Decision Analysis in Design: Identifying Valuable Configurations with Expected Utility and Search

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Abstract

We describe the application of an expected utility analysis, in conjunction with a search through a design state-space, to generate and test alternative parameters that describe the nature and configuration of key components of a liquid-crystal display (LCD) for use in aircraft cockpits. We compute the expected value associated with each candidate design by considering different dimensions of value in a display. We consider the expected utility of each design by weighting the multiattribute utility assigned to each view angle by the likelihood of each angle. Finally, we describe how the notion of reliability and robustness in productioncan be integrated with the search for an optimal design.

1 Introduction

We address the problem of identifying an ideal set of parameters describing the components of a design. Designs can be sensitive to the details of a specification. For example, the contrast and chromaticity of a liquid-crystal display (LCD), as a function of view angle, can be extremely sensitive to the details of parameters describing the layers of a display. We describe a methodology based on applying a multiattribute utility analysis under uncertainty, in conjunction with a search through a design-parameter state state-space, to generate and test alternative parameters describing the nature and configuration of components of an LCD display. We describe how the expected value of each candidate design generated by a search can be computed by considering multiple dimensions of value in a display at different view angles.

An overview of the proposed method is displayed in Figure 1. We assume the availability of a predictive model that takes as arguments real-numbered values describing parameters of components of a design. Given some initial "best design," we begin a process of searching for alternative designs. For each state generated by a search, we determine the properties of the design with the design model. We then compute the expected utility of the design. We compute the expected value of each candidate design by weighting a multiattribute utility assigned to each view angle by the likelihood of the angle. We represent the likelihood of view angles with a probability distribution that dictates the frequency of different views taken by a pilot. We shall also describe how reliability and manufacturability can be folded into the search for an optimal design by employing a sensitivity analsis to determine the stability of the expected value, or individual components of value, of a particular design to small changes in the values of key design parameters.

2 Expected Utility and Design

To generate and compare multiple designs, it is critical to have a measure of the value of a design, and a model of the uncertainty to consider the likelihood of alternative ways a design will be used.

2.1 Multiattribute Utility and Value of a Design

What is the value or relative value associated with a design? A design often can be associated with multiple dimensions of value. It can be important to identify dimensions of value in a design, and to determine how these attributes of value can be combined in a way that reflects preferences about the quality of alternative designs.

Several dimensions of value in the appearance of an image displayed by

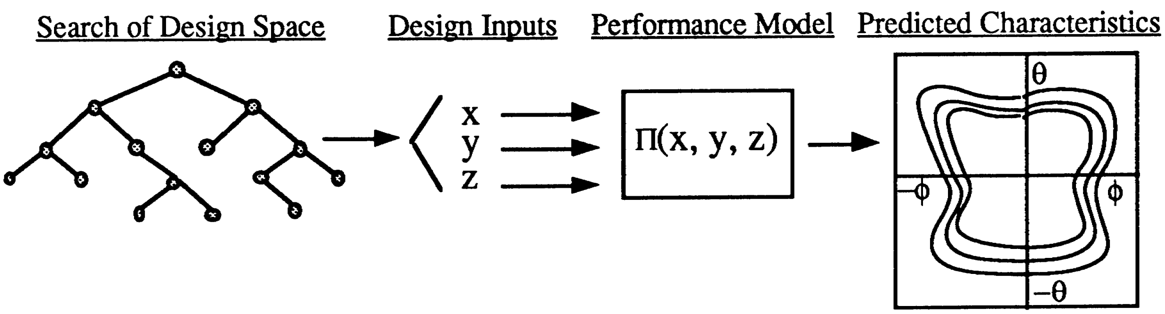

Figure 1: Overview of expected utility and search method for identifying new combinations of values of key parameters x, y, and z of an LCD. A search generates sets of parameters; for each set, we apply a design model Π to predict the properties of the design. Finally, we employ a utility analysis to determine the expected value of the design.

an LCD can be important in the perceived quality and usefulness of the LCD design. Let us consider feasible dimensions of value in the images displayed by an LCD *at a particular view angle.* We define a view angle $\phi\theta$, by the rotation from the normal of two perpendicular angles ϕ and θ. The value of the two angles defines an view angle in three space, $\phi\theta$. At any view angle $\phi\theta$, we might be concerned with the *contrast* and *chromaticity* of an image. We also may be interested in the *stability* of the contrast and the chromaticity of an image as small head movements are made around a view angle. Let us assume the latter four components of the utility of an LCD design $\mathcal{D}$. We assume that we have a predictive model Π that takes as arguments a set of design parameters x, y, z associated with a design. We shall use $\Pi(\mathcal{D})$ as an abbreviation of $\Pi(x, y, z)$.

