TOWARDS AN EFFECTIVE USER INTERFACE FOR INTERACTIVE COLOUR MANIPULATION

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ABSTRACT

To take full advantage of colour in producing visually effective images, a good interface between the user and the system is needed that will allow for the easy selection of colours. Interactive manipulation, using instantaneous colour updating as the feedback mechanism is, of course, well suited for many applications since the trial and error process involved in selecting colours is made continuous. Hence a colour matching experiment using a raster computer graphics system is being conducted at the University of Waterloo to determine which of a number of colour spaces and interaction techniques are most effective in building a user interface for interactive colour manipulation. This paper describes the experiment and reports some preliminary results.

KEYWORDS: user interfaces, colour selection, colour spaces, interaction techniques, colour matching, opponent colours

1. INTRODUCTION

The increasing availability of high colour resolution computer graphics systems has led to a wide range of sophisticated applications wherein users select from a multitude of colours. Typical high quality systems offer in excess of 16 million colour values. Selection from such a large number of colours is clearly not a trivial task. Thus, to take full advantage of colour in producing visually effective images, a good interface between the user and the system is needed that will allow for the easy selection of colours.

To this end, a colour matching experiment using a raster computer graphics system is being conducted at the University of Waterloo. The experiment is a preliminary investigation into the general problem of interactive colour manipulation. The ultimate goal of this study is to determine which of a number of colour spaces and interaction techniques are most suitable for an effective user interface. Such an interface should allow colour manipulation tasks to be performed as quickly as possible and with a minimum of cognitive and physical effort. In addition, the interaction procedure must be easily learned by inexperienced users.

Colour manipulation is a difficult user interface problem since human colour perception is, to a significant degree, a personal experience [Goetz82a]. Furthermore, visual effects often occur when an image is displayed that make its perceived appearance quite different from what is anticipated. As a consequence, trial and error methods are needed for sophisticated colour applications. Interactive manipulation methods using instantaneous colour updating as the feedback mechanism appear to be well suited for these tasks since the trial and error procedure is, in effect, made a continuous process. A colour representation scheme, or colour space, is needed that can be used to create an effective user interface for such a system.

This study focuses mainly on the analysis of colour manipulation problems in which the number of colours available to the user is too large to effectively use English-based colour naming schemes (such as those described in [Berk82a] and [Kelly55a]) for colour specification. The fundamental limit of the ability of human cognition to associate names with colours seems to be about 1000 [Cowan83a]. Above this threshold, it appears that one needs a representation that can be subdivided to whatever precision is needed. As a consequence, only colour spaces that represent theoretically continuous colour gamuts are considered here.

Many such colour spaces can be found in the existing computer graphics and colour science literature. For example, in [Smith78a] and [Joblove78a] several colour systems that are considered 'suitable for applications involving user specification of colour' are presented. While the use of many of the systems described in these papers is now common in computer graphics, they have been criticized for oversimplifying the human colour perception process [Goetz82a]. A number of colour spaces that have been developed in the colour science community are described in [Wyszecki82a]. Although frequently used as quantitative tools in such fields as physics, lighting engineering, and psychology, for the most part these systems have been ignored in computer graphics. In particular, their application to a colour specification user interface has been generally rejected because of their presumably unintuitive nature. Several colour systems from both these disciplines are examined in this study.

Most colour representation systems have the common goal of ordering colours in a way that approximates the human perceptual system as closely as possible [Cowan83a]. All existing systems are, however, only partially successful in achieving this objective. A colour system that has been used informally as a basis for psychophysical colour-naming tasks, but that has not been investigated in detail, is one based on the opponent colours scheme of human colour perception. This psychophysical model attempts to mimic the behavior of the human visual system at an intermediate neural level. For this reason, we feel intuitively that such a colour space may well prove to be more easily learned and used than others and should be included in the study.

A colour representation system, by itself, is not enough to provide a user interface. Each colour space implicitly defines a set of coordinate axes in the colour topology. Since every perceivable colour can be represented as a point in a three dimensional space, or volume, the number of axes in a colour space is normally three. In terms of interaction, each of these axes defines a separate degree of freedom that can be conceptually linked to a particular property of colour (e.g. brightness). In order for interaction to actually occur, a user must have a means by which the three degrees of freedom, or colour properties, can be controlled. In computer graphics this usually implies the use of some sort of graphical input device. A tablet and a button-pad, or puck, are utilized in this experiment to provide an interface for colour manipulation.

In designing an interaction technique, another issue arises here. Will the user want to alter only one degree of freedom at a time, or will it be useful to manipulate two, or even three, degrees of freedom simultaneously? It may well be that the solution to this problem is dependent on the colour space used. We feel that this is also an important issue and is worth investigation.

The underlying evaluation mechanism of the experiment described herein is *colour matching* [Boynton79a]. Colour matching experiments have been traditionally used in psychophysics as a simple and fundamental way of investigating the human visual system. Since these experiments are psychophysically based, no attempt is made to understand or explain any of the underlying physiological mechanisms; rather, only cause and effect relationships are studied. We feel that such experiments are appropriate for our purposes since they include many of the characteristic interactions involved in more general colour manipulation tasks.

The experiment reported in this paper, then, compares a number of colour representation systems and interaction techniques to evaluate how effectively each can be incorporated in a user interface for interactive colour manipulation. This experiment is designed specifically to determine relatively large differences in interactive performance. The results of this experiment will guide futher analysis of this and related interaction problems. These results should also aid user interface designers in constructing systems that will allow users to perform colour matching tasks with a minimum of difficulty.

