has the uncomfortable feeling that they

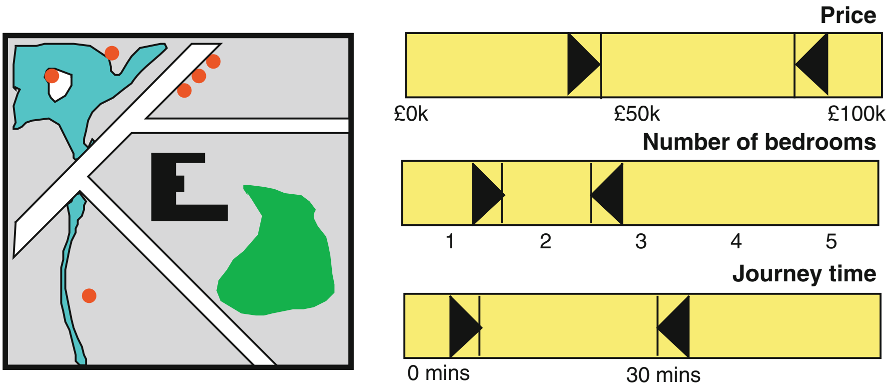

Fig. 7.13 Dynamic Queries: a home-finding example. Limits placed on house attributes by a user lead to the display of houses satisfying those limits on the map

could have made a better decision if only they knew more about the manner in which that solution was obtained.

The developers then pay particular attention to two visualization techniques which allow users to form better cognitive models of the decision space. They are Dynamic Queries and the Attribute Explorer.

The *Dynamic Queries* approach was named by Shneiderman and colleagues in 1992 and is illustrated in Fig. 7.13 by a 'home-finding' example. Attribute scales on the right allow lower and upper limits on a number of attributes to be positioned by a user, whereupon dots on the map on the left represent houses that satisfy all the limits. The positions of the limits can be varied manually, with instant response on the map, hence the term *Dynamic Queries*. The *Attribute Explorer* technique (Spence and Tweedie 1998) was introduced in Chap. 3 and will not be discussed further here. In connection with both these techniques the developers quote Kirsch (1997) as arguing that users should be offered a sort of playground in which they can manipulate the parameters of their problem and agree that interfaces for electronic shopping should allow users 'the opportunity to "play" with electronic artifacts of their decision parameters'. Recently, other interfaces supporting the flexible exploration of multiparameter objects have been developed (see, for example, Yi et al. 2005).

7.2.4 Bargrams

A crucial decision taken by the developers was to adopt – and indeed to name – the concept of *bargrams*. A one-dimensional bargram (Fig. 7.14b) is derived from a two-dimensional histogram (Fig. 7.14a) by tipping over the columns of the histogram and laying them end-to-end, ignoring any null bins. The relative count in a

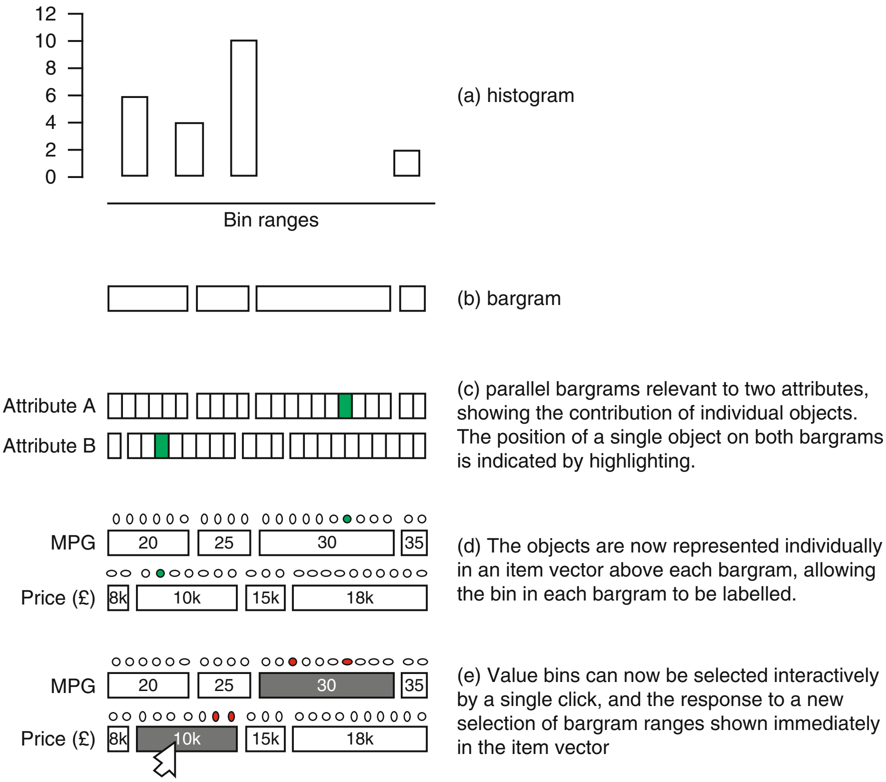

Fig. 7.14 Development of the bargram, parallel bargrams and item vectors

bargram is shown in the relative widths of the bars, in contrast to vertical heights in a histogram. Bargrams have the following properties:

1. They carry less information about value distributions; for example, gaps are not shown, neither are outliers identified as such.
2. There is no indication of whether adjacent items are close together or far apart in value.
3. They are generic: they can be used to represent numerical values, text, ordinal data and categorical data.
4. They can be used in parallel to represent a number of attributes.
5. They are simple.
6. They occupy little space.

The advantages of 3–6 tend to outweigh any potential disadvantages associated with 1 and 2.

7.2.5 Affordances

The developers then examined the *affordances* provided by bargrams. In a realistic scenario more than one attribute is of interest, so *parallel bargrams* (whose importance is rightly emphasized in the title of the paper) are appropriate (Fig. 7.14c). Since each object is represented once in each bargram, there is a *link* offering the potential for *brushing* and the display and exploration of *multi-attribute* information. Indeed, since the bin content of each bargram corresponds to the numbers of objects, it is possible – and very useful, as we shall see – to associate, with each bargram, what the developers called an *item vector* (Fig. 7.14d) composed of *domain-specific glyphs.* The placement of item glyphs above the bargram now allows the bargram value bins to support informative labels (e.g. *MPG* and *Price* in the car example) as well as providing an interactive mechanism by means of which a user can form queries (Fig. 7.14e). The results of those queries can then be reflected back into the item vector to indicate which objects satisfy all attribute range selections.

7.2.6 EZChooser

By exploiting the attractive features and affordances characteristic of parallel bargrams, the developers created the EZChooser interface. It is illustrated in Fig. 7.15 for the example of car purchase. The most noticeable addition to the parallel bargrams is the display, in the lower portion of the screen, of images of the 23 cars from which a selection is being made. The *appearance* of a car is an important attribute but is not quantifiable and would present a severe challenge to query systems that are based on conventional numeric, ordinal or categorical data. Since an attribute row (i.e. bargram plus item vector) has a minimum height, a scroll bar (Fig. 7.15) is provided to accommodate more attributes than can be handled in the available display area.

There are many ways (some of which were described in Chap. 2) in which the data presented in EZChooser can be explored: indeed, that is one of its advantages. For example, a single car can be identified by clicking it in the image set (as confirmation it is framed in yellow – see Fig. 7.15) whereupon, in a brushing activity, the corresponding car glyphs are highlighted in the item vectors above the bargrams. It is immediately obvious that the car highlighted in Fig. 7.15 is at the lower end of fuel efficiency and in the mid- to upper-price range compared with other available cars. Brushing can also be initiated by selecting a car glyph in an item vector. Alternatively the user might wish to identify attribute ranges reflecting his requirements in order to see how many cars satisfy those requirements, what ranges their other attribute values fall in and what they look like. In this case a user can click on any number of value bins in a bargram to impose a number of requirements; bins within a bargram are treated as a logical OR, while value restrictions between bargrams are treated as logical AND.

Fig. 7.15 Screen shot of EZChooser

A valuable feature of EZChooser is the ability to make highlighting 'sticky' to serve as memory cues. We often come to a tentative conclusion about a choice and want to 'tag' it in some way so that it is both easy to return to and can serve as a basis of comparison. In fact, EZChooser can be entered directly from a web page associated with a particular car, so that a user can start with an example at a detailed level and then later acquire an overview. This feature is important, not only in that it facilitates a particular exploration style but that it emphasizes the fact that 'overview first, then details on demand' (Shneiderman 1996) is not the only or even at times the most desirable approach to the exploration of a data set.

7.2.7 Sensitivity

Excellent use is made of the domain-specific glyphs (Fig. 7.16). If a car complies with all requirements established by clicked value bins it is represented by a *full glyph* in all the item vectors and, as mentioned earlier, can be moused-over in order to establish its location in all item vectors. All full car glyphs correspond to the set

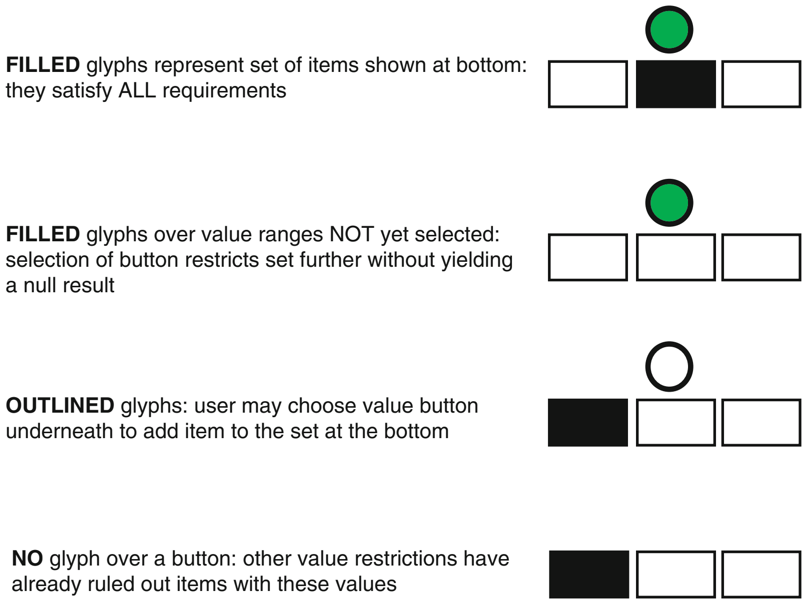

Fig. 7.16 Glyph states and the information they provide

displayed at the bottom of the screen. However, if a *full glyph* appears over a value bin not yet selected it is an indication that this button's additional value restriction can be invoked without yielding a null result. An *outline glyph* identifies a car which, although it does not satisfy all requirements, would do so if the value bin below it were to be selected. This is an extremely valuable feature of EZChooser and one which is regrettably absent from many websites. If there are *no glyphs* at all over a button, other restrictions have already ruled out cars with these values. Overall, this use of item vectors to encode information reinforces comments made in Chap. 5 about the value of sensitivity cues. In that context, the labelled bins together with the glyphs constitute SM encoding and the bins encode SI.

An example is shown in Fig. 7.17. The user has selected three favourable Consumer Guide recommendation values (row 2) and also a loaded price range (row 4). Four cars whose appearance is shown at the bottom match these restrictions and their feature values are indicated in every row by filled glyphs. Outlined glyphs in rows 2 and 4 show that the user could include those cars by selecting the bin buttons underneath the outline glyphs.

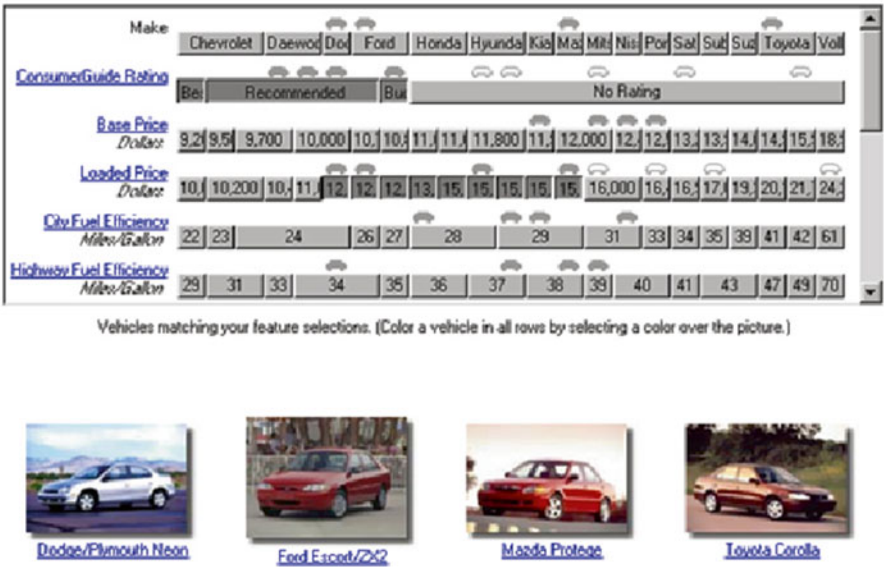

Fig. 7.17 Querying with the EZChooser. A user has selected some restrictions on the set of cars. Glyphs above the rows indicate relationships among the values and guide further restrictions

7.2.8 Related Work

After describing EZChooser it was appropriate for its developers to make a comparison with other ‘query systems’, though that term does not do justice to the exploration facilities and potential insight offered by an interface such as EZChooser.

Of the two other bargram-based interfaces existing at the time, one was *MultiNav* (Lanning et al. 2000). Its interface can perhaps best be understood by reference to Fig. 7.18 which illustrates the first prototype. We see a representation of three attribute values for each of 27 TV sets. Manufacturer B has been selected by clicking, thereby highlighting five objects in each of the attribute rows. While the second prototype (Fig. 7.19) allows the same interactions, the attribute ‘rods’ can also be moved horizontally: in the figure a user has dragged the *Price* bar slightly to the left to bring into the central focus position a TV set costing just under $400. In response the remaining attribute ‘rods’ slide to bring the identified object (a 19″ set from Manufacturer B) in line with that focus and the identified TV set is shown at the bottom of the screen together with more detail. Claimed advantages of MultiNav include the fact that users can observe correlations and reverse correlations by noting which rods tend to move in the same or different directions. However, a significant disadvantage is the lack of any sensitivity information that will bring a user’s attention to the fact that (say) a much larger screen size becomes available if the user is prepared to spend an extra $15.