There are several ways to combine dimension of utility. Combination rules include the multiplicative and additive models. Let us assume that the value of a design is captured by a multilinear utility model of the form,

$$\begin{aligned} U[\phi\theta, \Pi(\mathcal{D})] &= k_1 \times C[\phi\theta, \Pi(\mathcal{D})] + k_2 \times dC[\phi\theta, \Pi(\mathcal{D})] \\ &\quad + k_3 \times CH[\phi\theta, \Pi(\mathcal{D})] + k_4 \times dCH[\phi\theta, \Pi(\mathcal{D})] \end{aligned} \tag{1}$$

where U is the utility of a design, C is a function that returns the contrast, given view angle and design, CH is a function that returns the chromaticity, and dC and dCH are measures of the maximum change in the contrast and chromaticity as a function of a predefined small change in the view angle δ in any direction around the view angle $\phi\theta$ under consideration. We specify static and dynamic attributes because both can be important in the value of a display design: At any position, a pilot will notice the contrast as well as the instantaneous instability in a display based in small movements of the head and eyes that are a normal part of cockpit activities.

To date, to manage complexity, clients that are targets of an LCD design (e.g., Boeing) do not communicate expressive utility models. Rather, customers specify what is required in a design by dictating a set of simple constraints on a final display design. A utility model can be designed soley to satisfy the prespecified constraints. For example, to ensure that only designs that satisfy constraints are considered, designs that contain any view angles with constrast or chromaticity below thresholds required by the customer can be assigned an infinite cost. However, once constraints are satisfied, a more expressive multiattribute utility function can be employed to search for higher-quality solutions.

2.2 Expected Utility Under Uncertainty

In addition to identifying alternative dimensions of utility, we must determine the key uncertainties in a problem to make it possible to consider the *expected utility* of a design. The value of a design under uncertainty depends on the value associated with different actions and the probability of the different actions. In the case of LCDs, we must consider the set of mutually exclusive and exhaustive view angles and their likelihood. As highlighted in Figure 3, a pilots use of a display can be characterized by some probability distribution over view angles, $p(\phi\theta)$. The expected utility associated with a set of possible view angles is the sum of the utility of each view angle, weighted by the likelihood of the view angle. Thus, the expected utility of a design $\mathcal{D}$ is

$$\mathrm{EU}[\Pi(\mathcal{D})] \;=\; \int_{\phi\theta} p(\phi\theta) \times U[\phi\theta, \Pi(\mathcal{D})] \qquad (2)$$

The expected utility of an action is determined by summing together the utilities of different outcomes, weighting each by the probability of the outcome. We can expand this into a consideration of the distributions of ϕ and

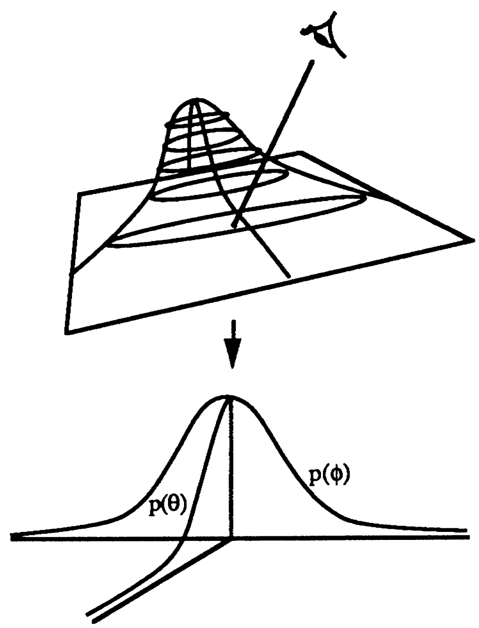

Figure 2: The value of a design depends on the way it is used. We describe the interaction of a pilot with a display with a probability desnsity function over view angle.

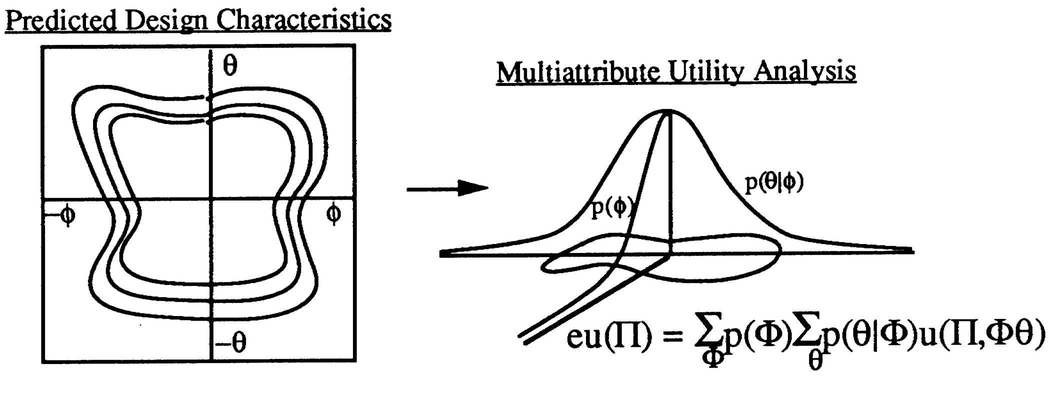

Figure 3: To compute the expected utility of a design, we weight the multiattribute utility associated with different view angles by the probability of that view angle as dictated by a probability density function.

