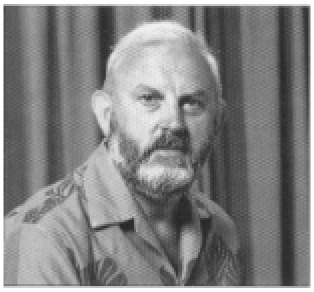
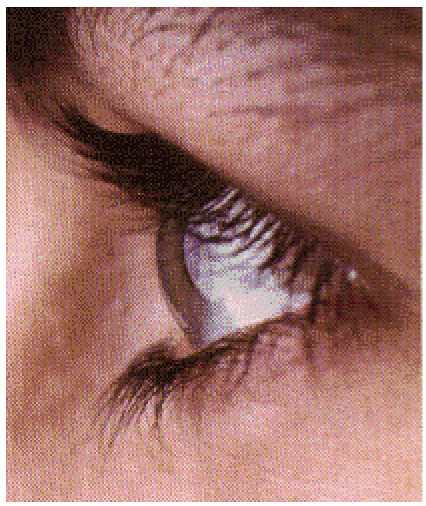
Bob Spence

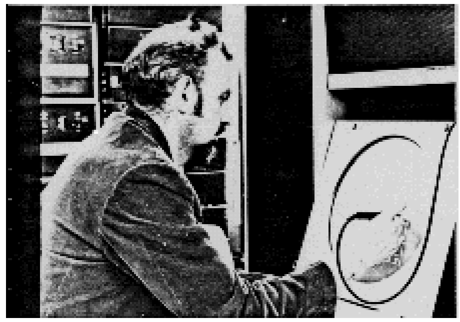


The Acquisition of Insight

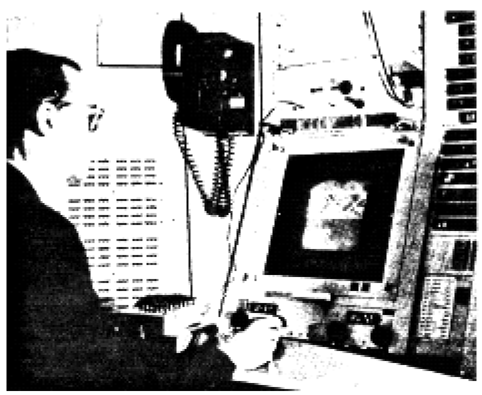


- Publications

THE BEGINNING



THE BEGINNING
A landmark in the effective harnessing of computer power to the ultimate benefit of mankind occurred in 1962. Ivan Sutherland demonstrated the SKETCHPAD interactive-graphic design system. With its integration of graphic presentation and responsive interaction it provided a dramatic demonstration of the potential associated with an ability to create and edit the presentation of data. The potential for creating a productive match between human skills and computer power was there for all who had the vision to see. SKETCHPAD provided a glimpse of the way in which an information-based tool might become an extension of the human mind, just as, for centuries, physical tools have often become 'part' of those who wield them.



MOTIVATION
My own involvement with human-computer interaction was influenced in three ways. First, by Ivan's work. Second, by Colin Cherry, then my professor and long acknowledged for his contributions to cognitive engineering. With his classic *On Human Communication* he reminded technologists that people are an essential part of any communication system. The third influence, which I describe below, was the then (1966) current use of a most unsuitable notation for engineering design.

NOTATION

Notation offers power. And a good notation is one of the most powerful tools available in the way it can support organised thought and discovery. As Bertrand Russell, in a preface to Wittgenstein's work, pointed out,

"*A good notation has a subtlety and suggestiveness which make it seem, at times, like a live teacher*"

ELECTRONIC CIRCUITS

For years, designers of electronic circuits had been using - and still *do* use - a graphical representation of connected components. This "circuit diagram" is itself a notation - a cognitive artifact - that helps the designer to understand a myriad range of circuit properties and, thereby, to create new circuit designs. Indeed, it does this so effectively that the circuit diagram is the universal notation employed by circuit designers the world over. Over many decades it has never been replaced as the preferred notation, a glowing tribute to its visual expressiveness.

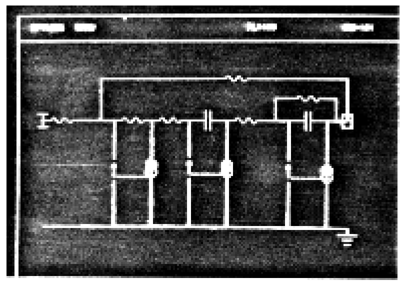
ALPHANUMERICS

Regrettably, though understandably in view of their eagerness to exploit the computer's ability to predict circuit behaviour and thereby replace tedious experimental circuit construction, an alphanumeric form of circuit description became the sole passport to the use of computer simulation. At once, most if not all of the benefits of the conventional notation were thrown away. A wrong connection, immediately obvious in a circuit diagram, could for a long time lie undetected. Even worse, such a mistake might *never* be detected, with the horrifying consequence that the designer is presented with the properties of a circuit which is *not* the one he or she thought was being simulated !

```
R1 2 3 3.9K
I1 0 1 DC 10E-6
I2 0 1 AC IE-6 0
V2 3 0 DC 9
Q1 2 1 0 Q2N2222
.MODEL Q2N2222 NPN(IS = 3.108E-15 BF = 217
+ ISE = 190.7E-15 IKF = 1.296 NE = 1.541 BR = 6.18
+ IKR = 0 VAF = 131.5 RC = 1)
.AC LIN 1 1000 1000
.PRINT AC VM(1) VP(1) VM(2) VP(2)
.END
```

INTERACTIVE GRAPHICS

The solution to this loss of notational power had, of course, been suggested in general terms by the seminal work of Ivan Sutherland. It was to use the technique of interactive graphics to allow designers to draw, with a 'light-pen", their richly suggestive circuit diagram, and to let the computer organise its transformation into the appropriate alphanumeric code. Almost certainly, the light-pen could be mightier than the keyboard. It is interesting to note, however, that almost 20 years were to elapse before the real electronic circuit designer in industry would be provided with the envisioned tool.



REAL POTENTIAL

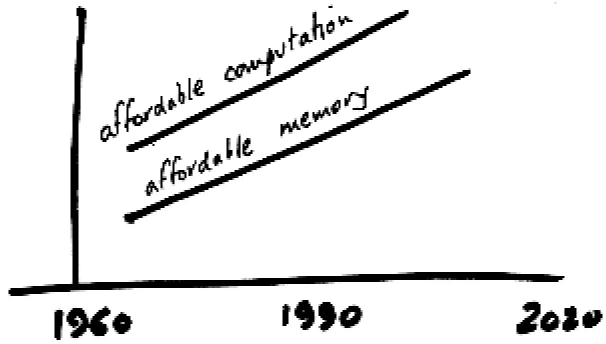
At first sight, the use of interactive-graphics to allow a designer to draw the familiar circuit diagram appeared to many, at that time (1966) to be an extremely mundane exercise of questionable worth. Such a superficial view, however, has since been proved more than a little misplaced: the richness and multi-faceted nature of the potential match between human expertise and computer power, as well as the many fundamental issues raised, only unfolded as time elapsed. They are still unfolding.

BENEFICIARIES

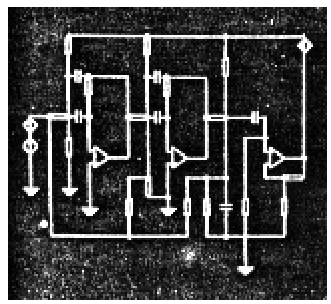
Who stood to benefit from the proposed use of interactive graphics for circuit design? After all, electronic circuit designers constitute only a minute fraction (10^{-10} ?) of the world's population. Fortunately, the concepts and artifacts and techniques developed to support the circuit designer, as well as the issues raised, were quickly seen to be relevant to the empowerment of a much wider population, including clerical workers and - most importantly - lay people as well as engineering designers.

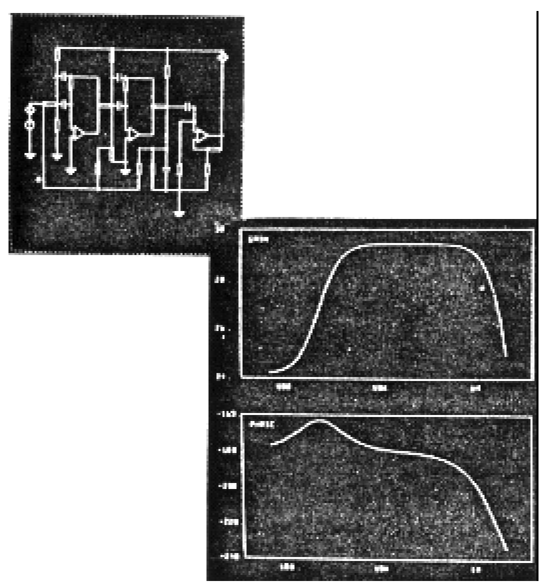
PHILOSOPHY

In charting the course of my work on human-computer interaction I was aware of the time it takes for new ideas to reach the maturity of being transformed into usable and available tools. And I was also aware of the incredibly rapid increase in both affordable computer power and memory. Thus, often to the desperation of my collaborators, my work was driven by long-term visions, and I often insisted on demonstrating concepts long before their commercial realisation - or even simple implementation - was possible. My bonus, of course, was the time thereby made available for calm consideration of the human-computer interaction issues before interface designs were frozen to permit implementation and marketing!



