DESIGNING THE "COCKPIT": THE APPLICATION OF A HUMAN-CENTERED DESIGN PHILOSOPHY TO MAKE OPTIMIZATION SYSTEMS ACCESSIBLE

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Abstract
The Cockpit is an interactive graphical display of results from analogue circuit optimization. It aims to overcome circuit designers' reluctance to use optimization systems by providing them with an interface that is easy and natural to use. The Cockpit presents the user with a 3D display which can be used both as a way of navigating the complex optimization data and as an overview of optimization progress. The Cockpit development process includes user interviews and rapid simulation of the user interface on a hypermedia system.

1. The Aim

Computer aided design (CAD) tools incorporating interactive-graphical techniques are found to be indispensable in many engineering fields. In the field of electronics, for example, a CAD system normally provides an analysis capability which computes the performance of an electrical circuit from input stimuli. Over the last decade or two, however, algorithms have been devised that would enable the computer to automatically change a circuit in order to meet specifications placed on its performance by a user. Such an automatic process is called **optimization.**

Although optimization algorithms have been successfully demonstrated, industrial integrated-circuit (IC) designers have shown a reluctance to use them. The lack of appropriate numerical methods is not responsible for this. Rather, the limited impact of optimization algorithms on industrial circuit design can partly be attributed to inadequate attention to the human-computer interface. The use of currently available optimization packages [1, 2] assumes a rare combination of skills: numerical analysis and circuit design as well as an (extremely rare) ability to fully specify an optimization problem before submitting it. Such demands result in confusion, reduced confidence in the system and consequently its rejection as a potential tool.

What is needed is a human-computer interface which allows access to algorithms but remains in the circuit designers' sphere of language and skills. An interactive graphical IC design system incorporating a symbolic rather than quantitative view of mathematical optimization could overcome designers' reluctance to use these algorithms.

2. Requirements for the Cockpit

Circuit design and optimization can be seen as multi-criteria decision-making processes. On many occasions the circuit designer is confronted with a decision in the face of competing objectives. To meet design objectives, design variables have to be chosen and adjusted in the presence of several trade-off relationships. In addition, the designer will also have a number of constraints which must be satisfied. The overall aim is to achieve the optimum circuit amongst several competing criteria, keeping design variables within given constraints

The user interface associated with the automation of such a process must allow designers to observe, control and modify the progress of circuit optimization in a fluent and natural way. As optimization is an iterative and often slow process, an on-line display of intermediate optimization results is a crucial element in this interface. This display, taken as the starting point for implementation, is named the "Cockpit", drawing on an analogy with an aircraft cockpit. The Cockpit must provide visualization of the problem solution path in "automatic pilot" mode until the user wishes to interrupt and take control. The cockpit has to keep the user informed of the speed at which a solution is being approached, or if a solution cannot be found with the chosen parameters then the user has to be informed as soon as possible.

A difficult problem the Cockpit has to deal with is presenting the mass of data associated with circuit optimization at each iteration. Not only does the user need to know about the progress of optimization but the following are also necessary: notification of design variable values; warnings of trade-off situations that have occurred; and signalling of critical electrical events and component states. This has to be done in such a way that the designer can assimilate all the relevant facts, but is not overwhelmed by a mass of information.

3. Design Solutions

The design of the Cockpit arose from the application of several user interface design principles [3]. Two factors played a large part in its development. Firstly, it was evident that the complex optimization process would be simplified if the designer could view the results of optimization at a high level of abstraction. This would reduce the amount of information being dealt with. Secondly, an approach which encourages visual thinking as an aid to problem-solving was felt to be appropriate for the Cockpit.

3.1 Symbolic Display

A 3D symbolic representation of optimization information constitutes part of the Cockpit display and is shown in outline in Figure 1. A hierarchical organisation of perspective windows (the polygon shapes in Figure 1) allows the user to customize what is viewed using a direct manipulation approach. The displayed hierarchy reflects the structure apparent in the objective function (a measure of the deviation between circuit response and specifications). The objective function can be decomposed into several levels containing weighted components reflecting the way it is calculated mathematically. For example, the overall objective function may be comprised of AC, DC, and Transient contributions. These, in turn, may be separated into circuit response contributions such as gain and power. Moving down a level, gain or power may be calculated at a particular node in the circuit. The next level may reveal a range of an independent variable, say frequency, over which a certain response is required.

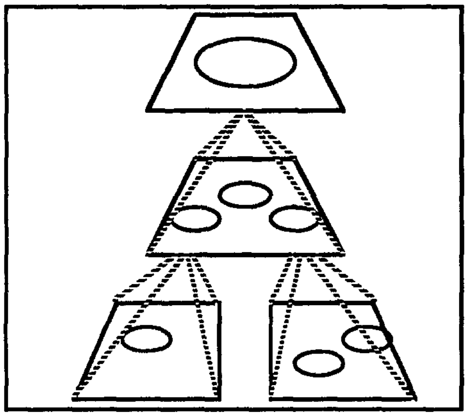

Figure 1: Hierarchical Display

This hierarchy is made overt by representing it graphically: a perspective window is created for each node in the objective function tree; and an ellipse-shaped symbol is added for each circuit response element on each level. All branches ensuing from the root of the tree combine to make the total objective function.