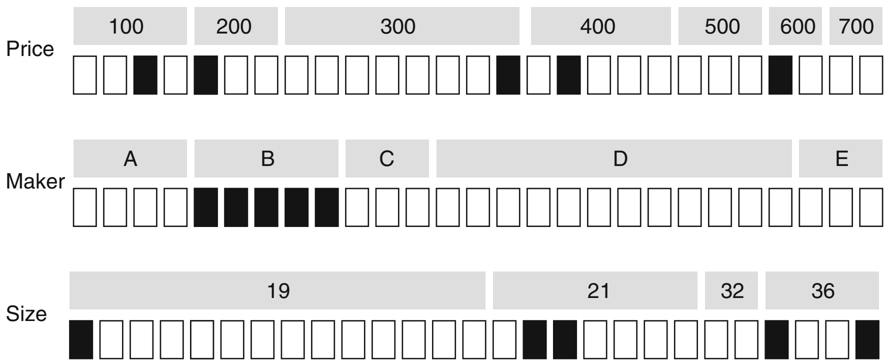

Fig. 7.18 Appearance of the first MultiNav prototype. A user has clicked on Manufacturer B to highlight the corresponding products on all attribute scales

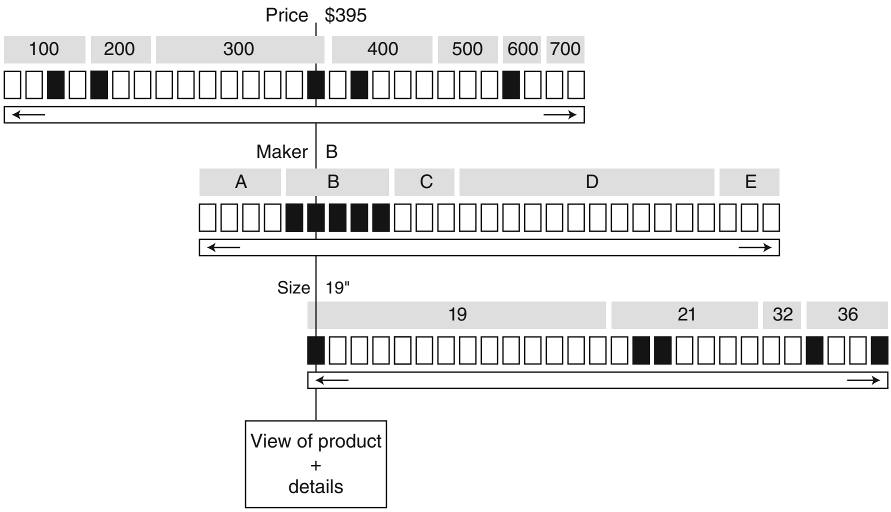

Fig. 7.19 The second MultiNav prototype. A user has dragged an attribute row to position a TV costing just under $400 in the central focus position

Colleagues of the EZChooser developers carried out user tests with a view to deploying MultiNav on the Internet for consumer e-commerce applications. However, the decision to go ahead with the development of EZChooser was triggered by two usability issues associated with MultiNav. One concerned the unusual and often disconcerting sliding action which, it was felt, might be appropriate to more specialized settings but not the general user: similar dynamics are associated with the Neighbourhood Explorer (Apperley et al. 2000; Spence 2001). The other arose because, when users selected a value restriction (e.g. Manufacturer B), they expected to see *all* valid objects at the bottom of the screen rather than just the one corresponding to the focus object. While the MultiNav technique can also be observed in the Neighbourhood Explorer, the developers of EZChooser nevertheless decided to revert to a more familiar form of interaction, namely, mouse button pressing.

The other existing system designed to support the same general task as EZChooser was *InfoZoom* (Lindner 2000) which uses parallel bargrams for larger set sizes and focus+context tables for small ones. While it supports simple selection as well as filtering (i.e. the suppression of groups of objects), it does not include item vectors with all the advantages they offer. For example, no sensitivity information is provided, neither is the marking/tagging of objects.

The developers also provide an illuminating discussion, under the heading 'Dynamic histograms', of the advantages of coupling item vectors with bargrams: in the interests of brevity the reader is referred to the original paper (Wittenburg et al. 2001, p. 57).

7.2.9 Evaluation

In an interesting conclusion to their discussion of EZChooser the developers conducted a preliminary evaluation by comparing it with simple tables containing the same data. Their hypothesis, confirmed by experiment, was that

> Users prefer EZChooser over static tables for larger sets, and they are more likely to use EZChooser.

The hypothesis that:

> Static tables are preferable for small sets

was not confirmed. However, the developers were quick to point out that their results were based on only two set sizes, of 3 and 50, and that many questions that spring to mind regarding the effect of set size on preference would have to wait for further research. They stress that their results are preliminary and make the interesting – and, for all developers of novel interfaces, the encouraging – comment:

> … it should be noted that achieving positive results for first-time users of novel visualization systems is rare.

7.2.10 Comment

In EZChooser, the developers have created an interface for the selection of one object from among many which reflects the manner in which this task is typically pursued, since it supports flexible sequencing, discovery and play. EZChooser combines the simplicity of button clicking with the potential offered by the combination of bargrams and item vectors, and crucially incorporates sensitivity information to support navigation.

7.2.11 Recent Development

With the EZChooser, a user was forming a mental model of a collection of objects (cars), each described by a number of attributes (e.g., price, HP, MPG), each of which could have one and only one value for a given car. In the new development, the user is still considering a collection of cars, but is now interested in (say) in-car Infotainment Systems that may have one or more features such as Navigation, TrafficInfo, iPod/MP3, and/or Bluetooth radio. One approach would be to treat each of these many possible infotainment system features as its own attribute, as shown in Fig. 7.20.

This solution requires that we considerably extend the number of attribute rows (each containing only a YES or NO indicating the presence or absence of an individual feature). While this solution might work for a small number of attributes and features, a better approach is to regard the (in this case) infotainment systems attribute as set-valued. In other words, each infotainment system can contain a different subset of the four possible values from the set {Navigation, TrafficInfo, iPod/MP3, Bluetooth}. The count of each of those values can be summed across all the subsets and shown as a somewhat different-looking bargram as in Fig. 7.21. We can still see right away, as before, that Bluetooth is the most common of the infotainment system features in this collection of cars.

A user could now explore the data (Fig. 7.22) by, for example, selecting iPod/MP3 and noting that 2 of the 5 cars offer this feature in their infotainment system but, interestingly, Bluetooth, Navigation, and TrafficInfo are still available as well

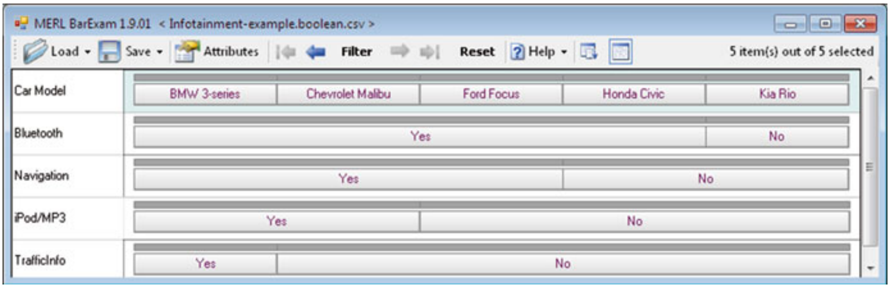

Fig. 7.20 A user explores the data by selecting iPod/MP3, which narrows the set of cars to just two, but other infotainment features are still available

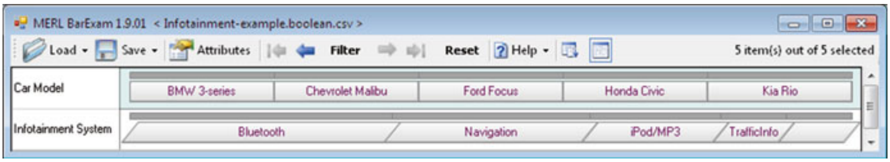

Fig. 7.21 Features of a car infotainment system where each is treated as a Boolean attribute

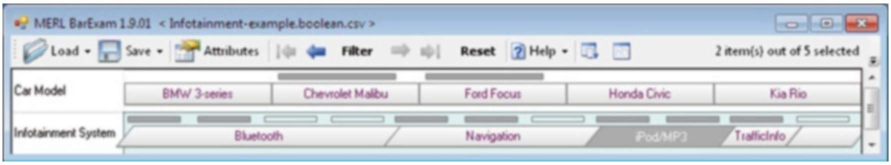

Fig. 7.22 Features of a car infotainment system where the attribute is set-valued and the number of individual values are each counted and shown as a somewhat different-looking bargram

(noting that the item vectors are solid). Users could explore further by selecting each of those other desired features in turn and see what car models remained. The significant point is that each item can contain one or more values from a set-valued attribute so restricting the items to include one value doesn't necessarily rule out other values. In this sense, set-valued attributes behave differently than other types of attributes, and thus the designers determined that it was best to make set-valued attributes look different.

What we have just seen is a toy example, but consider a database of movies, for example, whose attributes might start with genre, length, rating, and actors. There are almost always more than one actor per movie and the total set of actors in the database could easily number in the hundreds. Handling set-valued attributes in the way just described is one step towards an interactive design solution for choosing a movie based on multiple attributes that might include set-based attributes like actors.

7.2.12 Evaluation

The designers also performed an evaluation study of the design solution above. They asked a group of subjects whether they thought that using the different-looking bargrams for set-valued attributes as shown in Figs. 7.21 and 7.22 was preferable to using the same rectangular design as other attributes. The answer was clearly yes. The subjects also participated in a general usability study using the system on two types of tasks: (1) choosing a car based on price, length, warranty, and gas mileage and (2) comparing warranties offered across a similar class of vehicles. The subjects were asked to rate general satisfaction, confidence in the outcome, and likelihood of future use, all using a Likert scale [1–7]. In all cases, the results were positive.

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7.3 Web Browsing Through a Keyhole

7.3.1 Seeking News

'Keeping up with the news' is a familiar activity and often achieved by tuning into one of many available news channels. However, it is increasingly common to view news on the display of a mobile telephone or a PDA, thereby freeing the user from any constraints on location. But the display area available on these devices is very much smaller than that on a conventional monitor, giving rise to many design challenges. An example of how they can be addressed is provided by this case study: it specifically explores the problem faced by a user who, using a PDA, wishes to assess rapidly the nature of 10 or 20 news items so that one that is of interest can be selected without undue delay.

7.3.2 The Problem

On a monitor of conventional size, a web page such as that shown in Fig. 7.23 offers a collection of news items. Where a graphical picture and brief text constitute a link to more detail we shall refer to a 'link preview'. Without interaction (i.e. with 'passive interaction' as defined in Chap. 5) it allows the perusal of content sufficient to enable a user to choose an item of interest. If the available display area is much smaller, however, as it is with a PDA, the same approach to assessment and the formation of scent cannot take place, simply because the entire page cannot be perused without interaction of some sort.

One approach is to allow scrolling over the unchanged page. This is generally unacceptable in view of the time necessarily required to view content as well as navigational cues (SM and SI as introduced in Chap. 5). As well as having to engage in tedious scrolling activity the user must attempt to remember the content and cues from previously explored parts of the page.

Another approach is to avoid the need for scrolling by eliminating all or most of the graphic content of the page and providing simple textual links to news items, as shown in Fig. 7.24. Unfortunately, pictures or icons often provide many of the principal navigational cues and their absence could severely diminish the user's ability to formulate scent sufficient to help him or her to decide which news item is relevant to his or her interest.

Fig. 7.23 A typical news page, with a link preview identified by the green box

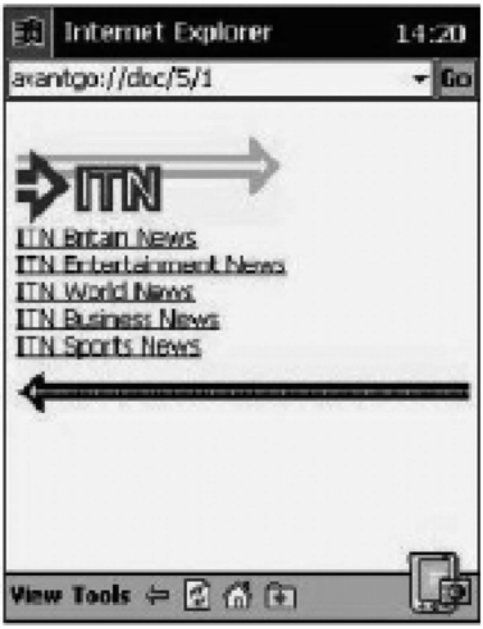


Fig. 7.24 The removal of graphic content to provide a complete menu in the display area, without the need for scrolling (*Courtesy Oscar de Bruijn and Chieh Hao Tong*)

Not surprisingly, a number of researchers (Woodruff et al. 2001; Cockburn et al. 1999; Ayers and Stasko 1995) have examined the benefit of using thumbnail images, in the form of reduced-size copies of target pages, to represent hyperlinks (i.e. SM and SI). Thumbnails can indeed provide powerful navigational cues, but Kaasten et al. (2002) showed that, for them to be useful, a significant fraction of the screen area would have to be dedicated to the display of these thumbnails. With mobiles and PDAs there is simply not enough display area available.

7.3.3 A Solution

To overcome the problems posed by small screen areas while at the same time retaining the powerful navigational cues offered by well-designed images, de Bruijn and Tong (2003) explored the potential of rapid serial visual presentation (RSVP) described in Sect. 4.2. Basically, instead of presenting a user with a single display containing a complete collection of link previews, those previews are instead presented *sequentially* (Fig. 7.25). As a consequence, each link preview can now occupy the *entire* display area; indeed, roughly the same room for graphics and brief text is provided as was the case with a conventional web page (see Fig. 7.23). This design choice is the major decision taken in this case study.