MINNIE



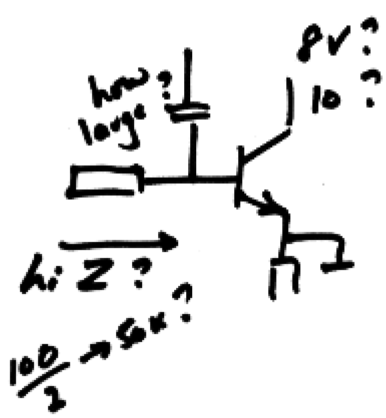


The electronic circuit designer's tool that my colleagues and I realised via innovation, design and research was named MINNIE. It allowed a circuit designer to describe a circuit by drawing it on the screen, whereupon the circuit so described was simulated and the the results of the simulation - the predicted performance of the circuit - presented on the same screen. MINNIE experienced many enhancements and transformations between its proposal in 1967 and its appearance on the market as a commercial tool in 1985. Its evolution benefited from attention to a host of fascinating issues, each of which deserves separate comment [3],[4],[9],[10]

PHILOSOPHY OF TOOL DESIGN

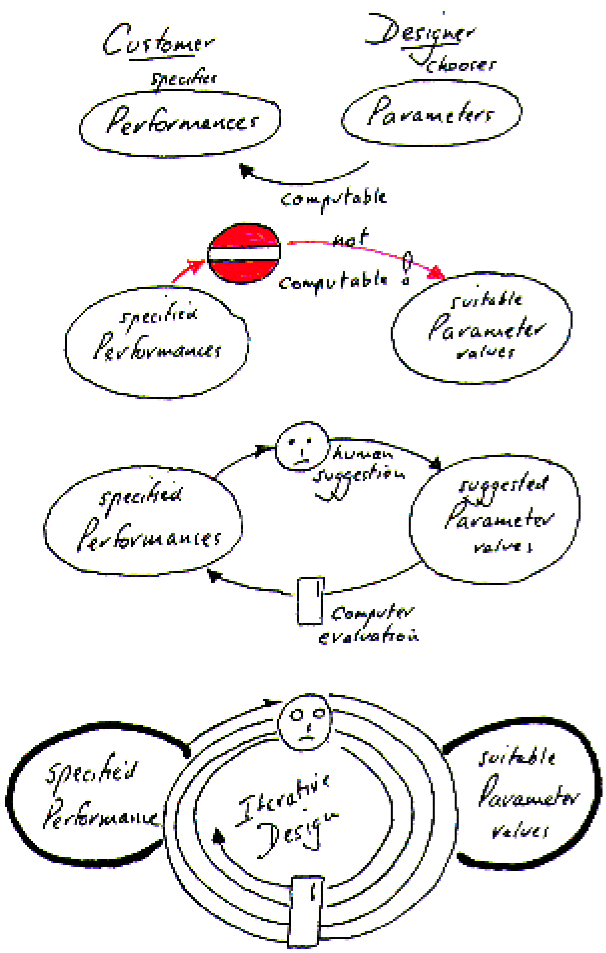
Much of the success of MINNIE derives from the fact that its principal architects (Spence, Drew and Apperley) were, or had been, practising engineering designers, with experience of how real design proceeds. We knew, for example, that it was vital to allow an engineer to describe illegal or **incomplete** circuits so that the process of circuit drawing, and more importantly the process of circuit *invention*, was not artificially and frustratingly constrained. It was also vital to acknowledge the fact that designers **formulate problems** at the same time as they search for a solution. A related issue is the designer's concern, especially in the early stages of design, with **qualitative** as well as quantitative properties of the designed circuit. It is also essential to facilitate **exploration**, since much of the design process involves the acquisition of insight into complex interrelations within a multidimensional space. And any new tool must not require its intended user to develop unnecessary new **expertise** in order to use it. A design tool which does not address these issues is unlikely to be a good tool.

TENTATIVENESS



True to stereotype, engineers do often sketch a new design on the back of an envelope, but in an interesting way. At first, only the topology may be sketched, with no indication (except in the designer's mind) of the numerical value of any component. That value might - or might not - be added later. Design would therefore be needlessly interfered with, at the risk of jeopardising creative thought, if the designer were required to provide a complete description of each new component immediately it was included in the diagram. In acknowledgement of the often tentative nature of circuit drawing, therefore, MINNIE allowed *any* detail to be added at *any* time. Sufficient expertise was, of course, built in to MINNIE so that, when a simulation was requested, the designer's attention was drawn to any omissions [49].

DESIGN IS DIFFICULT



Design tools like MINNIE are needed because engineering design is difficult. But *why* is it difficult ? In answering this question it is sensible to broaden the discussion to the design of *artifacts*, whether they be circuits or bridges or motor cars, since the same principles hold.

Engineering design involves a customer and a designer. The customer wants an artifact and specifies the **performances** it must exhibit, performances such as the loudness of a hifi or the traffic capacity of a bridge. The performances are in turn determined by the internal composition of the artifact and the values of its **parameters**. The designer must choose the parameter values to achieve the desired performances.

Given a set of parameter values, a mathematical model of the artifact can be exercised to compute the corresponding performances. But that does not solve the problem: the customer specifies the performances (not the parameters!) and we, as designers, must find appropriate parameter values. Unfortunately this 'inverse transformation' cannot be computed or expressed mathematically.

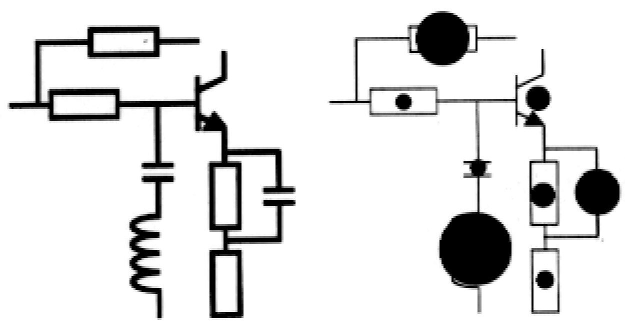
In practice it is the human designer who, on the basis of experience, proposes what is hoped will be a set of parameter values which satisfies the customer's requirements on performance. The corresponding per- formances are then computed: and if there is any discrepancy between computed and required performances, the designer then suggests a *modified* set of parameter values. This cycle is repeated - often many times - before a suitable design is found.

SUPPORT FOR EXPLORATION

A designed artifact such as an electronic circuit will typically contain many components whose parameter values must be chosen. The relevant parameter space is therefore muti-dimensional. During the course of design the designer is attempting to explore this space - usually by varying one parameter at a time and observing the effect on all the performances - in order to acquire insight into the relations between parameters and performances. Typically - even now (1995) - this would involve the (tedious) repeated choice of a parameter value followed by a simulation.

MINNIE pioneered *dynamic* exploration: the ability to sweep a parameter value over a range and immediately see the the effect on a performance. In so doing, MINNIE demonstrated a symbiotic relationship between the development of a new algorithm and the proposal of a new mode of interaction. The new algorithm allowed the very fast calculation of the effect of parameter change, but the calculation was fast only if some precalculation had been performed. This "investment" of time to reap the ensuing benefit of dynamic exploration provides an example of the influence that human needs can exert on algorithm development, as well as the values of having an interdisciplinary team developing a tool such as MINNIE

MAPPING OUTPUT ON TO INPUT

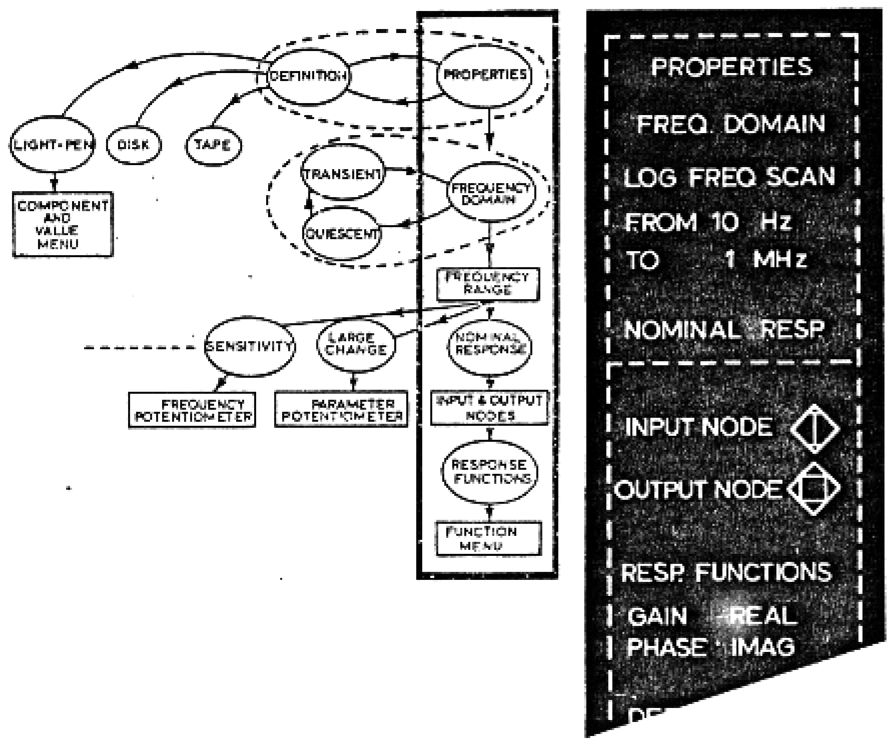


Conventionally, the input to a simulator (e.g., the conventional circuit diagram) and its output (typically graphs) were regarded as two separate entities. MINNIE demonstrated, possibly for the first time, the considerable cognitive benefit derived by mapping computed performances back on to the circuit diagram, especially when those performances are related to individual components. Thus, circles superimposed on - but not masking - component symbols indicated, by their size, the sensitivity of some performance to changes in those components.

These 'sensitivity circles' enable the designer to visualise - that is, form a mental model of - the parameter/performance relations. But it also posed a challenge: how to handle the fact that the circles have different sizes at different frequencies. The solution was simple: *animate* the display in synchronisation with the movement of a marker between "Bass" and "Treble" and back again [1]. This facility even supported discovery, as when two circles suddenly expanded and contracted [2], indicating the circuit's propensity to oscillate, a tendency that, in structural terms, was the death warrant of the Tacoma Narrows bridge.

QUALITATIVE DESIGN
The sensitivity circles were just one example of how MINNIE facilitated the **qualitative** aspects of design. Many of the episodes within the design process are qualitative in nature, and it is essential that they be supported.

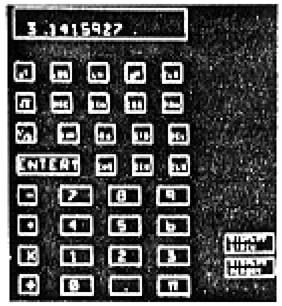
COMMAND DIALOGUE



Like many other systems created to support clerical work, enjoyable play and engineering design, MINNIE could exist in many different states. A simple means is therefore required, not only for moving between states but also for identifying the current state: the age old "Where am I?" problem which is still seeking a satisfactory solution.

To solve this problem within MINNIE we invented an hierarchically-based interactive command dialogue exhibiting two important features, reversibility and readability [22], [23]. The possible states of MINNIE were represented by the 'leaf nodes' of a tree, superordinate nodes serving to define categories and parameter values [25].. The current state - a trace from the root to a particular leaf - was summarised, in a **readable** fashion, in a menu on the side of the screen, but with all entries sensitive to **interaction**. In this way the state of MINNIE could be changed by a single 'selection' from the menu, with the special property of reversibility so that the ensuing dialogue was 'stable'. The addition of a dynamic default facility, also rare at that time, resulted in a command dialogue whose behaviour often triggered remarks such as "Wow ! it's gone to exactly the state I wanted !" [5].