Optimization progress is represented by changes in the size of ellipses contained in the perspective windows on the screen. The distance from the solution is represented by the size of an ellipse in the appropriate window. In simple terms, the aim of optimization is to reduce the size of the ellipse in the top window as far as possible, reflecting the fact that the objective function itself is very small.

Violations of specifications, represented on the hierarchy by shaded ellipses (see figure 3), can be traced down the tree to give more detailed information on where the problem has arisen. These violations are represented in a qualitative fashion to allow the designer to work with thresholds rather than detailed quantitative data (a reflection of the fact that designers use notions of good and bad, built up through experience, in the circuit design process).

In addition to viewing optimization progress, the hierarchy may be useful for other user interface tasks. It could provide a method for setting up the optimization session. The exact construction of the hierarchy may not be the same for every optimization problem the user wishes to tackle. Presented with a dynamic hierarchy, the user may select and move ellipses until the appropriate hierarchy has been configured. In this way, the tree provides a configurable, object-oriented view of optimization which is a good match to the model in the circuit designer's mind.

Symbolically encoding data reduces unnecessary detail on the circuit diagram display. Here a schematic view of the circuit is shown with important nodes marked as ellipses. (Illustrated in the third level in figure 2.) This idea is similar to a road map with important towns marked on it. At a glance, the user can view which nodes are violating constraints and which are contributing a large amount to the objective function.

3.2 Direct Manipulation

The direct manipulation approach is relied upon heavily to produce a versatile, flexible hierarchy. For instance, selecting a certain ellipse-shaped symbol with the mouse opens up a lower level window displaying the constituent symbols. Conversely, clicking on the "close window" button folds that window up into its parent ellipse. The further down a particular branch the user traverses, the narrower is the range of information viewed, in other words the user is selectively filtering the data to be displayed on the screen (as shown in Figure 2).

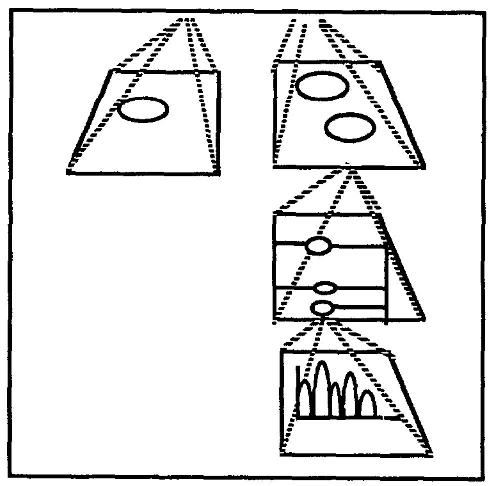

Figure 2: Accessing detailed data

Violations of user specifications, represented on the hierarchy by shaded ellipses, can be traced down the tree in this manner to give more detailed information about exactly where on the circuit, or where in the independent variable range, the violation occurred.

The window hierarchy can be scrolled, overcoming problems associated with crowding large quantities of information on the screen. The user can open up the appropriate number of windows and scroll to the chosen level.

Pull down menus are available on each perspective window enabling the user to alternate between several categories of information and change the form in which it is displayed. For example, rather than view the symbolic contribution to the objective function, the user can view the actual values or the weights associated with the objectives. By selecting the "detail" option on the menu, the schematic view of the circuit diagram can be changed to the actual view of the circuit.

Displaying the hierarchy in the perspective window format allows more data to be fitted on the screen and encapsulates the idea that the hierarchy is configurable rather than static. However, there are times when it is desirable to view the data in a flat format (for instance, when wishing to view the data in detail rather than in overview form). Again, the direct manipulation approach comes into operation by allowing the user to select a button which lifts the window into its upright position. In this position, all normal window management functions are available - the window can be stretched in size and moved around the screen.

The Cockpit display performs two functions: it aids in the navigation of a large quantity of data whilst maintaining a permanent trace of the chosen route; and it acts as a symbolic overview of the optimization process. Encoding information in this fashion reduces navigational problems in complex, hierarchical data and may have important implications for other domains.

3.3 Screen Design

The symbolic display is one of four windows on the Cockpit interface (Figure 3). Other windows allow the user to view a clock recording the iteration number, a bar chart display of design variable values, and icons which issue a warning alerting the user to some critical electrical event. These icons can be expanded to give more detailed information and advice to the user.