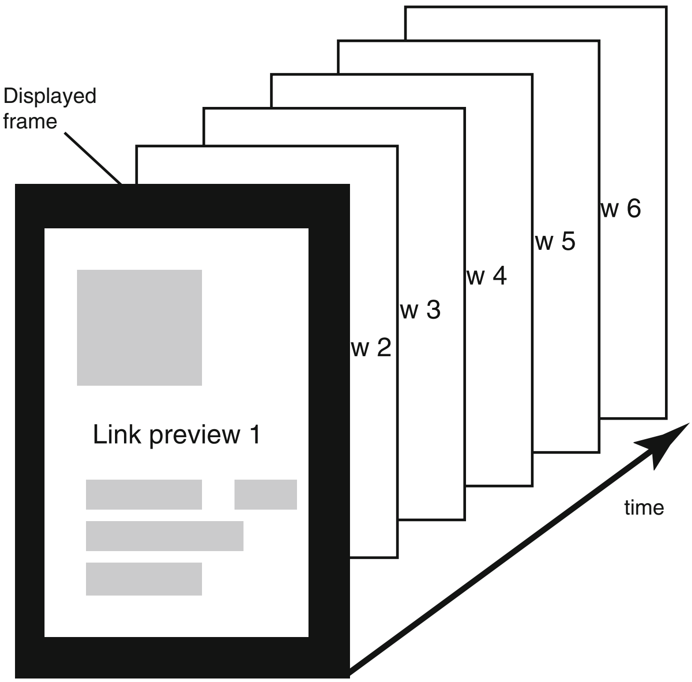


Fig. 7.25 The sequential presentation of link previews, each occupying the full available display area

Even with the decision to explore the sequential rather than concurrent display of link previews, many problems were still faced by the investigators, most again arising from the limited display area. While the sequentially presented previews provided valuable navigational cues, other issues of navigation and interaction had to be addressed.

The application chosen as the context in which to explore the potential of RSVP is a scenario in which a user either wants to see what news is available or has a particular interest and wishes to see whether any news channel addresses that interest.

7.3.4 The RSVP Browser

The structure of the experimental system called the RSVP Browser is shown in Fig. 7.26. In effect it provides a two-level menu system in which the available choices at each level are presented in slide-show RSVP mode rather than statically. Thus, any news item is represented by two link previews. An example of a link preview and the associated news item is shown in Fig. 7.27. In fact, the design of each link preview need differ very little from the news item's representation on a larger screen. Indeed, as far as the user's visual processing system is concerned, the effect

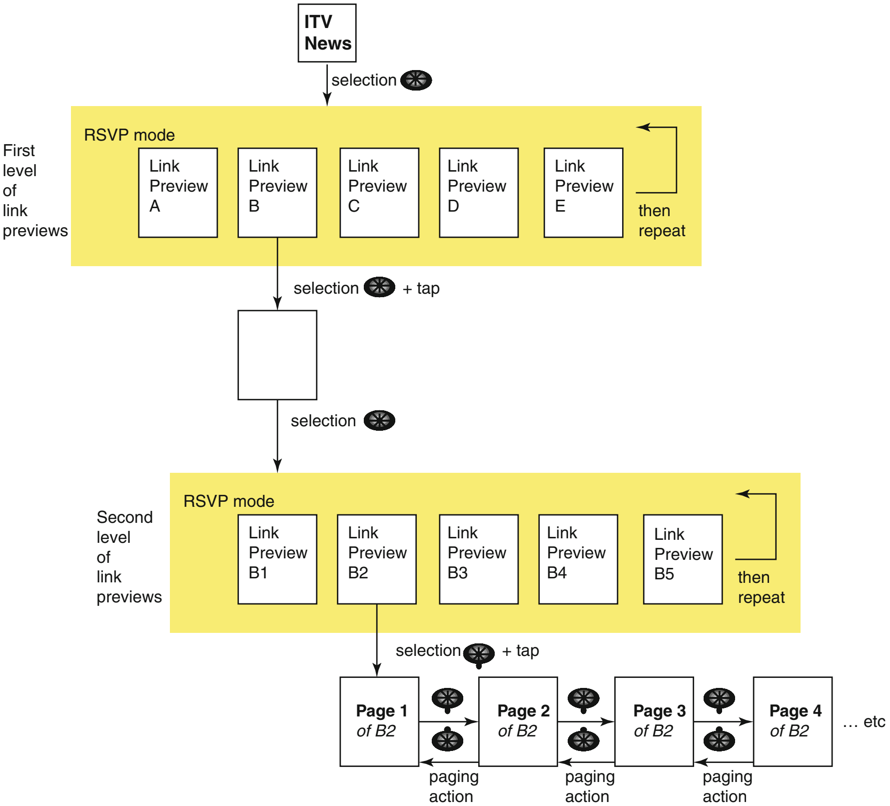


Fig. 7.26 Schematic diagram of the operation of the RSVP Browser. On two levels the presentations are in slide-show mode and continue until stopped. Icons indicate the interaction required with the main control button of the PDA employed. The effect of interactions is discussed in more detail later and illustrated in Fig. 7.28

Fig. 7.27 (**a**) The link preview mode and (**b**) the page mode of a news story. The news story can contain more than one page (*Courtesy Oscar de Bruijn and Chieh Hao Tong*)

of a sequential presentation of the link previews of Fig. 7.26 is very similar to that of the succession of images presented to the foveal region as the user scans a larger page such as that of Fig. 7.23. It can in fact be argued that the sequential presentation removes the need for the user to formulate an eye-gaze strategy and provides more time for each news item to be interpreted. As de Bruijn has pointed out:

> … reading content and following links are activities that can effectively be separated.

The initial view presented to a user is a static page titled 'ITV News'. A command initiates the slide-show presentation of link previews at the first level, a presentation that continues cyclically until the user stops it at a chosen preview (B in Fig. 7.26). After initiation, the second slide-show mode continues until stopped at the chosen news item (B2 in Fig. 7.26), whereupon appropriate commands allow the news item to be read, and support paging if the news item extends to more than a single page.

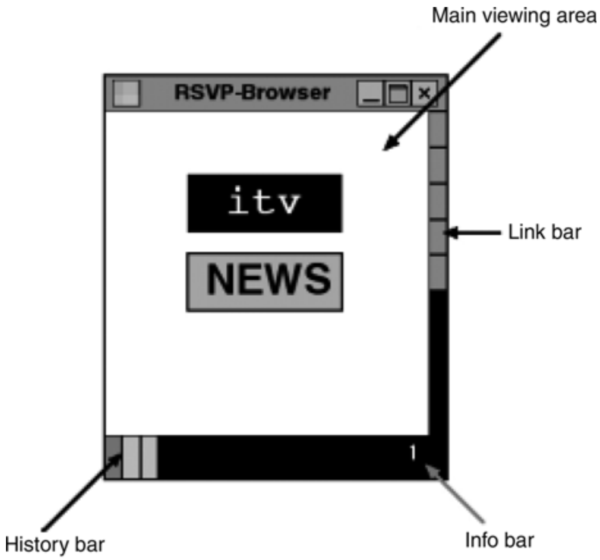
7.3.5 System Design

A major decision for the investigators concerned the amount of time for which each link preview should be visible. Too short a time would not enable the preview to be interpreted satisfactorily, while too long a time might be frustrating for the user. A value of half a second was chosen, a decision partly – though not wholly – justified by preferences expressed by users and discussed later in this case study.

Although the link previews were designed to provide powerful navigational cues, other features to enhance navigation were introduced. First, 'universe visibility' was supported by a link bar (Fig. 7.28) containing a small rectangle for each link. To support an awareness of where in the sequence the currently displayed link preview is, the appropriate rectangle is highlighted, thereby providing some indication as to when the user might halt the sequential presentation to select a desired link. Whereas link previews help to answer the question 'Where can I go from here', the developers were also well aware of the finding by Tauscher and Greenberg (1997) that a history of steps already taken provides a powerful and highly desirable navigational aid: in the RSVP Browser this information is embodied in a 'history bar' (Fig. 7.28) in which small rectangles represent already visited pages. An information bar also provides useful navigational information: in link preview mode the bar shows the position of the currently displayed preview in the sequence, whereas in page mode it shows the position of the currently viewed page in the sequence of pages comprising a news item.

The investigators took advantage of the control buttons associated with a PDA (Fig. 7.29) to explore the possibility of single-handed user interaction with the

Fig. 7.28 The link bar, history bar and information bar designed to assist navigation (*Courtesy Oscar de Bruijn and Chieh Hao Tong*)



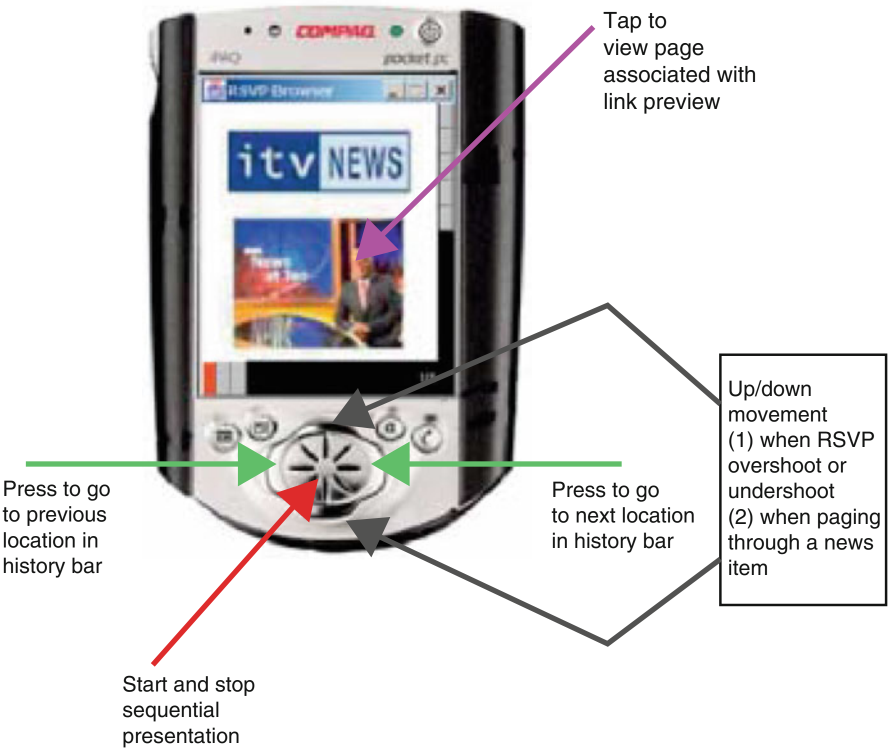


Fig. 7.29 Navigational controls of the RSVP Browser

RSVP Browser. Most of the functionality of the final version of the Browser was accessed using the four-directional pad near the bottom of the PDA, thereby avoiding problems associated with stylus-based interaction: the latter can give rise to the need for two-handed operation and for considerable accuracy when touching the screen.

7.3.6 Evaluation

The RSVP Browser was evaluated by comparing it with the pocket version of the Microsoft Internet Explorer (Pocket IE), both implemented on a Compaq IPAQ PDA. Thirty subjects were involved in an experiment in which they were asked to retrieve information from a set of five news items. In this way the investigators were able to explore the RSVP interaction mode within the constraints of an existing handheld device and test it against the benchmark offered by an existing and familiar browser operating under the same constraints.

Half of the 30 subjects were randomly assigned to use the RSVP Browser and the other half to the Pocket IE. The tasks given to experimental subjects were chosen to be realistic and independent of the device to which they were assigned. Each subject answered a series of eight questions, of which a typical example is:

> The cross-border train link between Belfast and Dublin has been closed after several explosions were heard near the line. Has the cause of these explosions been identified?
> [Answer: No]

The procedure adopted in the evaluation is of interest (Fig. 7.30). Initially, the subjects were given no instructions as to how to use either the RSVP Browser or the Pocket IE. This enabled the experimenters to gain some idea of the effect of a new mode of operation and to compare use at the beginning and end of a series of eight tasks. After answering the first of eight questions subjects could ask the experimenter for advice when answering questions 2–6. Then, for the remaining two questions, no advice was available to a subject. This scheme (Moyes and Jordan 1993) yielded interesting insights. Video recordings were made of the actions made by subjects so that certain aspects of interaction could later be evaluated. We deal first with measurable performance and then with preferences expressed by users.

Q 1	Q 2 to Q 6	Q 7 and Q 8
No instruction given	Subject could ask experimenter for advice	No advice available to subject

Fig. 7.30 Advice available to subjects taking part in the experimental evaluation of the RSVP Browser

7.3.6.1 Time to Solution

Not surprisingly, the time required to find the answer to the first question was an average of five times longer for the unfamiliar RSVP Browser than for the conventional Internet Explorer (Fig. 7.31). However, following the performance of six tasks, there was no statistically significant difference between the two devices.

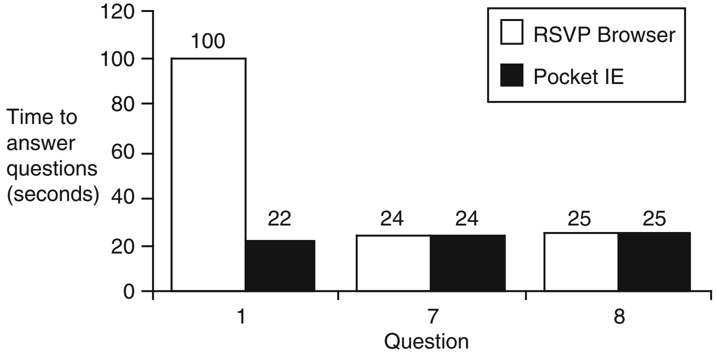


Fig. 7.31 The average times (rounded to the nearest second) needed to answer questions 1, 7 and 8 for subjects using the RSVP Browser compared with Pocket IE

7.3.6.2 Number of Steps

Figure 7.32 shows the number of unnecessary steps taken during the task of finding answers to questions 1, 7 and 8. An example of an unnecessary step is where an incorrect link preview is selected. What is plotted vertically is the number of unnecessary steps divided by the minimum number of steps. Again we see that familiarity acquired with earlier tasks resulted in essentially no difference between the RSVP Browser and Pocket IE in this respect.

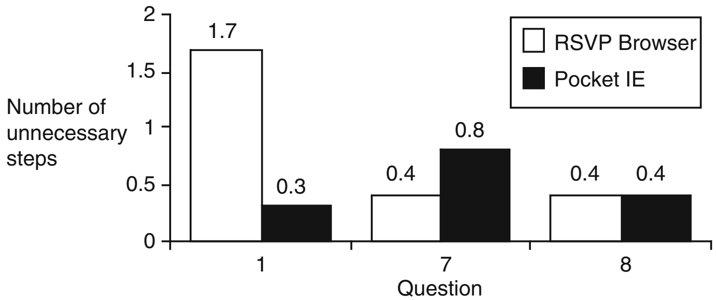


Fig. 7.32 The mean number of extra (unnecessary) steps taken by subjects in finding the answers to questions 1, 7 and 8 using either the RSVP Browser or Pocket IE

7.3.6.3 Personal Preferences

As is normal in any evaluation of usability, subjects were interviewed to elicit information that cannot be measured. After finding the answers to eight questions, subjects were asked about their subjective experience of the browser they used by answering a number of questions in a questionnaire. For example, the question ‘Did you find it easy to retrieve the answers to the questions?’ could be answered by selecting one of the following five alternatives: ‘Very easy’, ‘Easy’, ‘Indifferent’, ‘Difficult’ and ‘Very difficult’.