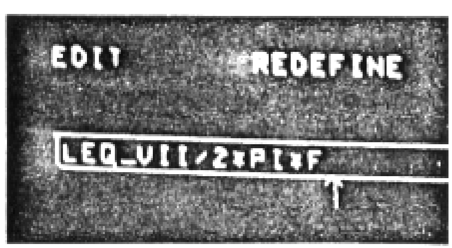
NEW ARTIFACTS



MINNIE was the environment for the introduction of two new artifacts [6]. One was the "on-screen pocket calculator", now only noticable if it isn't supplied ! It was first implemented in 1973 and thought to be the first such calculator. The other was a "count-down clock" which performed one revoluion to indicate the progress - which otherwise would not be obvious - of a calculation being performed by the computer [8]. A central STOP light-button could be selected to halt a calculation if an error of command or circuit diagram was suspected, and cancelled again to allow calculation to continue. These two artifacts eventually found their way into common use.

ADAPTABILITY

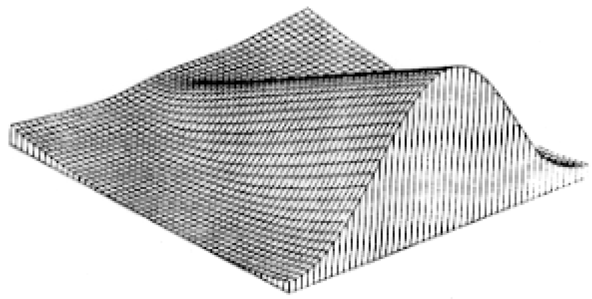
The functionality provided by any tool is often not exactly what the user requires [7]. We therefore devised a novel scheme whereby, using the programming language APL, the MINNIE system could, via the simple typing of a one-line equation, be made to compute and display a new circuit performance of interest and, most importantly, make that performance available to the very powerful post-processor within MINNIE.



THE DESIGN OF MODELS

Very early in the research associated with MINNIE it was realised that the design of a model of something is a process which shares many characteristics with the conventional design of an artifact. In recognition of this similarity, novel provision was made in MINNIE for the study - and particularly the simplification - of models of electronic circuits.

TIME DELAY EFFECTS

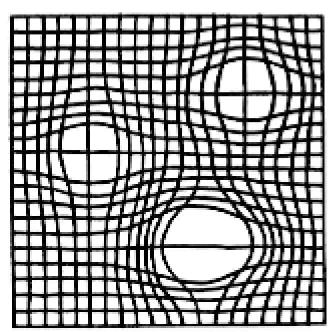


Early use of MINNIE demonstrated the possibly deleterious effect, on the process of design, of the time taken for the computer to compute the effect, on circuit performance, of a change in a parameter value [11],[12],[17],[18]. Since it seemed that 'response time effects' might well be of long term interest, I judged it worthwhile to perform some experiments. Briefly, the experiments, conducted in accordance with established statistical and psychological guidelines, involved subjects in the exploratory discovery of the values of two adjustable parameters which placed a nonlinear function within acceptable bounds, a task equivalent to finding the lowest point in a hilly but invisible terrain. The results showed that:

- Contrary to expectation, the computer's time delay had no effect on time to solution until it exceded one second.
- Again contrary to expectation, the *variability* of time delay is not serious in the selected condition.
- Most surprisingly, the ability to vary the two parameters simultaneously (using a 2-dimensional 'slider') yielded no advantage over the 'one parameter at a time' condition [16].

HAPPY ENDING
One advantage of anticipating the extensive use of interactive graphics for engineering design long before it was commercially viable was the opportunity to explore, with some thoroughness and without undue haste, many of the relevant issues [26]. Such exploration turned out to be a good investment when MINNIE finally became a commercial product and was marketed and futher developed by Interactive Solutions Limited. MINNIE is still in use in industry. With hindsight it has also been recognised as one of the earliest examples of direct manipulation long before that term was coined.

CONTEXT



Unlike some paper-based examples, such as the Chinese display of an entire newspaper, the dissemination of electronic-based information suffers from a severe limitation: there is usually far too much data to squeeze into the available display area.

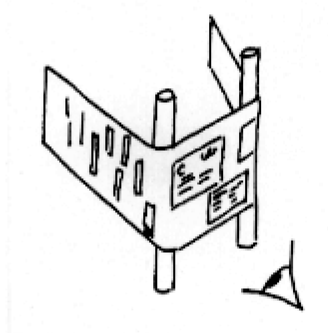
TOO MUCH DATA
The temptation - and the easy way out for the interface designer - is to display only that fraction of the data which is deemed to be currently relevant, and to provide a mechanism such as scrolling to arrange for the display of newly relevant data. Much can be lost, however, and many problems introduced, by so doing.

FOCUS+CONTEXT
By focusing exclusively on an item of interest (such as this page), all **context** is lost, often giving rise to the well-known 'where am I?' problem. Related questions include "Where can I go?" and "Where have I been?". As Bertin remarked,

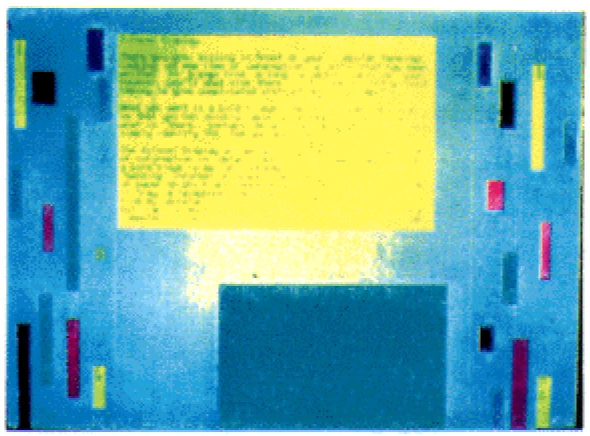
"*Items of data do not supply the information necessary for decision-making . . . the useful information is drawn from the overall relationships of the entire set*

Ideally, both focus and context should be available to a user, even though at times it may be appropriate to dispense temporarily with context. However, even if the need for context provision is acknowledged, it is still not easy to achieve. It is for this reason that the "**focus+context**" problem is regarded as a fundamental difficulty in the development of user interfaces, and continues to receive close attention from researchers.

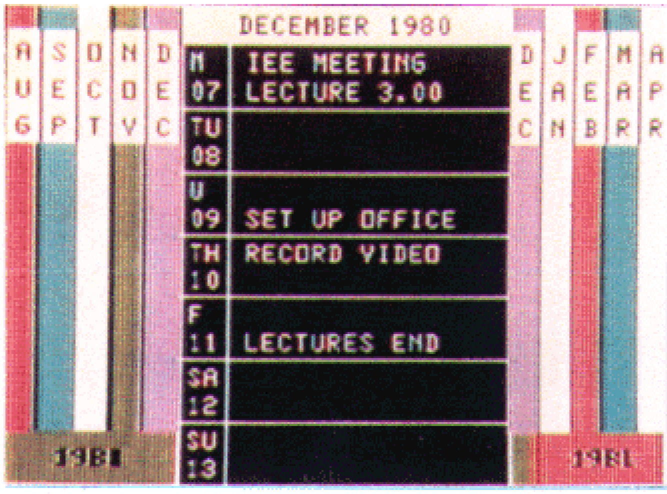
BIFOCAL DISPLAY



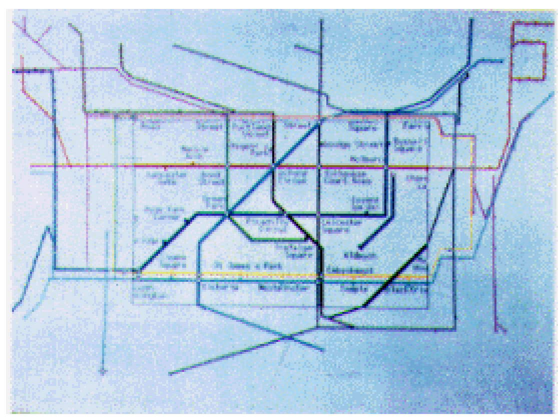
In a computational environment, the focus+context issue was first identified by Mark Apperley and me in 1980 and a solution called the Bifocal Display proposed (later to be better known as the 'fisheye display') [13],[14],[15],[19]. The underlying principle can be illustrated by imagining an 'information space' on a strip of paper which is bent in such a way that all items are visible in outline but a few - those that are currently of interest - are presented in readable detail.



Why is the Bifocal Display useful ? First, it presents the context of the current focus of interest: one has a 'bird's eye view of the entire information space while concentrating on part of it [20]. Second, by being able to scroll the information space through the central 'readable' region, there is a smooth transition between the focus and the context. Third, on noticing an item of urgent interest in an outer region (probably in the form of a tall thin rectangle of distinctive colour - "it's red, it's from my boss"), its repositioning in the central area does *not* require precise interaction but, instead, a familiar scrolling action: the human perceptual-motor system is easily able to control the extent of the scroll.

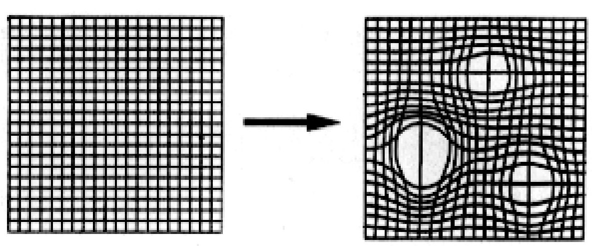


Many degrees of freedom are available to the designer of a bifocal presentation. For an 'in-tray', for example, timeof-arrival can be encoded by lateral position, type of document by vertical position, and the sender by colour. Shape, pattern and other visual encoding techniques can be exploited to take advantage of the perceptual abilities of the user.



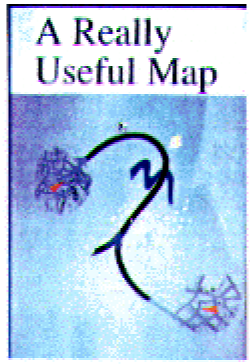
Various extensions of the Bifocal Display concept were immediately apparent. A combination of horizontal and vertical 'bifocalling' might be appropriate to a diary.

A two-dimensional bifocal display was implemented to allow easy examination of a transport network, and illustrated by application to the London Underground and Melbourne transportation systems [40].



It was also seen that the underlying 'stretching' basis of the bifocal display could be applied to situations in which multiple foci are of interest: computer generated maps come to mind as a fertile field of application.