2. COLOUR SPACES

The experiment described herein compares the interactive performance of five colour spaces. Each defines a different set of three independent coordinate axes, or alternatively, a different way for users to traverse the volume of perceivable colours. Since the visual stimuli displayed during the experiment are rendered using a CRT video monitor, each colour space is effectively limited to the subset gamut formed by additively mixing varying intensities of the red, green, and blue phosphors of this device. As a further consequence of the technology used, each colour space must be ultimately transformed into the internal representation of phosphor excitations used by the graphics system. This is necessary since the colour spaces being evaluated are defined in terms of intermediate representation systems (e.g. HSV is based on the RGB system, CIE LAB is based on CIE XYZ, etc.). The hierarchy of transformations used to achieve this conversion is shown in Figure 1. Coordinates specified in higher level representation systems are converted by these transformations into the digital colour table values which are used to drive the three electron guns of the display monitor.

2.1. RGB

The RGB colour space is a rectangular coordinate system based directly on the excitations of the display monitor phosphors [Cowan83a, Berk82a]. The R, G and B coordinates respectively specify the red, green and blue phosphor excitations in the normalized range 0.0 to 1.0. One of the characteristic problems associ-

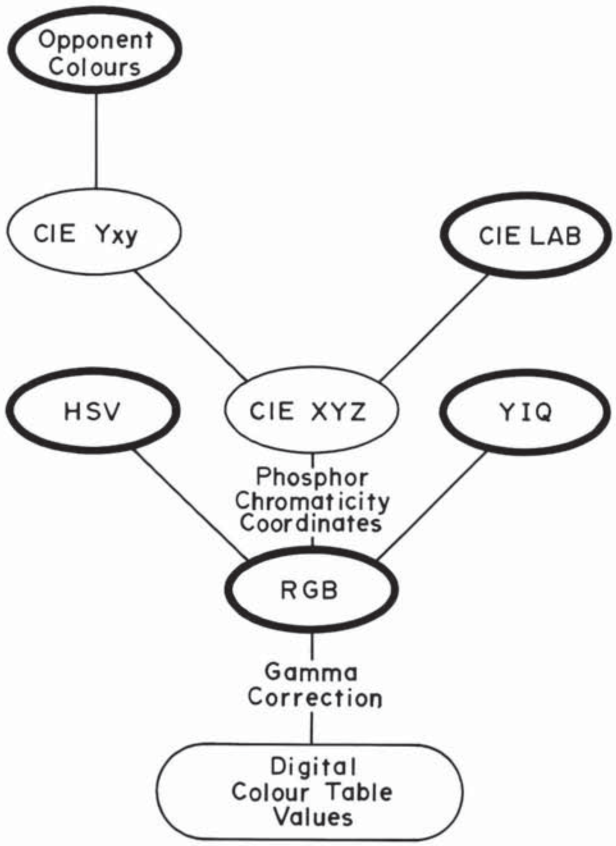

Figure 1. The colour spaces transformation hierarchy. Colour coordinates specified in higher level representation systems are reduced to digital colour table values.

ated with displaying images through a medium such as a video monitor is that the relationship between the driving voltages of the electron guns and the actual amount of light emitted is not linear. The implementation of the RGB space used here has been corrected for non-linearity using the gamma correction procedures outlined in [Cowan83b]. Coordinates specified in this system, therefore, represent linear excitation levels.

A colour representation based on the RGB model is available on practically all computer graphics systems since it is inherent in the display technology used. It is this availability and ease of implementation that make this system's use common in computer graphics. Many systems implementors are also partial to the RGB space because of its familiarity and simplicity. Furthermore, the RGB system is one of the standard colour representation systems adopted by the ACM/Siggraph Graphics Standards Planning Committee for the CORE graphics system. On the other hand, the RGB colour space makes little attempt to take into account any of the perceptual characteristics of the visual system and consequently is commonly believed to be counterintuitive for user interaction purposes.

2.2. YIQ

The YIQ colour system is the NTSC (National Television Standards Committee) standard for television signal transmission and is included in this study primarily because of its frequent use in television related industries. The YIQ colour space is derived from the RGB space using a simple linear transformation. The formula used to do this can be found in [Smith78a] and [Cowan83a].

The Y axis of this system is an estimation of *luminance*, or 'light energy emitted'. The separation of luminance from chrominance information (the I and Q axes) is an attempt to isolate a psychophysical property of the human visual system. It is a widely held belief that luminance is an independent degree of freedom at higher levels in the perceptual process. The YIQ system, however, makes several assumptions about the characteristics of the phosphors used in video monitors. The behavior of this system is consequently dependent on the display device used, since these assumptions are commonly not followed precisely by video monitor manufacturers.

2.3. HSV

The HSV colour space is based on the perceptual concepts of hue, saturation and value [Smith78a, Joblove78a]. *Hue* is defined as that particular property of a colour that 'enables it to be assigned a position in the spectrum' [Guralnik80a]. For instance, red, yellow and blue-green are different hues. Red and pink, on the other hand, are of the same hue but of differing *saturation*. Saturation is the attribute that quantifies the distance of a colour from the achromatic colours (i.e. white or gray). *Value* is loosely defined as the measure of a colour's distance from black. This property is related to luminance but is dissimilar in that all pure hues are considered to be of equal value but are not necessarily of equal luminance. Pure yellow, for instance, has approximately twice the luminance of pure red when displayed on a video monitor.

The HSV space used in this investigation is a direct implementation of the algorithm presented in [Smith78a]. Like the YIQ system, HSV is also defined with respect to the natural coordinates of the display monitor and is therefore also dependent upon the characteristics of this device.

Colour systems of the hue-saturation type are frequently preferred for colour selection tasks because they are based on concepts that users seem able to learn with relative ease. The HSV colour space is often used instead of other colour systems of the same 'family' because it is computationally inexpensive. It is also a standard colour scheme selected by the ACM/Siggraph Graphics Standards Planning Committee for the CORE graphics system.