Participants either found the speed of the RSVP action (two per second) fast or thought it was about right (Fig. 7.33). A presentation time of 500 ms is, of course, much longer than the approximate minimum of 100 ms required for the recognition of a known target (see Sect. 4.2) but this is to be expected since some considerable interpretation and evaluation must take place to decide which news item may be relevant to the question whose answer is sought. However, user feedback evidently suggests that 500 ms would be a minimum for the RSVP Browser. In practice, it would probably be wise to allow the user to preset their own preferred slide-show rate.

The questionnaire also revealed that more subjects who used the RSVP Browser were either confident or very confident that they knew all the functions of the browser compared with subjects who used Pocket IE.

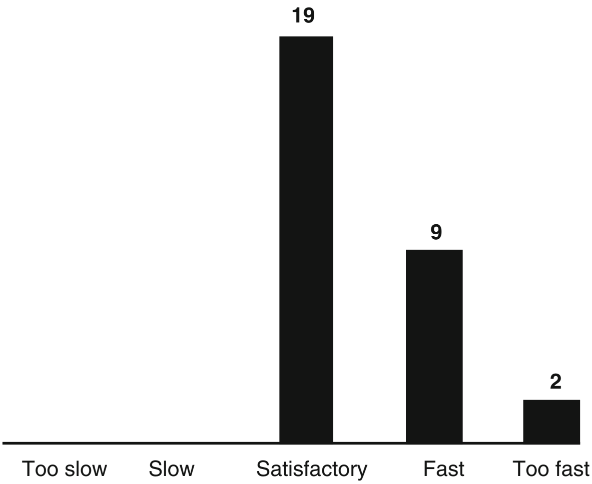


Fig. 7.33 Subjects’ perception of the speed of the RSVP presentation

7.3.7 *Discussion*

Both the performance measures and the subjective ratings seem to indicate that unfamiliarity with the concept underlying the RSVP Browser initially put it at a disadvantage compared with Pocket IE. That is, it appears that the Pocket IE interaction model conforms more closely to what people expect from interacting with a

PDA. Nevertheless, when subjects were given time to gain experience with the RSVP Browser with or without help from the experimenter, this initial disadvantage disappeared and a number of advantages of the RSVP Browser over Pocket IE became apparent. Indeed, it seems that breaking up stories into separate pages in the RSVP Browser may significantly reduce the effort required for scrolling through text documents. Moreover, the simplicity of the interaction model underlying the RSVP Browser ensured that very little training was required to make users feel confident that they knew all the options the RSVP Browser had to offer.

7.3.8 Comment

As with the other case studies, a valuable aspect of the present one is that it serves to emphasize that the factors affecting design are numerous. As a consequence, at the time of writing there is still debate about the best approach to the task of viewing a web page on a PDA or mobile. At the very least the case study has shown that RSVP offers a viable alternative to the standard web browser for pocket PCs. However, the investigators acknowledge that their study leaves interesting questions to be explored.

There are other technical considerations that impinge on the feasibility of employing RSVP in the manner described, including considerations of server-client architecture and the development of web standards. The reader who wishes to dig deeper is referred to the principal reference for further details and discussion.

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7.4 Communication Analysis

7.4.1 Command and Control

Communication is crucial to many activities and especially to the command and control of distributed safety-critical human activities such as firefighting, law enforcement and military operations. In these environments, multiple teams operate at separate locations under hazardous conditions to achieve common goals. The messages that are generated are not only essential to a successful outcome but also provide an observable trace showing how key actors performed. In this way, *communication analysis* can yield information of considerable value to the later redesign of a command and control system.

Morin and Albinsson at the Swedish Defence Research Agency created a system, called MIND, to facilitate communication analysis and have used it to support systems development, performance evaluation and training. Briefly, MIND supports two principal activities, *reconstruction* and *exploration*. The former involves several steps for constructing a multimedia model of the course of events in a distributed work session, a model that involves audio, video, photographs, statements, log files and position data from multiple sources in the operational environment. Exploration – the focus of this case study – refers to the rendering of this data in a tool that supports its explorative analysis.

7.4.2 System Requirements

What are the requirements for such a system and what sort of questions may be asked of it? Certainly, contextual data must be preserved and be available: full understanding requires awareness, not only of the message sent but also of the *situation* in which it was sent. Contextual data must, as we saw in Chap. 4, also be available to support an analyst's navigation through a mass of data. A major problem is that of formulating – or even knowing – relevant questions to ask and suggests that queries should be dynamic. This is important when designing complex socio-technical systems where problem *setting* and problem *solving* are inherently intertwined. Often, questions cannot be anticipated, so that flexible support for analysis is required. Rapid response is also required for questions such as 'Where are the actors?', 'What are they doing?', 'What tasks have they been assigned?' and 'What is the status of the communication system?' The ability to rapidly explore the data sets and view them from different perspectives provides opportunities to both answer questions we want to ask and identify the questions we should ask.

7.4.3 The MIND Tool

With the above and other requirements in mind, the investigators developed context-preserving methods and exploratory tools for communication analysis for the domain of emergency services and military operations, in order to identify commanders' information needs in command and control. Of particular interest in the context of this book is their choice of the Attribute Explorer discussed in Chap. 3 to support the analysis of complex and extensive communication data. The example employed below to illustrate the interface of the MIND tool is taken from a military exercise.

7.4.4 Exploratory Analysis

Within the MIND system the Attribute Explorer facilitates the exploration of recorded communication data. This vital component of MIND is illustrated in the simple example of Fig. 7.34, which refers to just three dimensions of some

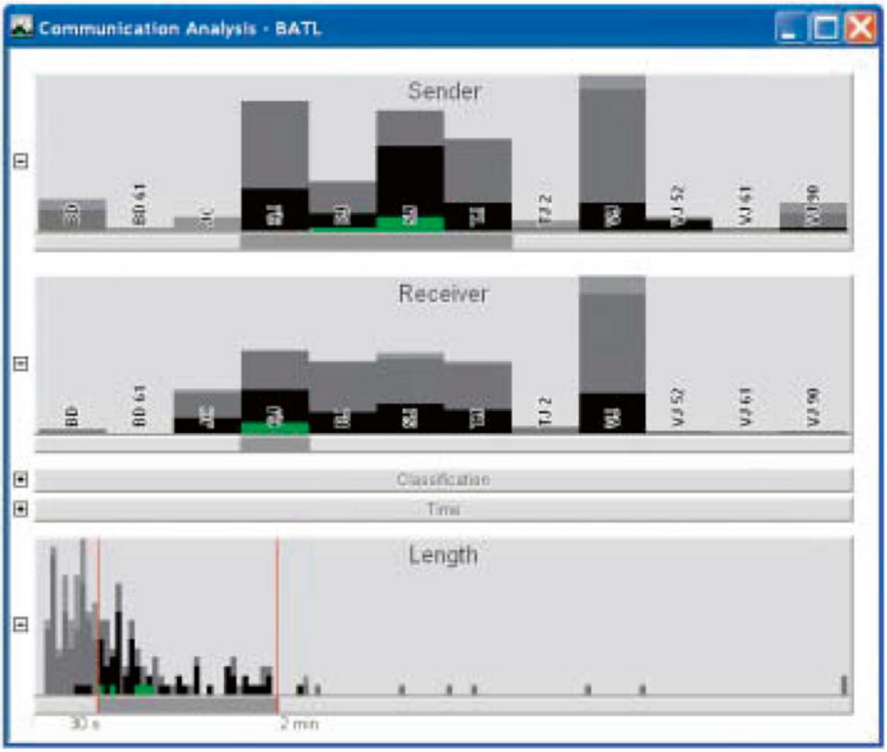

Fig. 7.34 Simple illustration of the application of the Attribute Explorer technique to the study of communication system use

communication data. It is being used to allow examination of the communications received by a company commander *QJ* initiated by any of the other companies, as well as communication sequences that are fairly long. As shown in Fig. 7.34, four companies have been selected in the sender dimension, *QJ* in the receiver dimension and the range from 30 s to 2 min in the length (time duration) dimension. The green elements disclose that *RJ* and *SJ* initiated the communication and that the sequences are in the shorter half of the selected length range. Colour coding provides additional contextual hints. For example, the black elements outside the selected limits in the length dimension represent communication links that fail in this dimension only, indicating that *QJ* did receive some shorter messages as well as a few longer ones, but no considerably longer ones. Furthermore, elements in shades of light grey – for example the unit *JC* in the sender dimension – represent communication links far from a hit, which reveals that *JC* never initiated any communication to *QJ*.

7.4.5 Scenario

As mentioned, the Attribute Explorer is only one, albeit important, component of the MIND system, one of whose advantages is its integration of multiple representations of data. Another component representation is the node-link diagram familiar from Chap. 3. A brief description of the use of MIND in the context of a military exercise will illustrate those representations and further illustrate the advantages, for the analyst, of the Attribute Explorer.

Figure 7.35 shows the interface of the MIND system and illustrates how an analyst follows a company carrying out a task during a particular period of time. The period, of about half an hour, is selected in the Time dimension. By limiting the sender dimension to include only the company of current interest (*TJ*), by restricting the receiver dimension to include only the supervisors of *TJ* on the battalion staff, and by selecting ‘reports’ in the classification dimension, we see how *TJ* sent regular progress reports (represented by green elements in the time dimension). These reports are immediately accessible in the list of hits at the lower left part of the MIND interface, enabling the analyst to review and replay the original communication as well as synchronizing other MIND views to a specific communication. The interface also provides a map view of the geographical situation at the time of the selected communication. A node-link view at top right shows the accumulated report communication at the time of the selected communication. The Attribute Explorer provides other hints as well. For example, *TJ* reported only to its supervisors (three of them), which is clear from the fact that there are no black elements outside the limits of the receiver dimension. Moreover, *TJ* initiated only report communication during the selected time period, since there are no black elements outside the applied limits in the classification dimension. Examining the length dimension we also see that all reports were short except for one that was considerably longer: that link represents a concluding summary report of the company’s progress.

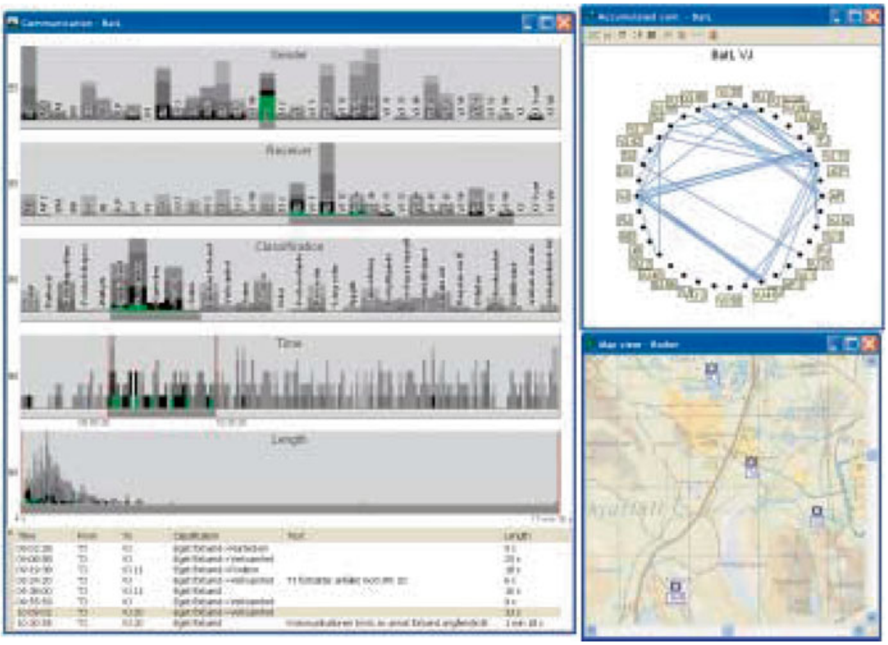

Fig. 7.35 The interface of the MIND system designed to support the analysis of communication behavior

7.4.6 Football

The application of the Attribute Explorer to the study of communication in the context of emergency situations was later extended to the field of sport (Albinsson and Andersson 2008) and, concurrently, led to an extension of the Attribute Explorer.

The analysis of team-sport data is an increasingly important activity in professional sports such as football, rugby and baseball, motivated by the fact that many such sports are both highly competitive and globally lucrative. There is motivation, therefore, to provide an investigative tool that will lead to an improvement in team capability through the development of effective training methods. The underlying concept of the Attribute Explorer was found to be relevant to such fields, but necessary extensions were suggested by the nature of team sports.

Taking football as an example, events that must be addressed include passes, shots, interceptions and ball runs, all of which are functions of time. The attributes involved include the various actors (i.e., players) (often in pairs, as with passes), location, quality and distance. The nature of football is such that certain events lead to new demands upon the Attribute Explorer. For example, data elements must be allowed to have multiple values: thus, a pass can also be a header, and a shot might also be a free kick. It also became clear, for example, that if an investigator wants to rule out all passes that are headers, a NOT selection should be added to

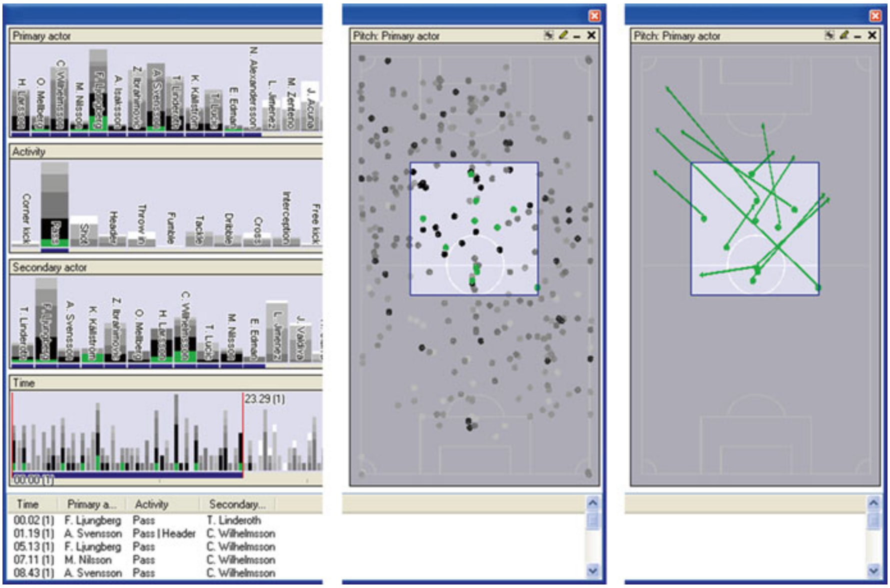

Fig. 7.36 A sample display from the extended Attribute Explorer

the existing AND and OR features of the Attribute Explorer. These and several other considerations arising from examination of the nature of football led Albinsson and Andersson (2008) to develop a visualization tool supporting the investigation of a football match, and validated it by entering data gleaned from a television record of an international friendly football match.