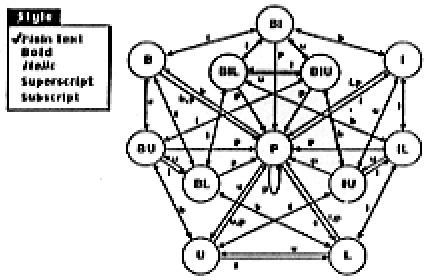
GRAPHICAL TAXONOMY



Since 1980, the bifocal display concept has been rediscovered and renamed by various workers and is now accepted as a valuable contribution to the focus+context problem. However, due to the likelihood of confusion between the 'stretching' concept of the bifocal display and Furnas' 'fisheye lens' concept relevant to data suppression, I devised a taxonomy of orthogonal graphical actions involving representation (encoding), stretching and suppression [42]. All these transformations, for example, might be appropriate to the generation of a map for a long journey.

MENUS

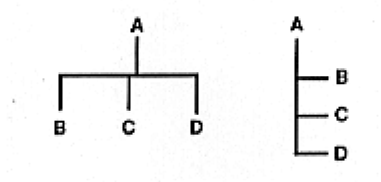
A vast number of human-computer interfaces, ranging from CD-based nursery stories to computer-aided design systems and holiday booking schemes, employ menus, either partially or totally, to support the human-computer dialogue. Menus have therefore to be designed, a task which is quite different from that of programming them.



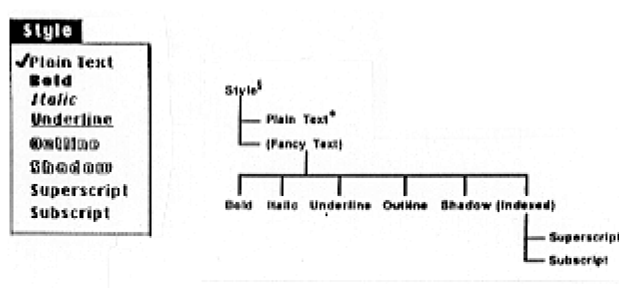
My colleague Mark Apperley and I realised in 1988 that no satisfactory notation was available for the menu *designer* as opposed to the programmer concerned with the *implementation* of a menu system. For example, for the reduced Style menu of MacWrite, the State Transition Network description is quite complex: moreover, for the *complete* Style menu, involving just three additional menemes (menu items), the State Transition Network expands to over 70 nodes and about 700 branches!

LEAN CUISINE

We therefore proposed a new notation, called Lean Cuisine [27], which offers a number of advantages: it is visually expressive; it separates dialogue description from implementation detail; it is suited to asynchronous dialogues (where 'state' is important); and it can be 'mentally executed'



The notation is based on two basic structures, a mutually exclusive group of menemes and a mutually compatible group. Additional simple notational marks can indicate default selections as well as the illegality of an absence of selection from a mutually exclusive set. Easily appreciated from a restaurant example, its application to the complete MacWrite Style menu shows its clear advantage over a State Transition Network containing about 70 nodes and 700 branches.



The Lean Cuisine notation [21] is particularly applicable to direct engagement interfaces, and has recently been extended to handle quite complex menu systems within a 'windows' environment.

MENU SYSTEM DESIGN

However successful it proves to be, Lean Cuisine is only relevant to part of the process of menu system design. It takes, for example, no cogniscance whatsoever of the cognitive aspects of menu use. For this reason, William Edmondson and I proposed a new Systematic Approach to Menu Design which would handle cognitive issues as well as the link between the menu and the background application [38].

NAVIGATION

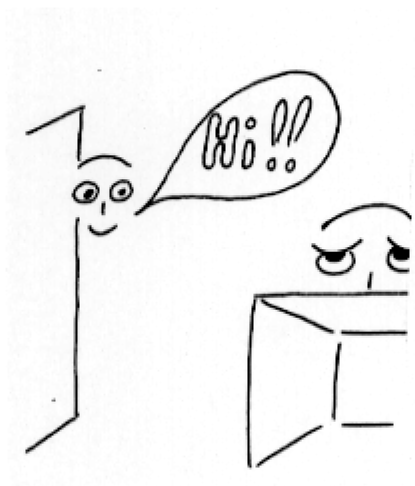
Describing a menu is one thing - but designing it to be an *effective* menu system is another ! What does effective mean in this context ?

Overall it involves empowering the human user to reach information, or place a tool in a required state, as fluently, conveniently and confidently as possible. If information can be regarded as existing in a 'space', we are talking about 'movement' in that space, movement guided by *navigation*.

Though widely discussed, the concept of navigation is neither easy to define nor simple to design. Indeed, the CEO of Apple Computer, Michael Spindler, recently remarked that navigation is one of the key issues requiring attention if we are to be able to make full use of the 'Superhighway'. Navigation seems to be linked intimately both to context models (both externally displayed and internal to the user) and to an interpretation of context that is needed to decide upon beneficial movement in information space.

We made contributions to what was loosely called the navigation problem in the late 'sixties and in the 'seventies. The concept of the **Parameter Node** - now obvious - was introduced in MINNIE to avoid artificial hierarchy, a bad design fault still perpetrated today. **Dynamic Defaults**, as described earlier, were also introduced within the MINNIE system and proved most successful. **Sideways viewing** was another novel navigational tool [24]. And, again as in the MINNIE system, a novel interactive **hierarchically organised system** of menus exhibited many desirable properties - such as reversibility - leading to a very stable command dialogue in which the user could safely and confidently undertake exploration.

INTERRUPTIONS
We are all aware of the disrupting effect that an interruption - a telephone call or even a simple "Good morning!" - can have on our use of a computer, especially if that use is 'creative' in some way. Surprisingly, very little study has been made of this effect. We therefore designed an experiment to elicit some insight into interruption effects and we selected, as the task to be interrupted, that of finding the answer to a question by reference to a tree-structured, menu-accessed data base [39]. The principal performances of interest were the time taken to locate an item and the number of frames accessed in so doing.



Interruptions were found to have a significant effect on the performance of the task. With interruptions, search time increased on average by 46% and the number of frames accessed by 25%. The experiment also served to identify many other interesting issues worthy of future research.

AUTOMATED DESIGN

"Why can't design be delegated to a computer?". "Surely we now have powerful optimisation algorithms which can improve a designed artifact better and quicker than a human designer"

- Yes, the algorithms exist. But no, they *don't* offer anything like the complete answer to design. The reasons are many, varied and compelling. For example,

- Imagine you give your design to the "optimiser" and receive back a modified design. Do you readily accept it ? Or do you wonder why it couldn't get more output or less noise or a better combination of .....? You wonder what trade-offs were discovered, whether better performance could have been achieved if only you had.....

- The electronic circuit designer has enough trouble developing his or her design skills without having to learn the new subject of numerical optimisation and, in particular, the way in which available algorithms demand that design requirements should be stated.

- Typically, the interface between the algorithm and its user is alphanumeric, and there is no opportunity to visualise - and thereby gain insight from - the progress of the algorithm.

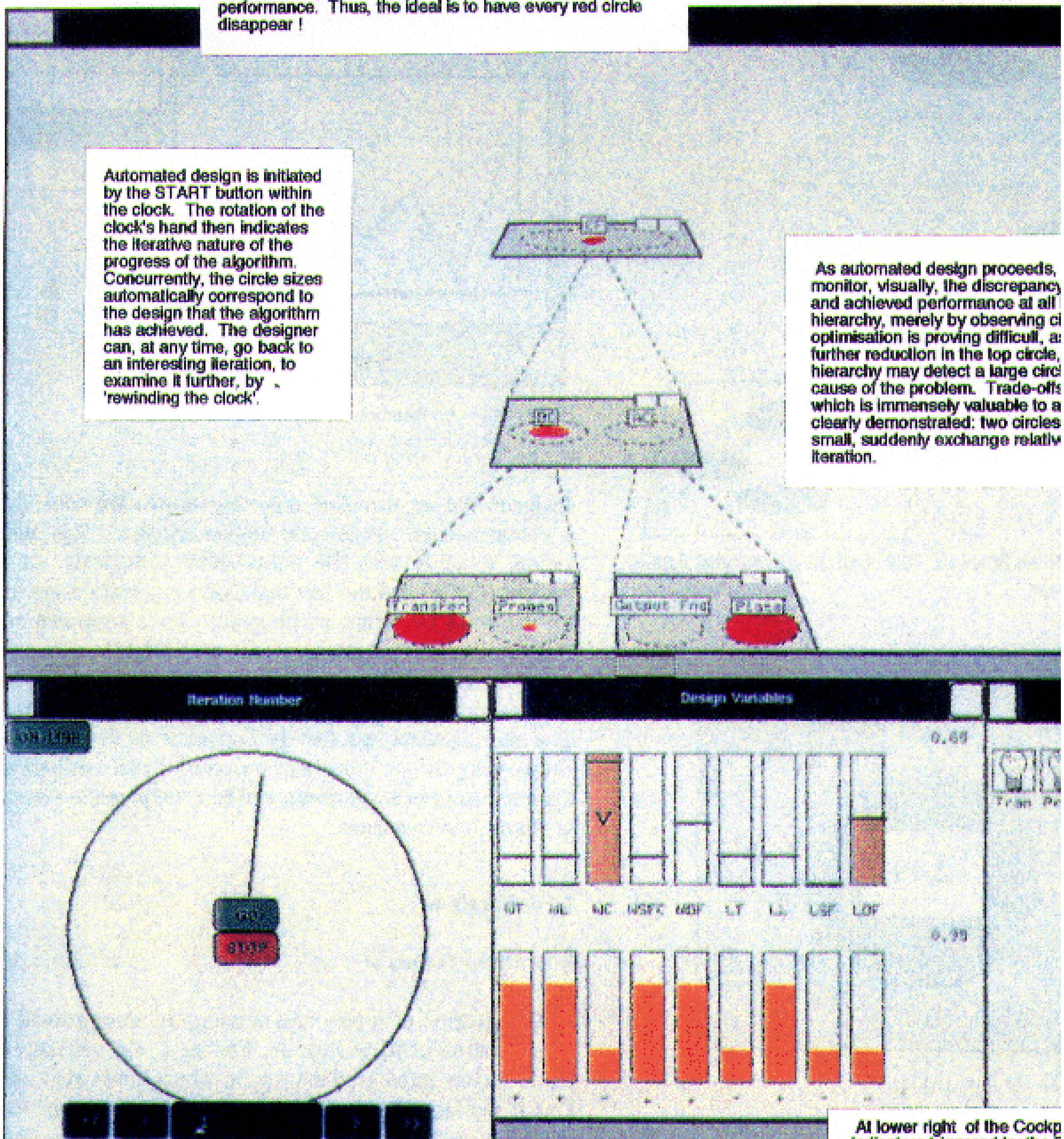
THE COCO DESIGN TOOL

The key to the effective use of automated design is to make provision for its *guidance and observation by the human designer*. In this way the designer's valuable skill and expertise can not only be brought to bear upon the design but can make the automated design *itself* far more effective. To demonstrate this view the CoCo design tool was proposed, designed, implemented and, finally, evaluated in a real industrial design context [33] [34]. CoCo stands for the **C**ontrol and **O**bservation of **C**ircuit **O**ptimisation [36]. CoCo also contained 'expert systems' to help the designer with the choice of algorithm and with actual circuit design.

