ABSTRACT
We survey tools for colour selection, reviewing their shortcomings and strengths, and suggest a way of integrating their best features into a single tool.

Keywords
Group Colour Selection, Colour Interface Design, Colour Scheme

INTRODUCTION
Many users designing documents, web-pages and new interfaces find great difficulty with the everyday, and apparently simple, task of colouring fonts and shapes. Designers often start by hunting for a particular colour. They are frustrated by the difficulty of locating a preconceived colour sensation using conventional colour pickers, and also by the phenomenon of simultaneous (colour) contrast [1], which causes a colour’s appearance to be affected by the colours that surround it. Colour selectors, rather than displaying a small area of a single colour (Figure 1), should allow the user to select, and see the effect of selecting, groups of colours. They should take cultural associations and physiological effects of colour into account, and should make colour selection easy for those without training in art or graphic design.

Most users would prefer not to have to understand colour design but are primarily interested in getting acceptable, rather than optimal results. Some heuristics that usually work would be acceptable, especially if the results they produce can be easily “fine-tuned.”

Defining the Problem
The difficulties with selecting groups of colours can be summarized as follows:

1. the model underlying the colour selector is poorly understood, making it difficult use and difficult to find colours
2. colours are chosen out of context, and frequently do not appear as expected when applied
3. colours are chosen, not as a set but individually, without regard to other colours in the document
4. the concepts of colour harmony are not widely understood nor supported by the colour selectors

The first two points could be addressed by a better colour selector and how it is interfaced to the rest of the system. Points three and four concern the selection of harmonious colour groups. There is one other factor that should be mentioned; is particularly difficult to quantify the emotive impact and symbolism associated with particular colours and colour groups.

Colour Association
Ideally a group colour selector would take the effects of colour symbolism and association into consideration, but colours fashions change and preferences vary with age - there are no universally applicable rules. The selection of colour groups must take the intended effect of the design into account. For example, should the overall effect be harmonious or discordant, vivid or restrained? Is the product intended for adults, teenagers or young children.

There have been many classifications of colour “meanings”, from those recorded in Italy in the 15th century [2] to non-western civilisations [3]. The only consistent view is that particular colours have virtually no fixed meanings, although the basic colour categories appear to be universal [4, 5]. Within a culture, the “meaning” or symbolism of particular colour groups is fairly stable [6-8].

One possible method of dealing with the issue of colour association and symbolism is simply not to handle it at all, but make it so simple for the designer to alter the colours used in a scheme that they automatically and unthinkingly select “appropriate” colours.

Colour Order Systems and Colour Selectors
Physiological studies have determined that there are only three colour sensors in our visual system, which respond to long, medium and short wavelengths of light (loosely referred to as red, green and blue) – all visible colours can be represented with varying combinations of these primaries [9]. This is the principle underlying colour displays that use RGB primaries, such as most computer monitors. A monitor is only capable of generating red, blue and green – it cannot generate yellow light; however when both red and green are mixed, we see yellow.

This mapping of colours onto a numeric range of RGB values is an example of a colour order system. The RGB
(red, green, blue) system is well known but is not a “natural” colour system – it is difficult to predict the perceptual effect of a given linear combination of R, G and B values.

There are and have been many ordering of colours, with many differing intended purposes. The most common “real-world” colour selector is the colour wheel. This can be traced to Newton’s discovery of the component nature of light and his insightful wrapping of the spectrum into a circle. Previously, Aristotle had produced a one-dimensional sequence with the colours fitted onto a scale from light to dark.

The arrangement of colours – colour order systems – stretch back into antiquity. Gage [10] and Silvestrini and Fischer [11] have extensive coverage of historical colour order systems and the insights and reasoning that led to each particular arrangement.

Aguilonious in the early 17th century was one of the first to attempt a colour system with the now widely accepted red-blue-yellow artist’s primaries. His system, while adhering to Aristotle’s linear sequence, introduced a second dimension and distinguished between primary and secondary colours.

Goethe, writing in 1810 was, unlike Newton, interested in the emotional and artistic significance of colours, not their physical reality. Following Aguilonious, he proposed an arrangement of colours based on the red-blue-yellow primaries.