A sample display from the extended Attribute Explorer is shown in Fig. 7.36. Its components include the *primary actor* dimension (the whole team is selected), the selected *activity* (a pass), the selected *secondary actor* (again, the entire team), the selected *time* (the first 23 min) and the two-dimensional pitch (an area around the midfield is selected). To the right in Fig. 7.36 is an alternative pitch view of the same data where all passes satisfying the selections are shown as vectors. For more detail see Albinsson and Andersson (2008).

7.4.7 Conclusion

The use of many such interactive displays of captured data (Albinsson et al. 2003) allowed the defence authorities to identify information and support needs for commanders. The investigators valued the opportunity not only to find answers to existing questions but also to identify questions that should be asked, a feature of considerable importance when designing complex socio-technical systems where problem setting and problem solving are inherently intertwined.

They also pointed out that an annotated version of the data set can be used as a teaching tool.

The MIND framework has been welcomed as a helpful tool and is under constant development. One aspect of such future development is the potential for more powerful coordination between different views of data. With any development, of course, evaluation is always a consideration. However, the view expressed by the developers of the Attribute Explorer component of MIND makes the point that formal evaluations of the Explorer – to compare it with other techniques – could be a non-trivial task and hard to make ecologically relevant. ‘Instead of trying to rationally figure out if the approach is *ideal* or *true*, we make use of the fact that it is *real* and let the ongoing use provide insight into ends as well as means’, (Albinsson et al. 2003).

Principal References

Albinsson P-A, Andersson D (2008) Extending the attribute explorer to support professional team-sport analysis. Inf Visual 7:163–169

Albinsson P-A, Morin M, Fransson J (2003) Finding information needs in military command and control systems using exploratory tools for communication analysis. In: Proceedings of the 47th annual meeting of the human factors and ergonomics society, Santa Monica, CA. The Human Factors and Ergonomics Society, pp 1918–1922

Morin M, Albinsson P-A (2005) Exploration and context in communication analysis. In: Bowers C, Salas E, Jentsch F (eds) Creating high-tech teams: practical guidance on work performance and technology. APA Press, Washington, DC, pp 89–112

7.5 Archival Galaxies

7.5.1 Large Collections of Documents

There are many large collections of documents which users would like to explore or search according to some precise, vague or even unarticulated criterion. They range from personal collections of articles to the archives maintained by news organizations for the benefit of journalists. It was for the latter purpose that a visualization tool known as InfoSky was designed and implemented by a team drawn from the Know-Center Graz, Hyperwave and Graz University of Technology, all in Graz, Austria.

The aim of this case study is to illustrate the value of information visualization for the exploration and searching of document collections and to draw attention to the value of specialized algorithms to organize data spatially. As with the other case studies it is our intention to show how the nature of a task influences the design of a visualization tool.

7.5.2 Background and Requirements

The type of archive envisaged by the designers of InfoSky is exemplified by the one that was first used to demonstrate the system (Andrews et al. 2002). It is a collection of 109,000 German-language news articles already manually classified into 6,900 collections and sub-collections and arranged in a hierarchical structure up to 15 levels deep.

The InfoSky system had to satisfy the following principal requirements:

- *Scalability:* it should be possible easily to visualize hierarchically structured repositories containing hundreds of thousands and even millions of documents.
- *Hierarchy plus similarity:* it is desirable to represent not only the relationships between documents implicit in their hierarchical organization but, additionally, other similarities between individual documents not accounted for in the hierarchical organization.
- *Focus+Context*: it is desirable to integrate, smoothly, both a global and a local view of the information space.
- *Stability*: a stable metaphor should be used to promote visual recall and the recognition of features. The representation should remain largely unchanged at a global level even if changes occur to the underlying document repository at a local level.
- *Exploration:* Interactions involved in both browsing and searching the repository should be intuitive.

7.5.3 Earlier Work

About a decade before InfoSky was envisaged, a number of innovative schemes were proposed for the exploration and search of a collection of documents. Although it is unsurprising in view of their early emergence that they did not satisfy all the requirements imposed on InfoSky, it is nevertheless instructive to examine those schemes to establish their principal features.

- *BEAD* (Chalmers, 1993) – documents are automatically clustered according to their keywords and these clusters are then displayed in a 2.5D landscape with meta keywords indicating categories (Fig. 7.37). No manual classification is

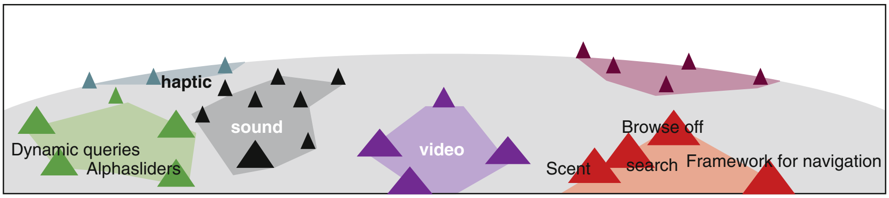

Fig. 7.37 A landscape representation of data about a collection of documents

Fig. 7.38 A themescape representation of 700 articles related to the financial industry

involved and no advantage is taken of any hierarchical relationships: the raw data is an unstructured repository.

- *SPIRE* (Wise et al. 1995) is illustrated in Fig. 7.38. Documents which are 'close' in high-dimensional thematic space are automatically transformed to be close in 2D space, with theme strength indicated by elevation. Again, the operations are performed on flat, unstructured repositories; any hierarchical relations that might exist are not exploited.
- The *hyperbolic browser* (Lamping and Rao 1994) has been discussed in Chap. 3 (Fig. 3.80, reproduced as Fig. 7.39). It offers an interactive representation of a hierarchical system, permits smooth exploration and directed movement within the hierarchy and, as a result of the distortion involved, allows the user to focus on a selected region of the tree while keeping sight of the context. Except for any *a priori* hierarchical organization, no account is automatically taken of content or keywords or other relationships between documents. No search facility is offered, though it could be incorporated.
- The *cone tree* (Robertson et al. 1991), discussed in Chap. 3 (Fig. 7.40), compactly represents a hierarchical system. There is, however, no means of focusing on regions of interest. Apart from the hierarchy, no account is taken of content or keywords or other relationships between documents. It supports interaction and a search facility is incorporated.

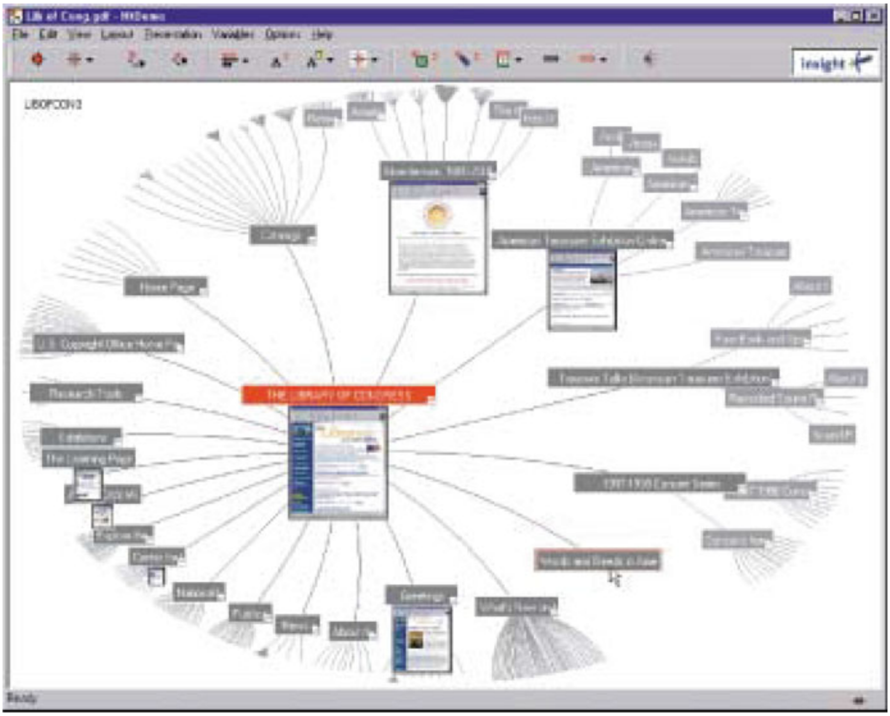

Fig. 7.39 A hyperbolic browser representation of a hierarchically ordered collection of documents

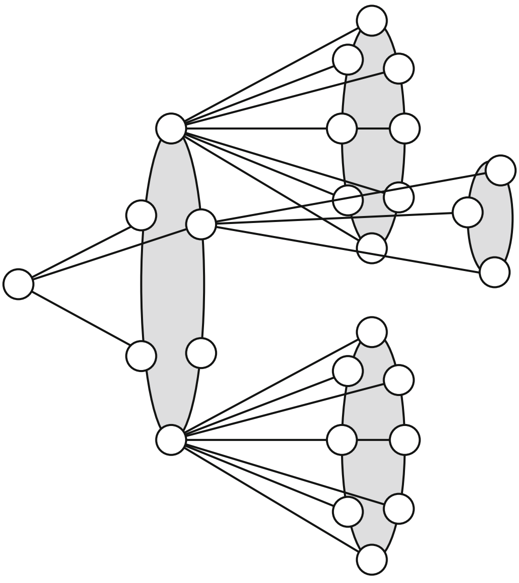

Fig. 7.40 The cone tree, tilted to allow the text associated with each node to be readable. Selective distortion could be applied to allow focus on any part

7.5.4 Design Decisions

With the above requirements in mind, the major decision made by the designers was to employ the metaphor of a *galaxy of stars* to represent the repository and its component documents; further, to employ the related metaphor of a *telescope* so that variable magnification, enhanced by *semantic zoom*, can facilitate exploration of the galaxy at any level of detail.

The top view of the galaxy is shown in Fig. 7.41, with each star representing a document. The galaxy illustrated in this case study is derived from a collection of approximately 109,000 German-language news articles from the German daily newspaper *Süddeutsche Zeitung*. The articles have been classified thematically by the newspaper's editorial staff into around 6,900 collections and sub-collections up to 15 levels deep.

Visible in Fig. 7.41 are the major collection titles (e.g. *Bundesländer Deutschlands*) forming the top level of the hierarchy. The corresponding subcollections lie within the piecewise-linear boundaries. The structure is the same all the way down the hierarchy. For example, in Fig. 7.42 the collection *Bundesländer Deutschlands* has been selected, prompting the segments within that collection to be centred in the display and the names of those segments to be displayed (e.g. *Bayern*). Selection of *Bayern* and a subsequent mouse-hover over *Wirtschaftsraum Bayern* highlights that collection (Fig. 7.43): selection then displays the appropriately centred next level of the hierarchy as shown in Fig. 7.44. This sequence can continue until document titles are eventually reached (Fig. 7.45).

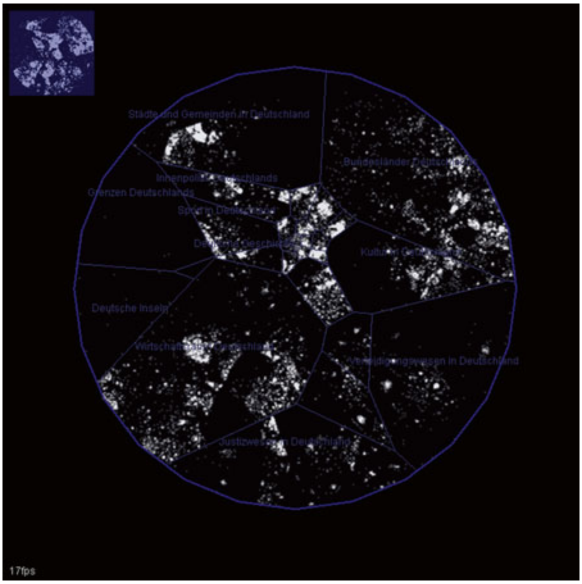

Fig. 7.41 View of the entire galaxy, showing collection boundaries and titles at the top level

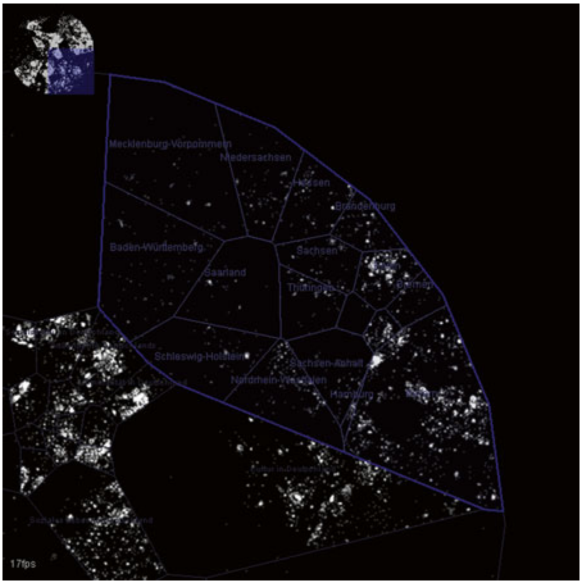

Fig. 7.42 View of the sub-collection *Bundesländer Deutschlands*

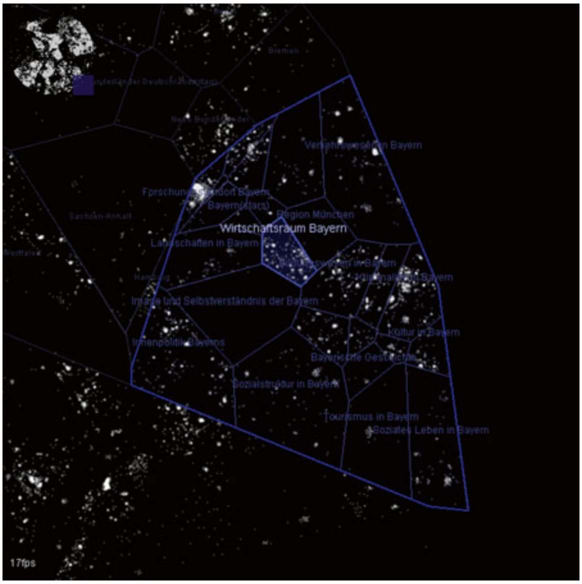

Fig. 7.43 The result of clicking on the title *Bayern* in Fig. 7.41 The mouse now hovers over *Wirtschaftsraum Bayern*

Fig. 7.44 The result of selecting *Wirtschaftsraum Bayern*

Fig. 7.45 At the lowest level titles are visible

7.5.5 Interaction and Search

Interaction with the galaxy is simple and consistent at all levels. A left mouse click on a collection title leads to semantic zoom to the next lower level, while a right mouse click reverses that zoom. Holding down the left mouse button causes continuous semantic zoom and allows users to reach a known position more quickly, an action that is helped by the fact that at each level of the hierarchy collections are contained within piecewise linear boundaries whose distinctive shapes make them easier to remember.