The part of CoCo relevant to this discussion is the interface known as The Cockpit, so called in view of the close analogy between an airline pilot's use of an autopilot and the guidance of automated design by a human designer [41], [28]. Both make use of automation, both can observe, and both can take over manual control when judged appropriate [31].

THE COCKPIT

The graphical interface known as the Cockpit exhibits many novel features. The essentially hierarchical nature of design is recognised by a hierarchy of 'sheets', the uppermost concerned with overall design quality, the next with those performances whose value has been specified by the customer, and so on down to more and more levels of detail. On each sheet is displayed a red circle whose size indicates, qualitatively, the discrepancy between the desired and (currently) achieved values of some performance. Thus, the ideal is to have every red circle disappear !



Automated design is initiated by the START button within the clock. The rotation of the clock's hand then indicates the iterative nature of the progress of the algorithm. Concurrently, the circle sizes automatically correspond to the design that the algorithm has achieved. The designer can, at any time, go back to an interesting iteration, to examine it further, by 'rewinding the clock'.

As automated design proceeds, monitor, visually, the discrepancy and achieved performance at all hierarchy, merely by observing ci optimisation is proving difficult, a further reduction in the top circle, hierarchy may detect a large circl cause of the problem. Trade-offs which is immensely valuable to a clearly demonstrated: two circles small, suddenly exchange relativ iteration.

The lower panel shows, by the 'bar' indicators, the current value of each designable parameter between limits chosen - often somewhat arbitrarily - by the designer. Thus, if a parameter is seen continually to be 'hitting' its upper limit, the designer may decide to see if any benefit accrues by relaxing that limit. Immediately below this set of bars is another set which indicates the sensitivity of the overall discrepancy in design (encoded by the topmost red circle) to changes in the designable parameters, information which is of considerable value to a designer.

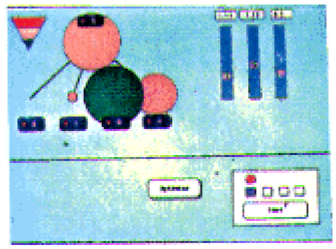
At lower right of the Cockp indicators triggered by the E concerned with circuits. Ma design are continually moni example, a device is seen t appropriate advice can be c forced upon) the designer.

The need for a designer to between concern with quali quantitative aspects of circu supported by the availability information about discrepan

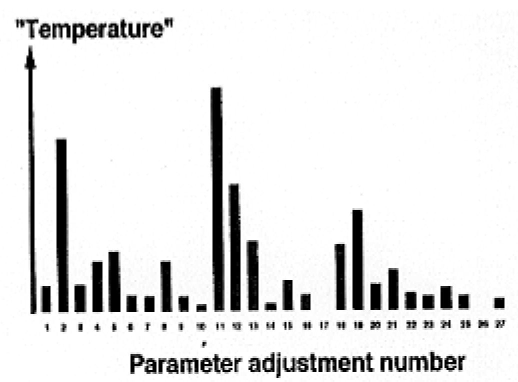
COGNITIVE MODELLING OF DESIGN

The process of engineering design, and especially its cognitive aspects, is nowhere near being fully understood. However, by interpreting the trials which were carried out (using real designers designing real circuits) on the CoCo system, my colleague Lynne Colgan was able to propose a cognitive model of the design process [32]. It offered the potential advantage of a simple 'atomic' structure capable of representing cognitive actions at any level in a deep hierarchy with, for example, keystrokes at the lowest level and the completion of a design at the top level.

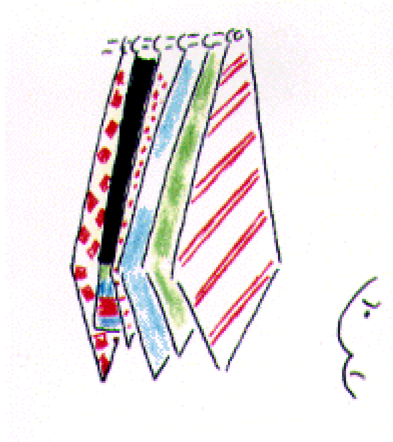
'TEMPERATURE' OF EXPLORATION



The nature of the dialogue between designer and automated design is fascinating, and rich with unanswered questions. To start answering them we built a 'mini-Cockpit'. The first study made with this new interface focused on the detailed nature of manual exploration of 'design space' and produced an interesting result. The successive parameter adjustments made in reaching a (local or global) optimum appeared, in magnitude, to decrease roughly exponentially with each iteration. Mindful of the relation between the energy of atoms and temperature, I suggested that the concept of 'temperature' may well be useful in the future to characterise exploration.



ASSESSMENT OF ALTERNATIVES



The selection of a tie from Marks and Spencers, some cheeses for tonight's dinner party from the delicatessen, a house from an estate agent or a video for viewing this evening is *a selection of one from many*.

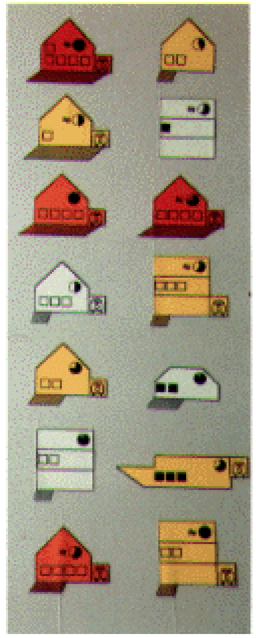
Conventional (boolean) database query methods are usually inappropriate. They fail to recognise that many objectives are imprecise: "we can pay *around* [[sterling]]80,000, we *probably* need central heating and, of course, we don't want to live *too far* from my Mum". Boolean type queries also don't show you 'near misses' - an extra [[sterling]]100 and you could have had the house of your dreams. Conventional methods often fail to give the user any idea of the overall population of available objects, whether they be houses, videos or ties.

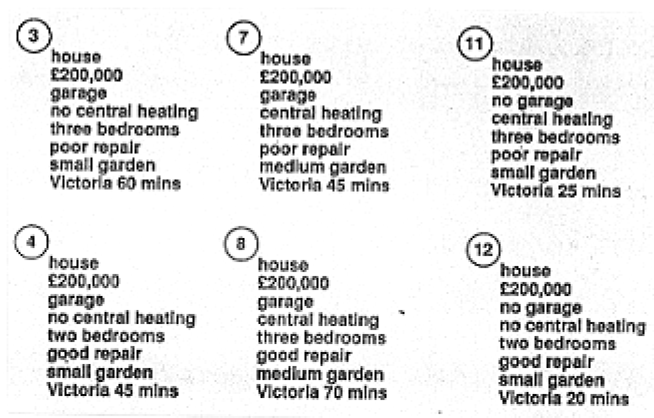
In seeking a better alternative to conventional database query methods it is also crucial to recognise that *problem formulation proceeds concurrently with problem solution*. For this reason alone, menu selection may be entirely inappropriate. A facilitation of browsing - the rapid assessment of content or state - may be more valuable.

I proposed two novel interfaces for the task of selecting one from many, one to enhance our knowledge of the field and the other to provide a useful and widely relevant tool.

ICONS ARE GOOD FOR YOU ?

A common view is that icons are more effective than text. But the crucial question - to which we have few answers - is, "if so, under what conditions?"





Many experimental investigations have contributed significantly to our understanding of icons. Mine focused on the relative merits of multi-dimensional (or 'integral') icons on the one hand and, on the other, normal text, to describe the attributes of an object. The experiment was based on the task of finding a place to live as representative of a one-from- many selection task [29].

Each **object** - in this case a dwelling - was represented by a multi-dimensional icon encoding eight **attribute** values [30]. I used colour to encode price, shape to encode type, the number of visible windows to encode the number of bedrooms, and so on. On a large (A1) board, 28 such icons were mounted, and each subject (of which there were over 70) was asked to locate the dwelling that satisfied a requirement, one of which was

The accommodation you select must be in good repair and as close to Victoria as possible, but *there must be a garage and at least three bedrooms; price is no problem.*

The task was then repeated with the 28 icons replaced by 28 textual descriptions occupying roughly the same space. The entire experiment was then repeated for a collection of 56 dwellings.

SURPRISES
The results were surprising.

It had been expected that, for this type of task, icons would lead to much faster solution. In fact, while task completion using icons *was* faster (and significantly so in the statistical sense), the difference wasn't very great. Time to solution was an average of 111 seconds with icons and 162 seconds with text. Also, against expectations, icons did *not* prove more beneficial as the number of objects displayed increased from 28 to 56.

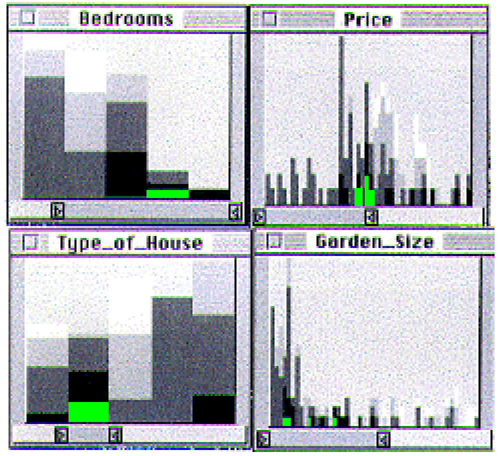
The experiment was additionally valuable for the questions it posed as well as answered. For example, "how do users tag (positively and negatively) the individual objects as they are examined ?". "How does tagging affect performance ?". By 'tagging', I mean 'crossing off' or 'ticking' - in our case with pieces of PostIt sticker - each dwelling as it is judged to be better or worse than previously examined dwellings.

DYNAMIC QUERIES
The presentation of attribute data describing objects in the manner just described was used merely to gain understanding, and *not* because it was thought to be a good method for practical use. Population size is one issue - there may be too many dwellings to display on the screen. Another is the lack of any way of focusing on one attribute - price, for example - and seeing how it interacts with the other attributes.