The items on the screen are positioned so that the display of optimization progress is central. The other windows are kept to the periphery. The user's attention is drawn to the icon display if an event of an interesting or critical nature occurs. The icons (displayed as lightbulbs) have a series of intensity-coded signals reflecting the seriousness of the warning. A very bright lightbulb may indicate the circuit is no longer electrically realisable. The user is then able to select the icon which will display the circuit diagram with the appropriate components highlighted. An explanation of the problem will accompany this.

4. User Studies

As part of the user interface design process, audio-taped interviews were carried out with circuit designers. These sessions involved giving experimental subjects a typical circuit design problem and asking them to spontaneously

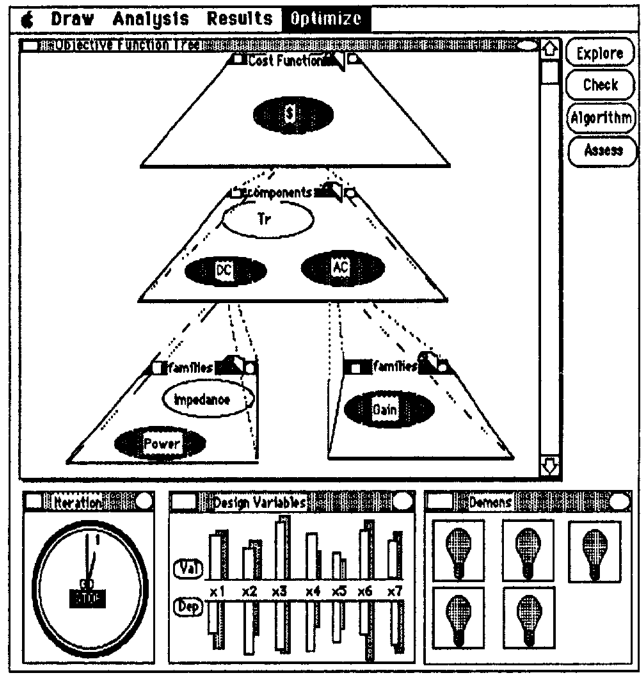

Figure 3: The Cockpit

verbalise their thought processes as they were attempting to solve the problem. The usefulness of this thinking aloud method has been indicated by Ericsson and Simon [4, 5]. The data were collected from retrospective and introspective angles. To achieve this, a circuit optimized previously by the subject, and an unseen circuit needing optimization were used. Protocol analysis aims to identify the internal models the user constructs when solving circuit design problems, so that they can be reflected in the user interface design. Specifically we aim to identify the episodes involved in the circuit design process and thus ensure that the interface allows the designer to work through similar stages when using an optimization system. This is useful not only for the user interface design, but may shed light on the circuit design problem-solving process.

5. Rapid Prototyping

Innovation and experimentation are necessary ingredients in the development of highly interactive, direct-manipulation user interfaces. If the cost of developing alternative versions is high, then inferior designs will result; it is unlikely that the first attempt at an interface will be the best. One solution is to incorporate an early assessment of a realistic interface simulation into the development process.

A number of ideas were generated regarding the Cockpit display, and a suitable means of evaluating these ideas prior to any significant implementation was required. Because of the complex nature of the application, any prototyping method which involved an actual interface to the application was out of the question.

Rapid prototyping, using HyperCard™ on the Macintosh™ resulted in an animated simulation of the Cockpit interface. Although primarily used as a testbed for design ideas, the HyperCard™ application provides a realistic, interactive representation of the user interface.

Using HyperCard in this fashion facilitates the production of a "storyboard", a term borrowed from the film industry, depicting typical sets of user interactions. A conventional storyboard involves the production of a series of snapshots of a dynamic sequence, in order to provide an overall impression of the continuous animation being described. This storyboard displays sequences of screen views demonstrating what happens when a user makes a selection. In this way it is possible to gain some impression of how the user interface will operate.

Implementation

Implementation on the Apollo™ profits from the use of an object-oriented User Interface Management System, Open Dialogue™. The 3D perspective graphics are being produced using a C interface to the X-Window system.

Conclusions

The Cockpit represents a novel solution to the user interface difficulties created by a complex problem-solving situation. The perspective window display captures the essence of the configurable hierarchy embedded in the problem.

It acts as a navigational aid for large quantities of data: overcoming user-disorientation by the maintenance of a permanent trace of the chosen route. It provides a symbolic overview of the optimization process that reduces the quantity of presented information, but still offers a powerful method of viewing progress.

The symbolic display may be generalised to other problem-solving domains which have an obvious internal hierarchy. Displaying this hierarchy on the screen for manipulation may offer a representation that is closer to the user's model of the problem than more typical computer displays.

The storyboarding approach facilitates communication of the user interface design to project team members and circuit designers for comment. The use of a hypermedia system supplies an element of realism to the interface in the very early design stages making visualisation of the eventual system easier.

Only when a set of user-evaluation experiments have been carried out will we know how successful our approach has been.

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