On receipt of a keyword, a search facility will highlight in yellow both relevant regions and relevant documents (Fig. 7.46): the latter pulsate to provide differentiation. In this way search results can be viewed in context.

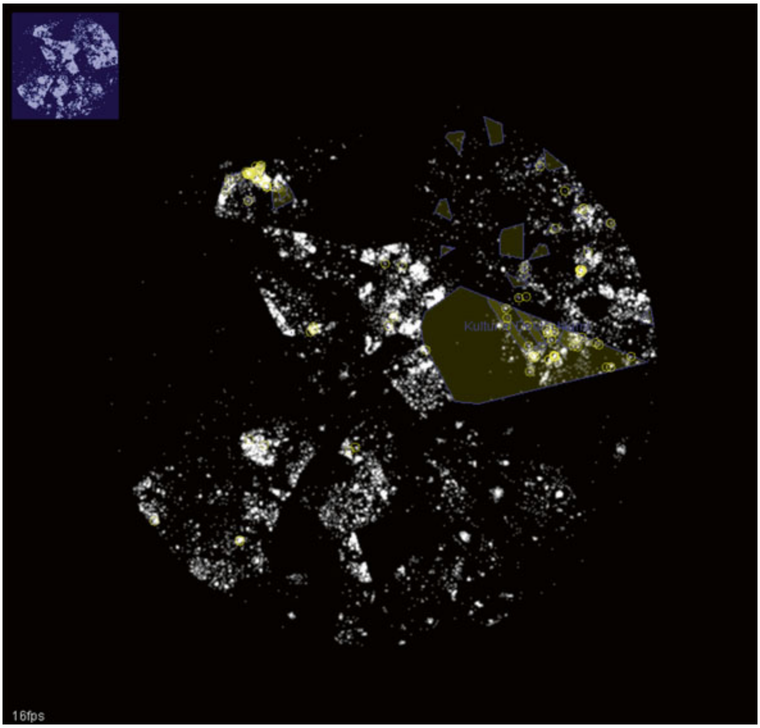

Fig. 7.46 Highlighting of both relevant regions and documents follows the entry of a keyword

7.5.6 Layout

The piecewise-linear boundaries defining the collections at each level of the hierarchy (Fig. 7.47) are determined by two factors. The size of each polygonal region is proportional to the number of subordinate documents in that collection. The position of the centroid of each region is influenced by the similarity between the documents within the sub-collections.

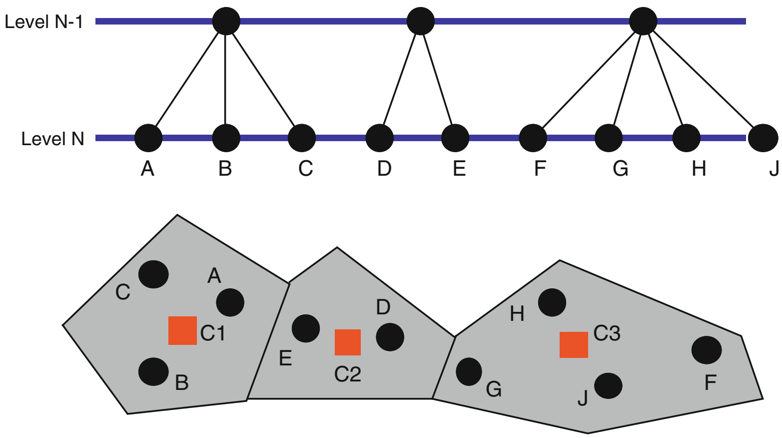

Fig. 7.47 Representation of collections at two levels of the hierarchy and, for the lower level, the layout of the collections (A, B, C, etc.) and their centroids (C1, C2, C3)

There are many algorithms that can compute the similarity between documents according to a specific criterion and others that can determine the piecewise-linear boundaries. In the present case study our principal intention in this respect is to draw the reader's attention to the fact that such algorithms, as well as the skill with which they are selected and applied, can exert considerable influence on the quality of a visualization tool. For the detailed nature of the algorithms the reader is referred to the principal reference.

7.5.7 Evaluation

The prototype InfoSky visualization tool was first formally evaluated by comparing its use with a conventional tree viewer whose appearance at the top level is shown in Fig. 7.48.

Eight subjects were divided randomly into two groups and were each invited to perform two equivalent sets of five tasks using both the InfoSky tool (called the Telescope browser TS) and the Tree Viewer (TV). They were not allowed to use the browsers concurrently, neither could they make use of the search facility. Two sets, each of two subjects, employed TS first and TV second; the other two sets used the browsers in the reverse order. The two sets of tasks were designed to be equivalent in the sense that their solutions lay at the same level of the hierarchy and involved approximately the same number of choices at each level. Again, the order in which the two sets of tasks were undertaken was evenly distributed over the sets of subjects and browsers. Two minutes of introduction to the Telescope Browser were provided before the experiment. The actions of the subjects were videotaped and

Fig. 7.48 Appearance of the conventional tree viewer at the top level

interviews took place after the tasks were performed. The time taken to locate a solution to each task was recorded.

Of the 80 task solutions (8 subjects, 2 sets of 5 tasks), allowing 40 comparisons of the task completion time, only in 8 cases was the solution found more rapidly with the Telescope browser. On average, the Tree browser performed better than the prototype Telescope browser for each of the tasks tested and this difference was statistically significant ($p < 0.05$). The average time taken for task solution with the Telescope browser ranged from 36 to 186 % greater than for the Tree browser.

The developers point to two principal reasons for the apparently disappointing performance of the Telescope browser. First, subjects had had many hours of experience in the past with traditional tree browsers and had become familiar with their metaphors and controls. The developers pointed out that, in comparison, 'two minutes' training could not make up the deficit'. Second, the Telescope browser was at a fairly early stage of development, with numerous bugs and issues affecting usability. Examples included small polygon sizes and 'jumping titles'.

The results of the evaluation should *not* call into question the inherent value of the galaxy and telescope metaphor, for many reasons. First, it was a prototype that was evaluated. Second, its use involved unfamiliar controls and metaphors. Third, the tasks did not test the value of the Telescope browser for finding related or similar documents or sub-collections. Fourth, the search facility was not provided to subjects. And fifth, concurrent use of the two browsers was not permitted in the evaluation. In view of all these constraints, the evaluation results are far from discouraging and the galaxy + telescope metaphor could eventually become a preferred method for browsing and searching large hierarchical collections of documents. The encouraging results of more recent evaluations can be found in the supporting references of Granitzer et al. and Kappe et al.

Principal Reference

Andrews K, Kienreich W, Sabol V, Becker J, Droschl G, Kappe F, Granitzer M, Auer P, Tochtermann K (2002) The InfoSky visual explorer: exploiting hierarchical structure and document similarity. Inf Visual 1(3/4):166–181

Supporting References

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Kappe F, Droschl G, Kienreich W, Sabol V, Becker J, Andrews K, Granitzer M, Tochtermann K, Auer P (2003) InfoSky: visual exploration of large hierarchical document repositories. In: Lawrence Erlbaum Associates, Proceedings HCI International 2003, pp 1268–1272

Lamping J, Rao R (1994) Laying out and visualising large trees using a hyperbolic space. In: ACM, Proceedings UIST'94, pp 13–14

Robertson GG, Mackinlay JD, Card SK (1991) Cone trees: animated 3D visualizations of hierarchical information. In: ACM, Proceedings CHI'91, pp 189–194

Wise JA, Thoma JJ, Pennock K, Lantrip D, Pottier M, Schur A, Crow V (1995) Visualising the non-visual: spatial analysis and interaction with information from text documents. In IEEE, Proceedings InfoVis'95, pp 51–58

Exercises

The value of these projects can be enhanced by having the outcomes presented in the following open class:

Each of the following design exercises will involve about 5 days of fulltime work by a group of three or four students. The objective is *not* to test programming skills but rather to consider a (possibly somewhat ill-defined) commission, decide the nature of the user(s) and the tasks, identify the design issues, make major decisions about a possible design and then describe that design. Continuous creative design and evaluation will be involved. Brain-storming and the production of many intermediate (hand) sketches (preferably maintained in constant view as in a real design house) are encouraged. An intermediate requirement is the *oral presentation* (with questions) by the group of progress to date (after about 2 or 3 days of design). The final requirement is an account of the group's work in *four pages* (no more) in ACM conference format: no additional appendices or figures or print-outs are allowed. The projects emphasize the use of information visualization, but not to the exclusion of other issues: they place information visualization in context.

Design 1 Flower Power

A company which owns a number of garden centres is considering whether to make it possible for customers to explore the products on offer via a large touch screen-operated display. Most of its customers have very little knowledge of plants and bushes or of the conditions necessary for their optimum growth. The company would like to see one or more possible designs for such an interface.

Design 2 What's Interesting?

Design a means of providing, on a PDA display, information about local services within a specifiable distance from the location of the PDA. Assume the PDA is fitted with a GPS or European satellite navigation system.

Design 3 Rail Travel

Select a major rail station. Design a printed display of train times to facilitate fast acquisition of travel information.

Design 4 Find that Photo

Most people possess a huge number of photographs and it is rare for them to be classified in any way except possibly by date. Finding one to show to a friend is difficult. Design an interface to support such a search. It can be for a mobile, a PDA or a standard monitor and an assumption can be made that pictures taken will be automatically classed according to date and location (via GPS). Recollections such as 'it was in Italy last summer …' should be considered.

Design 5 Journal Search

Given a research question in (say) biology, there are many scientific papers that could be relevant to one or more keywords and those keywords could be entered and removed according to their perceived relevance and the number of papers identified. Devise an interface to support the researcher.

Design 6 Postgraduate Study

Anyone contemplating postgraduate study must visit a large number of websites in order to come to some conclusion regarding universities to which a first approach might be made. Suggest a design for a website directed at such a person.

Design 7 Travel by Bus

In a major city such as London a bus ride can be a very pleasant way of travelling between one location and another. The major question is 'Which bus?' and the answer – especially where a change from one bus route to another is involved – is often difficult to find. Devise a bus map (for the centre of London, New York, Paris – the choice is yours) that will help the visitor to find a suitable bus route. It may be best to test your initial ideas with a small and fictitious city and to see how your ideas scale up.

Design 8 Online Shopping

A store that sells home furnishings (tables, chairs, beds, bookcases, carpets, lighting, etc.) requires a website to be designed so that customers can decide what purchases they wish to make. Suggest a possible design for that website.

Design 9 The Web on a Mobile

Web pages are large compared with the display area of a mobile. Also, there is usually no direct interaction device (such as a stylus) available with a mobile. Design a scheme that will allow web pages to be satisfactorily viewed and acted upon using a mobile or a PDA.

Design 10 Email Records and Their Exploration

Most users of email possess records of received and sent emails stretching back over a long time. First, make a list of tasks that the owner of such a record might want to undertake (aim for about ten) and the questions they might ask. Then, design an interactive representation of such records to support those tasks and questions as well as others that occur during the design.

Design 11 Mobiles for Very Young Children

Consider the possible advantages and disadvantages of making some type of mobile phone available for children between 3 and 5 years old and suggest some possible designs.

Appendix

Videos

Short videos (e.g. <5 min) and video clips (from 10 to 30 s) can lend very effective support to the teaching of information visualization.

The titles of 37 freely available videos and clips are listed below. Then, separately for each clip, the chapter within *Information Visualization* (Spence 2014) to which the clip is most relevant is stated, and an appropriate journal reference is given. There follows its format, file size and duration, as well as a discussion of the background to each video, the action that is to be seen and, briefly, the concepts that are illustrated.

V1	Qualitative Representation
V2	Dynamic Exploration of Relationships
V3	Encoding by Sound: a Brain Tumour
V4	Visualization 2020 AD
V5	Attribute Explorer
V6	Attribute Explorer: a short demo
V7	Infocanvas
V8	Interactive Venn Diagram
V9	The Cone Tree
V10	FundExplorer
V11	Bifocal Display I
V12	Bifocal display II
V13	Flip Zoom on a Mobile
V14	Distorted Map on a PDA
V15	Pliable display Technology on a Table
V16	Rubber Sheet Map Distortion
V17	The Perspective Wall
V18	Sunburst
V19	Combined Zoom and Pan

R. Spence, *Information Visualization*, DOI 10.1007/978-3-319-07341-5

V1 Qualitative Representation

Chapters 3.3 and 3.5

Spence, R. and Drew, A. (1971) Graphical exploration in electrical circuit design and modelling, NRC, Ottawa, Proc. 2nd Man-Computer Communications Seminar, pp. 61–70.

QuickTime Movie, 14.9 MB, 60 s

Background

MINNIE is an interactive-graphic computer-aided design system to facilitate the design of electronic circuits. It was created in 1968 and became a commercial product in 1985. The video dates to circa 1973.

Action

The size of each circle is a measure of the effect, on some property of an electronic circuit (here, its amplification), of small changes in the component on which the circle is superimposed. At any moment the display refers to one frequency in the range from bass to treble. Animation appropriately changes the circle sizes as an indicator (on right) moves through the frequency range from bass to treble.