A major advance in the effective exploration of data was made by Shneiderman and his colleagues. They presented the concept of *dynamic exploration* and demonstrated it with tools such as Filmfinder. The user was able to move pointers indicating acceptable values or ranges of attributes such as cost, number of bedrooms and commuting distance and, immediately, see points representing dwellings appear or disappear on a map. Not surprisingly, tests showed that the interaction and rapid response made this interface better than more conventional ones.

Nevertheless, I identified a significant omission from Shneiderman's interface: in effect, a failure to present data of the sort that could enhance both qualitative browsing and quantitative search. An omission that could be cured, moreover, very simply: use the attribute sliders as a basis for *output* as well as input. Thus was born the tool known as the Attribute Explorer.

ATTRIBUTE EXPLORER

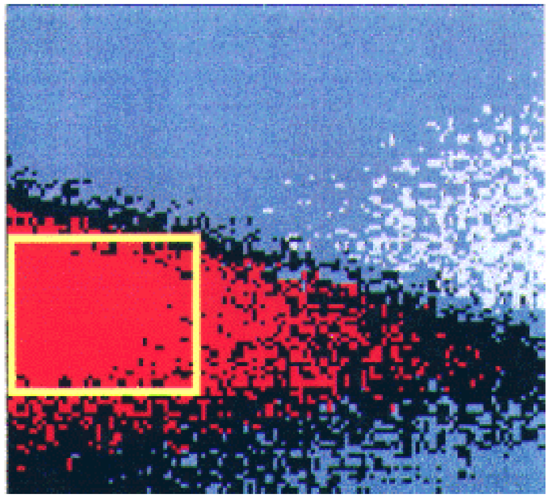


Even before the user interacts with the Attribute Explorer, histograms are displayed for each attribute to indicate their frequency of occurrence [43]. Thus, any given house - 27 Park Avenue, for example - appears as one of the small rectangles that together constitute the histogram, at an appropriate point on the attribute scale. Immediately, the user has some idea of total population and the avalability of each attribute. If the user definitely wants a 2-bedroom dwelling, then the appropriate selection is made on the 'number-of-bedrooms' slider. In response, all dwellings satisfying that requirement are colour coded green on the number-of-bedrooms histogram and, in addition, *on all the other attribute histograms*. Straightaway, therefore, we have some idea of *the interaction between attributes*.

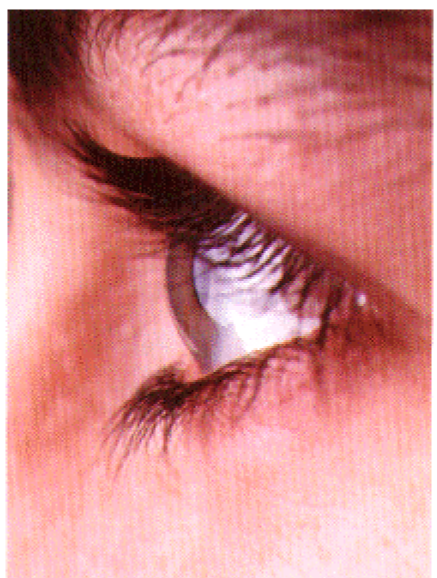
If we now position an upper limit on price, all dwellings satisfying that price limit are colour coded, again on all attribute histograms. Where both attribute requirements are satisfied, the dwelling is encoded green. In this way someone looking for a dwelling can, at one and the same time, explore the nature of the available dwellings, form some idea of the interaction between attributes and, gradually, achieve a 'short list' of possibilities that might be examined in more detail. The ability to vary an attribute limit and examine what one might 'just have missed' is particularly valuable and, indeed, can be supported by an alternative scheme of colour coding in which dwellings that satisfy all attribute limits are coded green, those that fail only one limit are coded black, those that fail two limits grey and so on.

Overall, three key properties can be ascribed to the Attribute Explorer. First, it supports the concurrent formation and solution of a problem. Second, it encourages exploration. Third, it allows fluent transition between qualitative exploration and detailed quantitative study. I take the view that, within a suitable display environment, the Attribute Explorer could be used by a lay person, either alone or guided by a trained person (e.g., the estate agent).

VISUALISATION FOR DESIGN



If you want something, you can either buy one or make one. The Attribute Explorer helps you to buy one. A related tool, called the Influence Explorer, helps you to make one.



The Attribute Explorer, just discussed, allows a user to visualise data; that is, to form a mental model of that data and thereby gain insight into it. This property suggested its extension to situations, such as engineering design, in which the designer benefits immensely by being able to visualise the very complex relations between parameters and performances, relations that were also discussed earlier [44] [45]. The Influence Explorer, proposed as a tool for engineering design, employed many of the techniques of data representation, presentation and interaction that were used so successfully in the Attribute Explorer.

THE INFLUENCE EXPLORER

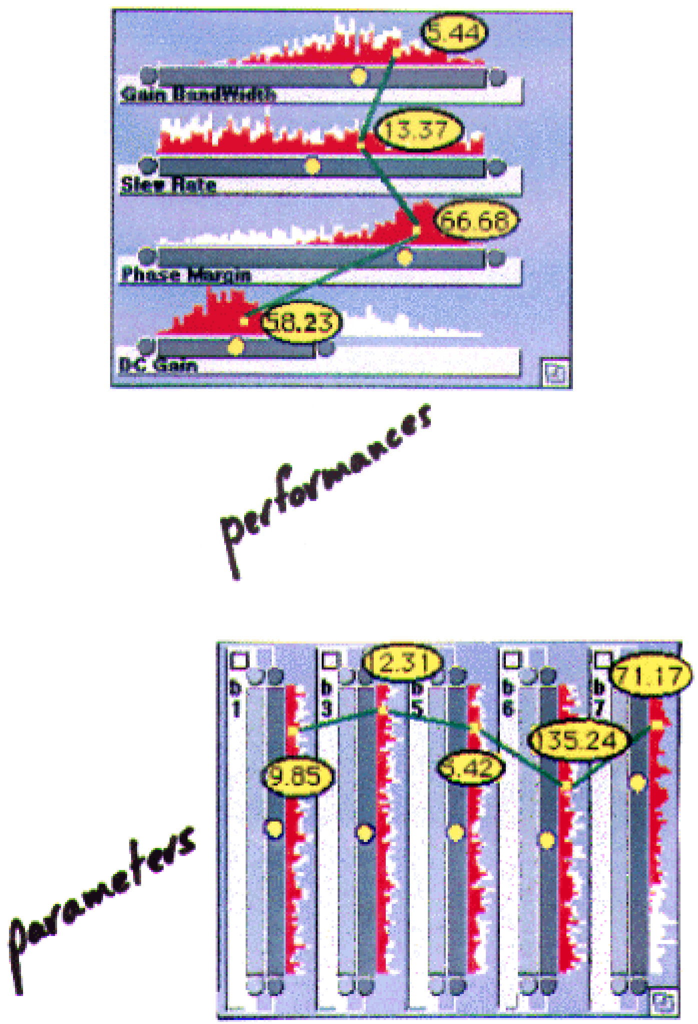
At the heart of any visualisation tool for engineering design is the set of equations (i.e., a **model**) linking performances to parameters, equations for which there is no inverse relation. Thus, the designer cannot point to a desirable performance and thereby identify a suitable set of parameter values, or 'vary' a performance and see the effect on other performances. The power of the

Influence Explorer lies in the fact that such *fluent and immensely valuable exploration* is made not only possible but easy.

The essence of the Influence Explorer is that the model is used to generate data about matching sets of parameter values and performance values so that this data can be responsively explored in either direction.

The designer is able to select a region of parameter space called the Exploration Region. This is a fairly large space within which the designer feels that a good design may well lie, but nevertheless a region in which it would be useful to explore in order to get some feeling for the interrelations of which a designer should be cognisant, relations such as trade-offs. A large number of points (e.g., 500) randomly distributed in parameter space is

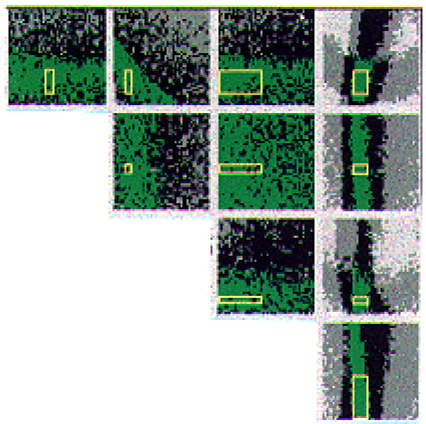
then generated, each point associated with a different design. For each point, the corresponding performances are then computed, using the model. What is then available is a table of data linking parameters to performances over a very wide exploratory range, data which can now be explored in either direction. Most importantly, since the customer specifies performance limits and the designer must choose appropriate parameter values, the designer can select a collection of points in one dimension of performance space and see how it corresponds to points in all the other performance dimensions and all the parameters [46] [50].



In the Influence Explorer the performance and parameter histograms are grouped separately. Interaction modalities similar to those used in the Attribute Explorer allow fluent exploration of the influence of parameters on performances, and support the wide variety of interleaving and concurrent tasks that constitute the process of real engineering design. The tool we implemented was also extended to handle the parameter tolerances which reflect ever-present though unwanted manufacturing variations.

The Influence Explorer has been demonstrated by examples taken from silicon chip design, structural design and mechatronics.

THE PROSECTION MATRIX



Nobody yet knows how to choose the best representations and presentations to support the performance of a task by visualisation. At present, much effort is devoted to the invention of new approaches, with the consequence that a 'construction kit' of visualisation tools is gradually being extended.

One such tool that we invented to support the design process is the Prosection Matrix. It is essentially an ordered collection of scatterplots. Each scatterplot refers to a pair of parameters. The ranges of the remaining parameters define a *section* of parameter space: all the data points (generated for the Influence Explorer) lying within this section are then *pro*jected (hence the name) onto the two-parameter plane. Colour-coding is employed to indicate satisfaction or otherwise of the performance specifications. Superimposed on each scatterplot is a yellow box indicating the expected spread of designs consequent upon the unpredictable manufacturing process. Thus, the yellow boxes represent all my mass-produced chips, and the green areas show me which chips will satisfy the customer. My task as a designer is therefore to position the yellow box as far as possible within the green area while - for economic reasons - making the yellow boxes as large as possible [37]. In this way the Prosection Matrix provides a good example of the advantage of converting a very difficult cognitive problem into a relatively straightforward perceptual task.

Within the field of visualisation the challenge for the future is to investigate and exploit the concept of linking two or more presentations and, in general, to search for schemes for automatically matching visualisation tools to tasks.