θ,

$$\mathrm{EU}[\Pi(\mathcal{D})] \;=\; \int_{\phi=-\frac{\pi}{2}}^{\phi=\frac{\pi}{2}} p(\phi) \int_{\theta=-\frac{\pi}{2}}^{\theta=\frac{\pi}{2}} p(\theta|\phi) \times U[\phi\theta, \Pi(\mathcal{D})] \qquad (3)$$

If we are uncertain about the accuracy of the predictive model Π to predict the properties of a design we can embed uncertainty into $U[\phi\theta, \Pi(\mathcal{D})]$ by considering probability distributions over the attributes. For now, let us assume that the Π is a deterministic model. The best design available, $\mathcal{D}^*$, is the design with the greatest expected utility, given the probability distribution and the set of utilities.

2.3 Search Through a Space of Possibilities

We can generate sets of parameters for designs by employing search, or direct optimization techniques such as linear and nonlinear programming. Application of linear and nonlinear programming is hindered by predictive models for designs that rely solely on numerical techniques. There are several forms of brute-force and heuristic search techniques. In one approach, we start with the prediction Π^* associated with the best design available and increment each value in turn, forming a tree of distinct sets of design parameters. We

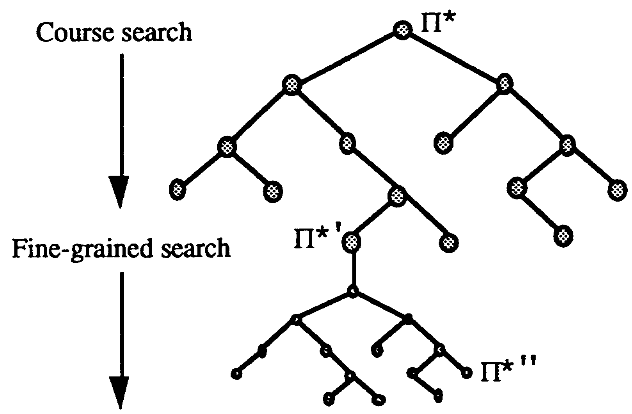

Figure 4: We increment or decrement each parameter to generate a tree of sets of design parameters. When we discover a promising result, we can change the granularity of the increments and, thus, perform a finer-grained search around the promising region.

increment each parameter by some constant amount tailored to the sensitivity of the design to that variable. We can constrain the search to include only reasonable values of each parameter. For each set of parameters output by the search, we can evaluate the expected utility of the design. We conserve memory by saving only those solutions with expected value near or greater than the expected value of the best design available so far. When we discover a new local maximum $\Pi^{*\prime}$, we can switch to a finer-grained search to explore the design space around the new maximum carefully. The finer-grained search is implemented by decreasing the size of the discrete steps taken to increment the values of the design parameters.

3 Considering Stability for Production Reliability

Often engineers are interested not only in the functionality of a design but in a design's *manufacturability* and reliability of operation. A design with optimal performance may not be easy to manufacture or may not be reliable in use, given small tolerances in the values of design parameters. A multiattribute utility function can include terms representing the value of the

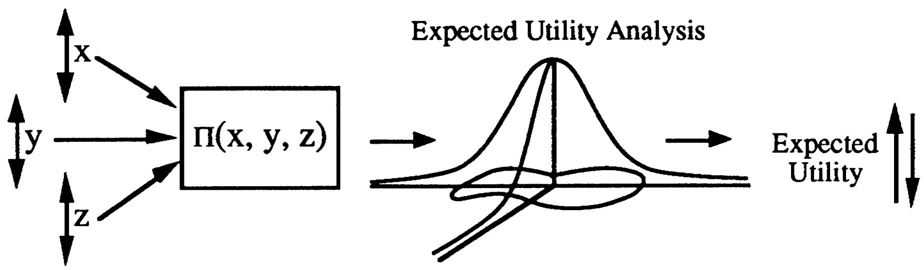

Figure 5: We can include in a multiattribute model a dimension of value associated with the stability of a design to small perturbations in the values of key parameters.

relative *insensitivity* of the performance of a design to small changes in design parameters. In particular, we can explore the sensitivity of the expected value of a design to parameters that are difficult to control precisely in manufacturing or in use. We perform sensitivity analyses of the expected value of a solution by varying the values of parameters around settings that yield a local maxima, and by observing the variance in the expected value computed for the design as these parameters are varied. In many cases, it may be best to select a more robust display at the expense of the utility associated soley with attributes that represent dimensions of functionality (e.g., contrast, chromaticity, etc.). For computational purposes, it is often best to identify local maxima before performing an analysis of the stability of the expected utility to small changes in parameters, as the stability analysis involves making multiple changes to the parameters around an expected-utility maxima.

4 Summary

We described a multiattribute utility analysis and search methods to generate and test alternative parameters describing the design of a liquid-crystal display (LCD). We discussed how we can compute the expected value of candidate designs by considering distinct components of value in a display at different view angles. For each design, the multiattribute value assigned to each view angle is weighted by considering the the likelihood of each angle with a probability distribution that dictates the frequency of different views.

Finally, we described how reliability and robustness in manufacturing can be folded into the search for an optimal design by considering the stability of the expected value, or individual components of value, to small changes in the values of design parameters.

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