Illustrates

Representation by size, especially where qualitative insight is important; the use of animation to handle an additional dimension (here, frequency).

Notes

A designer finds such sensitivity information extremely useful when deciding what component value to change if the circuit's performance is unacceptable. Also, since the designer probably has an a priori idea about the effect of each component, any departure from this (e.g., a large circle where a small one is expected) has a useful educational effect.

V2 Dynamic Exploration of Relationships

Chapter 5.4

Spence, R. and Apperley, M.D. (1974) On the use of interactive graphics in circuit design, IEEE, Proceedings of the International Symposium on Circuits and Systems, pp. 558–563.

QuickTime Movie 3.5 MB 38 s

Background

There are many occasions when an engineering designer can benefit immensely by being able to explore the relationship between some property of the artefact that is being designed and a single parameter whose value must be chosen. The designer's mental model of the relationship can be enhanced if the designer can manually vary the parameter value and immediately see the effect on the artefact's property.

Action

The clip, converted from a film (ca 1974) of the MINNIE CAD system for electronic circuit design, shows an electronic circuit designer exploring, interactively, the relation between the performance of an electronic circuit and the value of a component, by adjusting the value of that component continuously.

Illustrates

Responsive interaction; dynamic exploration.

V3 Encoding by Sound: A Brain Tumour

Courtesy Georges Grinstein, University of Massachusetts, Lowell, USA.

Chapter 3

QuickTime Movie, 15.8 MB, 1 min 14 s

Background

The term 'visualization' is usually interpreted, though incorrectly, to imply the sole use of visual images to represent data. Such use is indeed very common, but it is also possible to encode data by sound.

Action

The video demonstrates the encoding of data in sound in the context of the exploration of a brain scan. As a cursor is moved between different parts of the brain, the skull and a tumour, distinctive sonorities convey appropriate information.

Illustrates

The encoding of data by sound.

V4 Visualization 2020 AD

Chapter 3

Spence, R. (1995) Visions of Design, Journal of Engineering design, 6, 2, pp. 125–137.

QuickTime Movie, 9.88 MB, 45 s

Background

In 1995, 12 eminent engineering designers were asked for their visions regarding the way engineering design would be carried out 25 years later, in the year 2020. The visions were presented via a video showing a dinner party taking place in the year 2020, during which leading engineering designers of that year describe how they undertake design. One common vision had to do with the visualization of data, using large displays, collaborative working and the use of sound to encode data.

Action

Three designers involved in engineering design interact with visually and aurally presented data.

Illustrates

Collaborative working; visual and aural encoding of data.

V5 Attribute Explorer

Chapter 3.5.4

Spence, R. and Tweedie, L. (1998) The Attribute Explorer: information synthesis via exploration, Interacting with Computers, 11, pp. 137–146.

QuickTime Movie, 36.8 MB, 3 min 32 s

Background

There are many situations in which a user must select one object from among many on the basis of the values of a number of attributes. Typical examples include house and car purchase and the selection of a mobile phone to buy.

Action

For all objects, each attribute is displayed in the form of a histogram, and limits can be placed on an attribute to select a range and, consequently, the objects for which the attribute lies within the chosen range. When more than one attribute is explored, the histograms are linked so that a selection based on one attribute is 'brushed' into the other histograms. Through interaction with the attribute limits the user can form a mental model of the data and, gradually, whittle down the large number of objects to one or a few worth further and more detailed examination.

Illustrates

Dynamic exploration by direct manipulation; colour-encoded sensitivity to guide the user, especially in a 'zero hits' situation; the fact that a user will typically not be familiar with the data, and will therefore initially (qualitatively) explore to form a mental model before making a quantitative decision concerning objects worthy of further examination.

V6 Attribute Explorer: A Short Demo

Chapters 3.5.4 and 5.4.4

Spence, R. and Tweedie, L. (1998) The Attribute Explorer: information synthesis via exploration, Interacting with Computers, 11, pp. 137–146.

QuickTime Movie, 72.2 MB, 1 min 35 s (silent)

Background

There are many situations in which a user must select one object from among many on the basis of the values of a number of attributes. Typical examples include house and car purchase and the selection of a mobile phone to buy.

Action

This short clip (without sound) shows some of the major features of the Attribute Explorer.

Illustrates

Some major features of the Attribute Explorer; colour-coded sensitivity information.

V7 Infocanvas

Courtesy John Stasko

Chapter 3

Miller, T. and Stasko, J. (2001) Information Conveyance through personalised, expressive art, ACM, Proceedings CHI'01, pp. 305–306.

MPEG movie, 70.8 MB, 6 min 37 s

Background

There is often some information that a user might wish to refer to quite frequently without the need to do more than simply glance at a display: traffic conditions, the weather, stock prices, breaking news.

Action

The solution offered is to create, from a conventional monitor, a wall-hanging display in which information of interest is portrayed artistically within an attractive scene.

V8 Interactive Venn Diagram

Courtesy Ron Bird

Chapters 3, 5 and 6

Quicktime Movie, 15.1 MB, 58 s (silent)

Background

A Venn diagram need not be static: it can benefit considerably if it is interactive, allowing a user to flexibly explore the data.

When an interaction designer must convey an interface design to a client, much time can be saved if an animated presentation – NOT a fully implemented application – can be shown, especially since considerable modification to the design might well be suggested.

Action

The video illustrates, in a financial context, a design in which interaction allows Venn diagram representations of a body of data to be flexibly examined.

Illustrates

Venn diagrams; the use of an animated sketch when presenting a first proposed design to a client.

V9 The Cone Tree

Courtesy George Robertson, Jock Mackinlay and Stu Card

Chapters 3.6.2 and 5.3.8

Robertson, G.G., Mackinlay, J.D. and Card, S.K. (1991) Cone Trees: Animated 3D Visualizations of Hierarchical Information, ACM, Proceedings CHI'95, pp. 189–194.

Quicktime Movie, 10.5 MB, 1 min 5 s

Background

The representation of hierarchically structured data by means of a tree has the drawback that, as soon as the tree becomes realistically large, it is difficult to display it in its entirety on a conventional display. The Cone-Tree offers a solution to this problem. All nodes subordinate to a given node are arranged in a circle underneath it, the corresponding links thereby identifying a cone. Such a conceptual 3D arrangement, viewed on a 2D display, is called a Cone-Tree.

Action

The video shows that when a query is entered to identify one node of a tree, all cones revolve in such a way as to bring the relevant node to the fore. Most importantly, when another node is identified, the new view of the cone-tree does not appear immediately: animation lasting about 1 s ensures a smooth transition between the two views, thereby helping to maintain the user's mental model of the tree.

Illustrates

The cone-tree as a means of presenting hierarchically structured data; the use of animation to help preserve a mental model during a transition between two views.

V10 Fundexplorer

Courtesy John Stasko

Chapter 5.4

Csallner, C., Handte, M., Lehmann, O. and Stasko, J. (2003) FundExplorer: Supporting the Diversification of Mutual Fund Portfolios Using Context Treemaps, IEEE, Proceedings of Information Visualization 2003, pp. 203–208.

MPEG movie, 87.8 MB, 3 min 57 s

Background

An equity mutual fund is a financial instrument that invests in a set of stocks. Any two different funds may partially invest in some of the same stocks, so that overlap is common.

Action

The video describes a system called FundExplorer that implements a distorted treemap to allow a user to explore both the amount of money invested and the context of remaining market stock. The system allows people to interactively explore diversification possibilities with their portfolios.

Illustrates

Treemaps; interactive exploration; context.

V11 Bifocal Display I

Chapter 4.2

Spence, R. and Apperley, M.D. (1982) Data Base Navigation: An office environment for the professional, Behaviour and Information Technology, 1, 1, pp. 43–54.

QuickTime Movie, 2.78 MB, 13 s

Background

The Bifocal Display, invented in 1980, was arguably the first demonstration of the use of distortion to provide a focus+context view of an electronic information space. A user can focus on (e.g., read) one or two documents and, at the same time, have an overall view of the whole of the information space.

Action

The video (quality dates from 1980) shows a simulation of the scrolling action which brings a desired item from the distorted region into the focus region.

Illustrates

Focus+context; distortion; smooth transition from distortion to focus region; touch interaction.

V12 Bifocal Display II

Chapter 4.2

Spence, R. and Apperley (1982) (as for V11 Bifocal Display I)

QuickTime Movie, 12.2 MB, 60 s

Background

As for V11 (Bifocal Display I).

Action

A demonstration, using a paper representation of information space, of the concept of the Bifocal Display.

Illustrates

As for V11 (Bifocal Display I).

V13 Flip Zoom on a Mobile

Courtesy Ron Bird

Chapter 4.2

Holmquist, L.E. (1997) Focus+Context Visualization with Flip-Zooming and Zoom Browser, Exhibit, CHI'97.

Quicktime Movie, 11.7 MB, 1 min 57 s

Background

Many solutions have been proposed for the Focus+Context problem, a significant number involving distortion. The interesting feature of the Flip-Zoom technique is that equal X- and Y-distortion is used, so that what results in the 'distorted' region is a recognisable miniature, especially valuable if the item is an undistorted, albeit smaller, image.

Action

The clip shows an animated sketch prepared as a proposal by an interaction designer to a manufacturer of mobile phones. It presents a suggested (and accepted) means whereby the mobile user can scan through a collection of stored photographs.

Illustrates

The Flip-Zoom technique; presentation of an image collection; the use of animated sketches in the ‘proposal’ stage of interaction design.

V14 Distorted Map on a PDA

Courtesy David Baar

Chapter 4.2

Same reference as for V11 (BIFOCAL DISPLAY I).

AVI, 2.1 MB, 52 s

Background

The Focus+Context concept first embodied in the Bifocal Display, together with the technique of suppression, has been applied by IDELIX and are illustrated in the demanding requirement to present a useful map of Boston on a PDA.

Action

A user is seen moving rectangular areas around a (principally transportation) map of Boston, showing how parts can be selectively magnified and, concurrently, filled with appropriate data. It also shows to good effect the continuity between regular and distorted regions which is an essential feature of the Distortion technique.

Illustrates

Distortion, continuity; suppression.

V15 Pliable Display Technology on a Table

Courtesy Chia Shen

Chapter 4.2

Same reference as for V11 (Bifocal Display I). Videos V14 and V16 are also relevant.

Quicktime Movie, 15.9 MB, 3 min 1 s

Background

As for V11 (Bifocal Display I).

Action

The video shows an effective combination of distortion technology and an interactive table. A video projector positioned above a table projects on to the table surface a map. The map can, however, be distorted in a rubber sheet manner through the action of a user's fingers placed on the surface of the table.

Illustrates

Distortion; focus+context; interaction; collaboration.

V16 Rubber Sheet Map Distortion

Courtesy David Baar

Chapter 4.2

Same reference as for V11 (Bifocal Display I).

Quicktime Movie, 5 MB, 33 s

Background

The Focus+Context concept first embodied in the Bifocal Display, and the technique of suppression, have been applied by IDELIX and are illustrated in the context of exploring a conventional map. A magnification region is moved over a map, using distortion to maintain context, to a location of interest, whereupon a magnified portion of that map is presented.

Action

A highly magnified region is moved over a conventional map while maintaining full context and continuity. When a feature of interest is found, it and its immediately surrounding area are displayed conventionally.

Illustrates

Distortion; continuity; suppression.

V17 The Perspective Wall

Courtesy Jock Mackinlay, George Robertson and Stu Card

Chapter 4.2

Mackinlay, J.D., Robertson, G.G. and Card, S.K. (1991) Perspective Wall: detail and context smoothly integrated, ACM, Proceedings CHI'91, pp. 173–179.

QuickTime, 11.3 MB, 54 s

Background

See background for V11 (BIFOCAL DISPLAY I).

Action

Demonstrates, with a real implementation, the 3D effect characteristic of the Perspective Wall, the variable distortion, the encoding and the movement to bring a desired item into the central region.

Illustrates

Distortion of information space.

V18 Sunburst

Courtesy John Stasko

Chapter 3.6.2

Stasko, J. and Zhang, E. (2000) Focus+Context Display and Navigation Techniques for Enhancing Radial, Space-Filling Hierarchy Visualizations, IEEE, Proceedings of Information Visualization 2000, pp. 57–65.

MPEG movie, 37.9 MB, 3 min 53 s

Background

Radial representations of hierarchical data suffer from the problem that as the hierarchy grows in size, many items become small peripheral slices that are difficult to distinguish.

Action

Three techniques are demonstrated that provide flexible browsing of a radial representation, allowing the examination of small items in detail while providing context within the entire hierarchy.

Illustrates

Hierarchical data representation; focus+context techniques.

V19 Combined Zoom and Pan

Courtesy Andy Cockburn

Chapter 4.2

Cockburn, A. and Savage, J. (2003) Comparing Speed-Dependent Automatic Zooming with Traditional Scroll, Pan and Zoom Methods, in People and Computers XVII, pp. 87–102.

MPEG Movie, 30.8 MB, 3 min 5 s (silent)

Background

Zooming and panning are well-known techniques made familiar through cinema and television. A combination of the two, and especially where zoom takes place automatically according to the nature of a panning action, can offer advantages.

Action

The short video presents the technique of automatic scrolling during panning. It demonstrates two different forms of automatic zooming: Speed dependent zooming and displacement dependent zooming.

Illustrates

Automatic zooming during panning.

V20 Floating RSVP

Courtesy Kent Wittenburg

Chapter 4.4

Wittenburg, K., Chiyoda, C., Heinrichs, M. and Lanning, T. (2000) Browsing through rapid-fire imaging: requirements and industry initiatives, SPIE, Proceedings of Electronic Imaging, pp. 48–56.

MPEG movie, 6.1 MB, 30 s

Background

Rapid Serial Visual Presentation (RSVP) is a means of presenting a collection of images in rapid sequence and exploits the fact that the human being only needs sight of an image for around 100 milliseconds to be able to identify it as the image being sought.

Action

Shows a user browsing through a department store's contents using the Floating RSVP technique. Manual control allows the user to control the forward and backward movement of all the items, and to stop the display when an item of interest has been seen.

Illustrates

The Floating RSVP mode of image presentation; a situation wherein a user's goal may not have been precisely identified, and which benefits from the ability to explore rapidly.

V21 Image Browsing – Video on Demand

Chapter 4.4

Lam, K. and Spence, R. (1997) Image browsing – a space-time trade-off, Proceedings INTERACT'97, pp. 611–612.