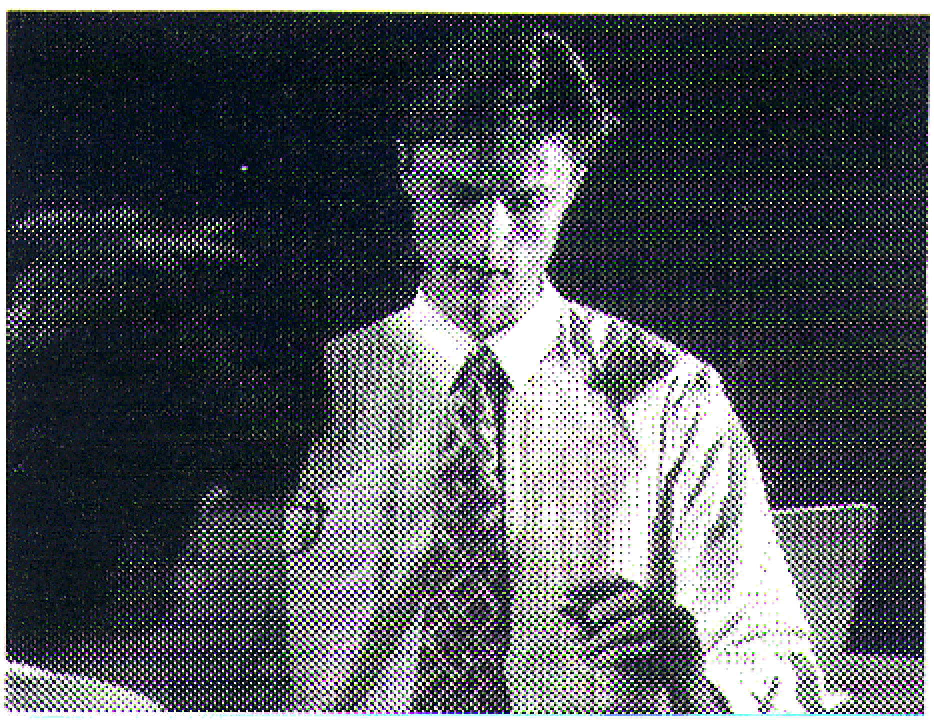
DATA MINING

The Attribute Explorer, Influence Explorer and Prosection Matrix are, essentially, tools which allow us to explore a multi-dimensional space. For this reason they are potentially relevant to the design of an extremely wide variety of artifacts and schemes.

One obvious extension worthy of study is to topological relations, where 'connectedness' rather than numerical values are principally of interest . But all these developments are part of a far larger field of research which is currently receiving much attention, that of Data Mining.

FUTURE INTERFACES

Visions of 2020 AD: engineering designers in a question and answer session with advisory agents. From the envisionment video Translations.



A designer in London collaborates with another in Tokyo as if they can see each other through a glrass wall on which the design is being sketched

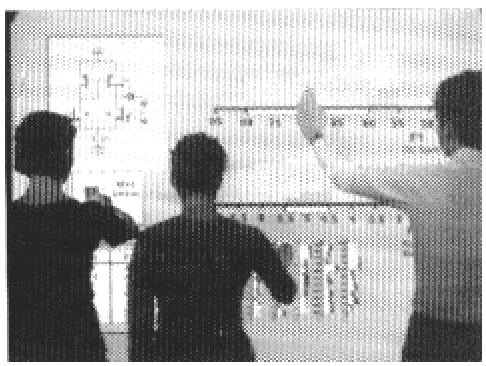
Many people, including myself, take the view that, over the next 20 to 25 years, affordable computational power, memory size and display capability will continue to increase at the same explosive rate we have witnessed over the last 20 or 25 years. An immediate implication - for me, at any rate - is that the inventor of user interfaces is limited primarily by imagination.

The same view was endorsed by the 12 visionary engineers I separately and confidentially interviewed last year with the aim of eliciting their visions of engineering design in the year 2020AD.

TRANSLATIONS
Many of the visions I elicited supported one conclusion:

"the convergence of computation and communication will especially be directed towards the building of 'bridges' between people of different expertise and between them and sources of data and knowledge".

This major envisioned outcome is reflected in the title, *Translations*, of the envisionment video I produced based on the elicited visions [47] [48]. *Translations* shows a dinner party taking place in the year 2020AD, hosted by an eminent engineer for other engineers who describe, for the benefit of a journalist, how they practice design.



The strong message carried by the video, reflecting the views of the designers I interviewed, was essentially concerned with *human-to-human communication* facilitated by computer. This focus was evidenced by examples which included collaborative work based on perceptualisation (a generalisation including visualisation), the use of 'transparent walls' linking designers in remote locations and the use of 'advisory agents' accessed via spoken questions addressed to a computer-generated face.

ACQUISITION OF INSIGHT
In conclusion, the situation now is similar to that of 1967 when it was clear to me that the computer offered enormous potential to support the acquisition of insight. It still does, and it is clear to me that we shall be investigating that potential, with increased vigour, for the next 25 years. I shall be one of those doing so.

Robert Spence: Publications on Interface Design

1 Spence, R., ***Interactive graphics in electrical circuit design: the user's requirements***, Convegno sulla Interazione Uomo-Macchina, Sorrento: Informatica, II, 1, supplemento, pp.196-206 (1971)

Probably the first description of a complete working interactive-graphic system for electronic circuit design, incorporating novel interface techniques.

2 Spence, R. and Drew, A.J., ***Graphical exploration in electrical circuit and model design***, Proc. 2nd Man-Computer Communication Seminar: Ottawa, NRC, pp.61-70 (1971)

Contains the first proposal of the use of animated Playfair circles for the qualitative presentation of circuit data, and the concept of interactive tolerance design. First identification of the value of interactive model design

3 Apperley, M.D. and Spence, R., ***Innovation in the application of interactive computer graphics to circuit design***, Proc. 1974 European Conf. on Circuit Theory and Design, IEE Conference Publication 116, pp.62-67 (1974)

4 Spence, R., ***MINNIE, a new direction in circuit design***, Electronics Weekly, 3 July 1974

5 Apperley, M.D. and Spence, R., ***A graphical dialogue for computer-aided circuit design***, Proc. 5th Colloquium on Microwave Communication: Budapest, Akademiai Kiado, pp.CT-17 to CT-24 (1974)

6 Spence, R. and Apperley, M.D., ***On the use of interactive graphics in circuit design***, Proc. IEEE Int. Symp. on Circuits and Systems, New York, IEEE, pp.558-563 (1974)

These four publications provide descriptions of an innovative, working, circuit design facility offering novel facilities such as (1) an on-screen calculator with result assignable to an on-screen object, (2) an interactive time-to-completion clock, (3) animated and interactive qualitative encoding of circuit properties mapped onto the circuit diagram, (4) a novel interactive hierarchical control mechanism offering summary 'state' information, and the extensive use of static and dynamic default options.

7 Apperley, M.D. and Spence, R., ***Flexibility in a minicomputer CAD system - a new approach***, Computer Aided Design, 7, 4, pp.262-264 (1975)

The provision of an executable APL-like notation enabled the user of a CAD system to easily modify that system to compute and display a wide range of performances of interest to the user rather than a small subset envisaged as sufficient by the system designer.

8 Spence, R., ***Human factors in interactive graphics***, Computer Aided Design, 7, 4, pp.49-54 (1976)

9 Spence, R. and Apperley, M.D., ***The interactive-graphic man-computer dialogue in computer-aided circuit design***, Proc. 1976 IEEE Int. Symp. on Circuits and Systems: NY, IEEE, pp.134-137 (1976)

10 Spence, R. and Apperley, M.D., ***The interactive-graphic man-computer dialogue in computer-aided circuit design***, IEEE Trans. on Circuits and Systems, CAS-24, 2, pp.49-61 (1977).

Key publications describing one of the first complete working interactive graphic CAD systems for electronic circuit design, and one which pioneered many advances in human-computer interaction. Novel interface techniques included the symbolic encoding of circuit properties, on-screen calculator, and advanced menu techniques. The system also demonstrated for the first time the human guidance of automated design, the interactive control of model simplification and many algorithms specifically designed to allow useful human interaction.

11 Spence, R., ***Aspects of highly-interactive graphic computer-aided design***, Proc. Conf. on Interactive Techniques in Computer-Aided Design, Bologna, 4 pages (1978)

12 Goodman, T.J. and Spence, R., ***The effect of system response time on computer-aided problem solving***, Proc. 1978 SIGGRAPH Conference, Atlanta, 4 pages (1978)

The first investigation of the effect of computer response time on the time taken by a human subject to solve, interactively, a prototypical graphical engineering problem.

13 Spence, R., ***New concepts in visual displays***, Proceedings of 'Vision and Visual Display Units', Institute of Opthalmology, pp.6-1 to 6-9 (1981)

14 Spence, R., ***Tomorrow's office with today's technology***', Electrical Times, pp.8-9 (Oct. 1981)

15 Apperley, M.D. and Spence, R., ***A Professional's interface using the bifocal display***, Proc. 1981 Office Automation Conference, pp.313-315 (1981)

Outline descriptions of the newly invented Bifocal Display technique for information presentation

16 Spence, R., ***Dynamic graphical interaction in engineering design***, in Proceedings of the NATO Advanced Study Institute on Man-Computer Interaction, Shackel, B. (ed): Noordhoff, Alphen aan der Rijn, pp.501-518 (1981)

17 Goodman, T.J. and Spence, R., ***The effect of computer system response time variability on interactive graphical problem solving***, IEEE Trans. on Systems, Man and Cybernetics, SMC-11, 3, pp.207-216 (1981)

The first investigation of the effect of response time *variability* on interactive-graphic problem solving of the type encountered in engineering design.

18 Goodman, T.J. and Spence, R., ***The effects of potentiometer dimensionality, system response time and time of day on interactive graphical problem solving***, Human Factors, 24, 4, pp.437-

456 (1982)

First investigation in which the effect of *simultaneously* variable parameters on graphical problem solving was observed under realistic conditions.

19 Spence, R. and Apperley, M.D., ***Data-base navigation: an office environment for the professional***, Behaviour and Information Technology, 1, 1, pp.43-54 (1982)

Describes the newly invented Bifocal Display technique, some of its forms and applications, and a vision of one context of its future use.

20 Apperley, M.D., Tzavaras, I. and Spence, R., ***A Bifocal Display Technique for Data Presentation***, Proceedings, Eurographics 1982, pp.27-43 (1982)

Discusses the hardware and software issues involved in, and provides solutions for, the implementation of a Bifocal Display.