Quicktime Movie, 21.4 MB, 1 min 55 s

Background

Riffling the pages of a book is quite an efficient – and very common – way of rapidly obtaining an overall understanding of the nature of that book. Electronic riffling can be an equally valuable means of browsing an information space. This method of presentation is called Rapid Serial Visual Presentation, or RSVP.

Action

The video shows how RSVP supports the act of browsing and how it additionally provides a trade-off between space and time, a trade-off of especial value when – as with a mobile or a PDA – available space is very limited.

Illustrates

RSVP; the activity of browsing; the space-time trade-off inherent in RSVP; a video-on-demand interface based on RSVP.

V22 Navigation via a Small Display

Chapters 4.4 and 5.3

de Bruijn, O. and Spence, R. (2001) Movement in the Web, Extended Abstracts, CHI 2001 Companion Proceedings, pp. 209–210.

QuickTime Movie, 34.1 MB, 2 min 22 s

Background

There is an increasing need to be able to navigate through vast quantities of information (e.g., the Web) via a small display such as that associated with a mobile or a PDA.

Action

A solution is to use the space-time trade-off provided by Rapid Serial Visual Presentation (RSVP). RSVP can be used both to look ahead at outlinks (i.e., images representing possible destinations one click away) and to look at 'footprints', images representing previously visited locations in information space.

Illustrates

RSVP; space-time trade-off; navigation.

V23 to V28 Image Presentation Modes

Chapters 4.3 and 4.4

Cooper, K., de Bruijn, O., Witkowski, M. and Spence, R. (2006) A Comparison of Static and Moving Image Presentation Modes for Image Collections, ACM, Proceedings AVI 2006, pp. 381–388.

AVI movies, about 5 MB each. Duration between 3 and 4 s each.

Background

Rapid Serial Visual Presentation (RSVP), involving the presentation of images in a rapid sequence, can take on many different forms. These video clips offer a selection and include, for comparison, the Tile image presentation mode in which all images are presented concurrently.

Action

A set of six very short clips showing image collection presentation modes (three 'static' modes followed by three 'moving' modes):

V23 Slide-show
V24 Tile
V25 Mixed
V26 Diagonal
V27 Ring
V28 Stream

Illustrates

The image presentation technique generally known as Rapid Serial Visual Presentation (RSVP).

V29 Involuntary Browsing with a Coffee Table

Chapter 5.5

Stathis, K., de Bruijn, O. and Macedo, S. (2002) Living Memory: agent-based information management for connected local communities, Interacting with Computers, 14, 6, pp. 663–688.

QuickTime Movie 14.3 MB, 65 s

Background

An important mode of interaction is that called Involuntary Browsing (IB). In IB, the user is unaware that an image on which their eye is temporarily fixated is being categorised and consolidated to see if is relevant to one of the user's interests.

Action

The video shows people engaging in conversation around a table on to which images describing local activities are projected. The images move slowly around the table and are eventually replaced by other images. If a person notices an information item that is of interest they can 'push' it, with their finger, into the centre of the table where it increases in size and provides more detail.

Illustrates

Involuntary browsing.

V30 Discovery via Dynamic Representation

Chapter 5.4

Spence, R. and Drew, A. (1971) Graphical exploration in electrical circuit design and modelling, NRC, Ottawa, Proc. 2nd Man-Computer Communications Seminar, pp. 61–70. (as for V1 Qualitative Representation)

QuickTime Movie, 4.77 MB, 18 s

Background

See V1 Qualitative Representation.

Action

See V1 Qualitative Representation.

Illustrates

how the unexpected can usefully occur in a visualization tool. Two circles suddenly expanding and contracting indicates a (usually) undesirable effect (resonance) in a circuit (similar to the destructive resonance of the Tacoma Narrows bridge). Subsequent manual variation of the frequency indicator can then identify the frequency at which resonance occurred.

V31 Influence Explorer

Chapter 5.4

Tweedie, L., Spence, R., Dawkes, H. and Su, H. (1996) Externalising Abstract Mathematical Models, ACM, Proceedings CHI'96, pp. 406–412.

QuickTime Movie, 47.8 MB, 4 min 53 s

Background

An engineering designer has to choose the values of a number of parameters to ensure that the corresponding values of some performances lie within prescribed limits. For the Influence Explorer a large number of designs are selected (i.e., parameter value sets are chosen to 'cover' a large exploratory region of parameter space) and the corresponding performances calculated. The Influence Explorer visualization tool then allows the precalculated data to be fluently explored in the same way as with the Attribute Explorer.

Action

The video relates to the design of a structure, about 4 in. long, which supports the filament of an electric lamp. The parameters, 4 in number, are various dimensions of the structure whereas the performances, also 4 in number, are the stresses at various points of the structure (Su et al. 1996).

Illustrates

Exploration to discover trade-offs between performances, and correlations between parameters and performances; the transformation of performance limits to the location of satisfactory designs in parameter space; the process of selecting tolerance ranges for the parameters with a view to achieving a high manufacturing yield.

V32 Model Maker

Chapters 3 and 5.4.4

Smith, A.J., Malik, Z., Nelder, J. and Spence, R. (2001) A Visual interface for Model Fitting, Quality and Reliability Engineering International, 17, pp. 85–91.

QuickTime Movie, 47.5 MB, 4 min 51 s

Background

A frequent requirement in scientific investigation, engineering design and data mining is for a mathematical relation to be fitted to measured or simulated data. This task is difficult for a user unfamiliar with statistics. The Model Maker 'hides' the underlying theory and algorithms and makes good use of the user's domain expertise.

Action

Each term in the mathematical model (e.g., a polynomial) is represented by a square. The circle inside each square indicates, by its size, how important the term is in achieving a good fit to the data. Black circles indicate terms already in the model, whereas white ones refer to terms which are not yet included in the model.

Illustrates

Encoding by size (value of term to the model); encoding by colour (term is already within model or not); direct manipulation (click on square) to include or remove term from model.

Notes

The interface displays the effect of all possible single changes to an existing model, and significantly reduces the statistical knowledge required to find a model.

V33 Human Guidance of Automated Design

Chapters 1.5 and 5

Colgan, L., Spence, R. and Rankin, P.R. (1995) The Cockpit Metaphor, Behaviour and Information Technology, 14, 4, pp. 251–263.

QuickTime Movie, 79 MB, 5 min 40 s

Background

So called ‘optimisation algorithms’ exist which, given an electronic circuit design, will automatically and iteratively change the values of its components so that the circuit is ‘better’ in some sense. However, such ‘automated design’ has many drawbacks: the human designer has no idea how the new circuit was obtained (were any significant trade-offs encountered, for example? could a vast improvement have been obtained if a parameter limit were minimally relaxed?) and it is far from easy to define ‘better’.

An optimisation algorithm can more effectively be employed if its progress can be monitored and, if necessary, modified, by bringing to bear the domain expertise of a human designer. The interface linking the optimisation algorithm and the human designer is called The Cockpit.

Action

Following an introduction showing the relevance of the topic to many areas of design, the video addresses, in some detail, the (real) task of improving the design of a circuit on a silicon chip.

Illustrates

The human guidance of automated design; encoding by size and colour; the complexity of a real visualization tool.

V34 Prosection Matrix

Chapter 5.4

Tweedie, L. and Spence, R. (1998) The Prosection Matrix: A tool to support the interactive exploration of statistical models and data, Computational Statistics, 13, pp. 65–76.

QuickTime Movie, 28.6 MB, 2 min 52 s

Background

As for the Influence Explorer, but the same precalculated data is now examined by means of a visualization tool called a Prosection Matrix. A prosection refers to a pair of parameters, and shows, by colour coding, the location of satisfactory designs in that 2-dimensional space, but only those designs selected by limits placed on the remaining parameters. In the same 2-dimensional space is shown a yellow rectangle defined by the tolerance on the two parameters, and within which all mass-produced versions of the design will lie. Thus, to achieve a high manufacturing yield, the yellow rectangles should be positioned to lie, as far as possible, totally within the red (acceptable) regions.

Action

The video provides a summary and demonstration of the Prosection Matrix.

Illustrates

The simplification of a difficult cognitive problem by replacing it with a simpler perceptual task.

V35 Dust And Magnet

Courtesy John Stasko

Chapter 5.4

Yi, J.S., Melton, R., Stasko, J. and Jacko, J.A. (2005) Dust & Magnet: multivariate information visualization using a magnet metaphor, Information Visualization, 4, 4, pp. 239–256.

QuickTime Movie, 46.6 MB, 4 min 46 s

Background

Data which is multidimensional in nature is difficult to represent in a manner that is easy to understand by the general population. Dust & Magnet is a visualization technique which uses a 'magnet' metaphor and appropriate interaction techniques, and allows a user to flexibly explore alternative objects on the basis of their attributes.

Action

The video presents many examples of the use of the Dust and Magnet interface, including unanticipated strategies employed by users.

Illustrates

A multidimensional and interactive representation technique; the exploration that often occurs when a user formulates questions as they explore the data.

V36 RSVP Browser

Chapter 4(2), 6(3)

DeBruijn, O. and Tong, C-H. (2003) M-RSVP: Mobile Web Browsing on a PDA, in O'Neill, E., Palanque, P. and Johnson, P. (Eds) People and Computers – Designing for Society, Springer, pp. 297–311.

V22 (Navigation via a small display) is also relevant

QuickTime, 2.2 MB, 7 s

Background

There is an increasing need to be able to navigate through vast quantities of information (e.g., the Web) via a small display such as that associated with a mobile or a PDA.

Action

The video illustrates the application of Rapid Serial Visual Presentation (RSVP) to the presentation of news items on the display of a PDA. The user sees a series of 'previews' each comprising an informative image and few but relevant words, so that the choice of a news item can be made without undue delay.

Illustrates

RSVP; space-time trade-off; navigation.

V37 Infosky Visual Explorer

Courtesy Keith Andrews

Chapter 7.5

Andrews, K., Kienreich, W., Sabol, V., Becker, J., Droschl, G., Kappe, F., Granitzer, M., Auer. P. and Tochtermann, K. (2002) The InfoSky visual explorer: exploiting hierarchical structure and document similarity, Information Visualization, 1, 3/4, pp. 166–181.

AVI Movie 25.2 MB 2 min 34 s

Background

There is an ongoing challenge posed by the need for users to visualise the structure and content of very large hierarchical databases. An example is a large collection of newspaper articles.

Action

The video demonstrates the use of the InfoSky visual explorer in the exploration and search of a hierarchically structured collection of over 100,000 newspaper articles. The Explorer employs a ‘galaxy and telescope’ metaphor. Exploration and search are additionally enhanced by the fact that articles are also positioned in space according to their similarity.

Illustrates

The galaxy and telescope metaphor; semantic zoom; algorithmic placement according to similarity of data items.

Glossary

Key:
Dict = dictionary definition
IV = definition in the context of information visualization

Attribute
Dict: a quality or characteristic belonging to a person or thing.

Attribute visibility (dimension visibility)
IV: representation of data such that the distribution of objects' attribute values in each attribute dimension is clear.

Breadcrumb trail
IV: representation of a path already traversed in discrete information space. (*Often loosely applied to paths that could be traversed.*)

Browse
Dict: [www.etymonline.com] 'peruse'.
IV: an activity involving the (usually visual) perception, interpretation and evaluation of content, including navigational cues.
Typically involves eye-gaze movement both during the perusal of a static display and during the perusal of a sequence of displays.
Browsing can be qualified according to the underlying intent or absence of such. It may be *opportunistic* (where content is unknown), *exploratory* (with a view to forming a mental model of some space) or, in a special case where it is undirected, *involuntary.*

Brushing
IV: a change in the encoding of one or more items essentially immediately following, and in response to, an interaction with another item.

Conceptual short-term memory
IV: a model of the human sensory system accounting for performance during a period of up to one second from an initial stimulus.

R. Spence, *Information Visualization*, DOI 10.1007/978-3-319-07341-5

Derived value
IV: one or more values derived from an existing set of values.
Example: average, variance.

Detail (n)
IV: information about a number of attributes of a single member of a set.

Dynamic query
IV: an interface in which a continuous manual adjustment of one or more data values results responsively (e.g. well within one second) in a visual representation of some function(s) of those data values.

Exploration
IV: navigation and browsing undertaken solely with the aim of forming a mental model of part or all of an information space.

Fixation
Dict: the dwelling of eye-gaze on an essentially fixed point.

Glyph
IV: a graphical object designed to convey multiple data values (Ware 2004, p. 145).

Insight
IV: an enhancement of an internal model of some data (could involve additions to or removals from an internal model). Understanding.

Navigation
IV: directed movement in discrete or continuous information space.

Object visibility
IV: the representation of an object as a single coherent visual entity so that its attributes are clear.

Overview (n)
IV: the assessment of one or more attributes of a set of objects. Concerns the acquisition of knowledge about metadata or scope. There is often an implication that the assessment is rapid and preferably pre-attentive. The assessment could be conscious or unconscious (pre-attentive).

Pre-attentive processing
IV: visual processing that occurs prior to conscious attention (Ware 2004, p. 149).

Presentation
Dict: to offer to view: display.
IV: the layout of encoded data in space and/or time.

Pursuit
IV: a navigational step undertaken with the sole aim of enhancing some aspect of movement towards a target.

Relation
Dict: a logical or natural association between two or more things; relevance of one to another; connection.

Represent
Dict: to depict, portray.
Dict: to present clearly to the mind.
IV: to encode data in visual, aural or any other sensory medium.

Residue
IV: an indication of distant content in sensitivity encoding.

Saccade
Dict: ballistic movement of the eye.

Scent
IV: the perceived benefit associated with a movement in information space, evaluated following interpretation of one or more cues.

Search
Dict: to make an examination in order to find something.
Search is directed and associated with a specific target. Within informatics the word often implies an *automatic* search carried out by a machine. If carried out by a human being it could involve one or more forms of browsing and navigation.

Sensitivity
IV: a movement in discrete information space and the interaction required to achieve it.

Suppression
IV: removal from view of a representation of data, according to some automatic or manually chosen criterion as in, degree of interest.

Tree
IV: a network of nodes and links containing no loops.

Visualization tool
IV: usually a software system involving a visual display, which allows a user to interact with and change the view of some data with a view to forming a mental model of that data.

Visualize
Dict: to form a mental model of something.

Wayfinding
IV: a combination of exploration and pursuit.