21 Apperley, M.D., Spence, R. and Koanantakool, T., ***A Locate-and-Select device for touch screens***, Displays, July 1982, pp.131-134

A new touch screen mechanism allowing separation of the human activities of locating and selecting menemes within a menu system

22 Spence, R. and Apperley, M.D., ***Hierarchical dialogue structures in interactive computer systems***, Proc. 1982 Int. Conf. on Man/Machine Systems, IEE Conference Publication 212, pp.11-15 (1982)

23 Spence, R. and Apperley, M.D., ***Hierarchical dialogue structures in interactive computer systems***, Software - Practice and Experience, 13, pp.777-790 (1983)

Publications describing a new model for the control of an interactive, hierarchical menu-based system such as MINNIE characterised by extensive use of static and dynamic defaults.

24 Heppe, D., Edmondson, W.S. and Spence, R., ***Helping both the novice and advanced user in menu-driven information retrieval systems***, Proc. HCI'85, University of East Anglia, pp.92-101 (1985)

Presents novel techniques to support navigation in menu-based systems, including the first proposal of the 'sideways viewing' technique.

25 Apperley, M.D. and Spence, R., ***The role of a user's system model, and its relevance to user interface management***, in Pfaff, G.E.(ed) User Interface Management Systems: Berlin, Springer-Verlag, pp.195-202 (1985)

Contribution to the then current debate concerning the architecture of user interface management systems, a debate which generated to so-called Seeheim Model

26 Spence, R., Cheung, P. and Jennings, P., ***MINNIE: the way ahead for analogue CAD***, Silicon Design, March 1986

A description of the first commercially available interactive-graphic facility for electronic circuit design, now in industrial use, and based on earlier research.

27 Apperley, M.D. and Spence, R., ***Lean Cuisine: a low-fat notation for menus***, Interacting with Computers, 1, 1, pp.43-68 (1989)

A key paper presenting an entirely new notation to assist the human designer of menu systems. Its main advantages are that its complexity increases only approximately linearly with the number of menemes (menu items) and that its visual nature renders it a useful tool for creative thought. The paper introduces the new concept of virtual menemes. As has since been demonstrated, it is capable of extension to include semantic and presentation details, to be executable, and to be appropriate, following extension, to the description of direct manipulation interfaces.

28 Colgan, L., Spence, R., Rankin, P.J. and Apperley, M.D., ***Designing the 'Cockpit': the application of human-centered design philosophy to make optimization systems accessible***, SIGCHI Bulletin, pp.92-95 (July 1989)

Summary description of a new interface designed to support the human guidance of automated design.

29 Spence, R. and Parr, M., ***Decision support with multidimensional icons***, Proc. IMAGECOM, pp.252-255 (1990)

30 Spence, R. and Parr, M., ***The Cognitive Assessment of Alternatives***, Interacting with Computers, 3, 3, pp.270-282 (1991)

Presents the 'supermarket' metaphor and compares, through experiment, the effectiveness of integral icons and text in the human solution of a multi-parameter optimisation task.

31 Spence,R., Brouwer-Janse, M., Edmonds, E., Kasik, D. and Rankin, P., ***Practical Interfaces to Complex Worlds***, ACM, Proc. CHI'90, pp.257-260

A panel presentation, considering issues raised by engineering problems associated with the realisation of very complex engineering design tools such as MINNIE and CoCo of which I was a co-architect.

32 Colgan, L. and Spence, R., ***Cognitive modelling of electronic design***, Proceedings, Conf. on AI in Design, Edinburgh: Oxford, Butterworth-Heinemann, pp.543-559 (1991)

Describes the experimental method which led to the proposal of a new model of major aspects of the human activity of electronic circuit design

33 Colgan, L., Rankin, P.R. and Spence, R., ***Steering Automated Design***, Proceedings, Conf. on AI in Design, Edinburgh: Oxford, Butterworth-Heinemann, pp.211-230 (1991)

34 Spence, R., ***Automated Engineering Design: a Novel Interface***, Proc. 12th New Zealand Computer Conference: Wellington, NZCS, pp.207-215 (1991).

Two papers providing an overall description of the novel CoCo system for the human guidance of the automated design of electronic circuits

35 Spence, R., ***A New View on Electronic Circuit Design***, Proc NELCON'91 Conference: Palmerston North, NELCON, pp.1-6 (1991)

Describes a new form of interface appropriate to the qualitative stage of engineering design. It exploits the availability of simple models

36 Colgan, L., Gupta, A., Rankin, P.J. and Spence, R., ***Empowering Industrial Designers***, SIGCHI Bulletin, 23, 4, pp.50-51 (1991)

Within the context of an overall description of a novel automated design facility, this publication identifies important issues raised by such computer-aided design systems.

37 Spence, R., ***The exploration of multidimensional space: a critical industrial problem***, Proc. 13th IMACS World Congress on Computation and Applied Mathematics, Dublin, pp.174-175 (1991)

This paper shows how the realistic design of a manufacturable artifact involves the positioning of an N-dimensional Tolerance Region to have maximal weighted overlap with an N-dimensional Region of Acceptability, and advocates an awareness of the essential human involvement in this optimisation process.

38 Edmondson, W.S. and Spence, R., ***Systematic Menu Design***, Proc. HCI'92, Cambridge University Press, (eds. A. Monk, D. Diaper, M.D. Harrison), pp.209-226 (1992).

Describes a new approach to the systematic design of menu systems, and identifies notations appropriate to the component parts of the design.

39 Field, G. and Spence, R., ***Now, where was I ?*** New Zealand Journal of Computing, 5, 1, pp. 35-43 (May 1994).

Describes the results of experiments to determine the effect of interruptions on a human subject's use of a menu-based information system

40 Leung, Y., Spence, R. and Apperley, M.D., ***Applying Bifocal Displays to Topological Maps***, International Journal of Human Computer Interaction, 7, 1, pp.79-98 (1995)

The application of the bifocal display technique, and particularly its two-dimensional form, to the use of topological maps.

41 Colgan, L., Spence, R. and Rankin, P., ***The Cockpit Metaphor***, Behaviour & Information Technology, 14, 4, pp.251-263 (1995)

Describes the rationale and design of a metaphor which enables a human designer to observe and control the progress of automated design. It includes a description of the implementation of the metaphor within a fully operational design system

42 Spence, R., ***A Taxonomy of Graphical Presentation*** INTERCHI'93 Adjunct Proceedings (1993) pp.113-114.

Presents a novel taxonomy of graphical presentation which comprises four transformations having the useful property of being mutually orthogonal

43 Tweedie, L., Spence, R., Williams, D.M.L., and Bhogal, R., ***The Attribute Explorer***, Video Proceedings of CHI'94 and Conference Companion Proceedings, CHI'94, pp.435-436.

A new visualization tool which facilitates the acquisition of insight into the attributes of a collection of objects, and especially valuable for the identification of one best object - or a small group of 'interesting' objects - from that collection. It employs a novel form of interactive histogram and considerable enhances 'dynamic queries'.

44 Tweedie, L, Spence, R., Dawkes, H. and Su, H.,***The Influence Explorer***, Interactive Poster, Conference Companion Proceedings, CHI'95, pp.129-130, 1995

45 Spence, R., Tweedie, L., Dawkes, H. and Su, H.,***Visualisation for Functional Design*** Proceedings Information Visualization '95, pp.4-10 (1995).

A new visualisation tool called the Influence Explorer allows a designer to explore, interactively and dynamically, the interrelation between the performances and parameters of a designed artefact or scheme. New encoding and presentation techniques provide both global and contextual guidance, enabling trade-offs and correlations to be discovered and investigated, both qualitatively and quantitatively.

46 Spence, R., Bhogal, R., Tweedie, L. and Su, H., ***Responsive Visualisation - A Tool for Analog Designers*** Proc. IEEE Int. Symp. on Circuits and Systems, May 1995.

Describes an early application of the techniques embodied in the Influence Explorer to the task of analogue electronic circuit design

47 Spence, R., ***Visions of Design***, Journal of Engineering Design, 6, 2, pp.125-137

48 Spence, R., ***We Shall See***, New Zealand Journal of Computing, 6, 1a, pp.9-13 (August 1995)

Visions of engineering design in the year 2020AD were elicited via confidential interviews with 12 eminent designers. These visions were presented in conventional journal form and (see publication 59) via an 'envisionment video' using a dinner party being held in the year 2020 as the occasion for a discussion of "current" (2020) design practice.

49 Edmonds, E.A., Fischer, G., Mountford, J., Nake, F., Rieken, D. and Spence, R., ***Creativity Interacting with Computers*** , Companion Proceedings, CHI'95, pp.185-186 (1995).

The computer's potential to support creativity is debated......

50 Tweedie, L., Spence, R., Dawkes, H.,***Externalising Abstract Mathematical Models***, ACM, Proceedings, CHI'96 (accepted) (1996).

Description of the novel visualisation tools called the Influence Explorer and the Prosection Matrix, with a particular focus on the linking between different representations and the effective use of colour coding.

Note: The following publications are Video-tapes

51 **Minnie** (1976)

Presents the prototype (1977) MINNIE system for electronic circuit design, and describes the many novel interface techniques incorporated in, and designed for, that system. This video was possibly the first to be incorporated in the legal specification of a new product, the commercially available system described in publication 26.

52 **Bifocal Display** (1980)

Presents the newly invented Bifocal Display technique for information presentation, as well as a visionary context (the office of a professional) in which it could be used. This video was said to be the first 'Envisionment System'

53 **Minnie** (1986)

I produced and directed this video which presents a description of the industrial version of the MINNIE concept, in a form appropriate to potential users.

54 **Human Guidance of Automated Design** (1990, revised 1993) 6 minutes

Describes the generic problem of engineering design and how it can potentially be enhanced through the provision of an interface permitting human guidance of automated design. Shows, in action, a novel system (CoCo) for the human guidance of automated design, and focuses upon the three graphical interfaces involved.

55 **CoCo** (1991) 55 minutes

A detailed description (including publication 55 as an introduction) of the facilities and use of the implemented CoCo system for the manual and automated design of electronic circuits.

56 **The Attribute Explorer** (1993) 6 minutes

Presentation of a new artifact which allows responsive interaction with a volume of data in which items characterised by multiple attributes can be browsed in order to gain the insight that will permit the selection of a 'best' item or an 'interesting' group of items.

57 **The Influence Explorer** (1995) 6 minutes

Presents a new visualisation tool supporting fluent interactive exploration of the interrelation between properties and parameters of a designed artefact or scheme. It employs novel techniques to generate and encode data, and supports both qualitative and quantitative exploration.

58 **Translations - Engineering Design 2020AD** (1994) 20 minutes

A dinner party taking place in the year 2020AD is the setting for the exposition, by engineers (played by actors), of visions about how engineering design will take place in 25 years time.

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