Classifications such as Goethe’s dealt primarily with the emotive effects of single colours, not groups. Although Newton did not consider such matters, and was primarily interested in the physical nature of colour, his wrapping of the spectrum into a circle and the placing of blue opposite orange led ultimately to the concept of colour complements and the formalisation of colour harmony.

Algorithmic Colour Harmony
The first algorithm for selecting harmonious groups of colours was developed by Albert Munsell [12]. This work on harmonious colour selection has been overshadowed by his Munsell Colour Order System – a three dimensional arrangement of colours, with a black-white axis and complement pairs derived from measurements of human perception. This was the first colour space to exhibit perceptually uniformity – the property that a line of a given length positioned anywhere in the colour space always passes through a set of colours with the same perceived amount of variation. This is important, as human vision is highly non-linear in its response to luminance, and even more so in its response to variations in wavelength. Experiments by MacAdam [13] showed that the human visual system is unable to perceive quite large colour variations in the green part of the spectrum, whereas its ability to discriminate small changes in blue is much more acute. Munsell’s colour order system, being based on measurements of human perception, rather than philosophical or physical considerations, automatically takes these nonlinearities into account.

Using his colour order system, Munsell theorised that an arrangement of colours would be harmonious if the product of (Chroma x Value x Area) of pairs of coloured areas averaged out to a mid-grey [12]. The underlying idea is that one should not simply use complementary colours in an image without taking into account the intensity of each colour – that is, how light or dark it is and how great an area of each colour is present. In Munsell’s terminology chroma specifies the purity or saturation of a colour and value specifies lightness and darkness. Today saturation is used instead of chroma (the mathematical definitions are similar, but not identical). The term value is still used, although lightness is more common.

Intense yellow and intense blue have equal chromas, but yellow’s value is much higher. Munsell theorised that in an image consisting of yellow and blue, the area of blue would need to be larger to counteract the greater lightness of the yellow. For two coloured areas to appear balanced, the product (chroma1 x value1 x area1) should equal (chroma2 x value2 x area2). This necessitates the use of complementary colours and produces an average colour of mid-grey. The resultant schemes do appear harmonious but are somewhat subdued.

In a generalized version of the algorithm Munsell allowed for arbitrary numbers of colours, positioned on an ellipse in the colour space. In this generalized algorithm, each coloured area was counterbalanced by an appropriately sized area of its complement. Munsell’s theory of colour
harmony automatically takes into account most of the seven forms of colour contrast later defined by Itten [14]:

- value contrast (light-dark)
- hue contrast (differing colour)
- saturation contrast (differing intensities of one colour)
- warm-cold contrast (red-yellow vs. blue-green)
- complementary contrast
- simultaneous contrast (the apparent presence of a complement)
- contrast of extent (size)

Although Munsell’s colour order system was phenomenally successful, having been adopted as the basis for colour classification systems world-wide, his colour harmony theory has been largely ignored because of the practical difficulties of matching coloured chips and calculating areas. Instead, non-professionals in the use of colour have turned to books such as the well-known Color Harmony 2 [6] and the more recent Colour Harmony Workbook [15]. These contain swatches for hundreds of colour schemes and have recently become available in machine-readable form. Kobayashi’s book A Book of Colors [7] is similar but uses a categorisation of colours based on surveys of colour-word associations to derive his color image scale [8]. This also differs from the more straightforward swatch books by incorporating secondary requirements, such as that high-intensity colours should occupy smaller areas than low intensity colours, as illustrated in Figure 2:

![Figure 2](image)

**The Current Situation – Selecting Colours**

This brings us to the present day. We now have personal computers with high-resolution true-colour displays, very fast processors, large amounts of memory and vast amounts of disk space. How has this increase in computing and display technology aided the non-artistic computer user wishing to choose a set of colours for a document? Sadly, the answer is “hardly at all”.

Software developers commonly present raw RGB values to users because the underlying hardware represents colours using the RGB space. The connection between RGB values and the colour seen is obscure and has led to much confusion. For example, to make a colour a little more subdued, a user should reduce the range between the maximum and minimum values of the RGB colour triad. However, most users do not understand the RGB colour space well enough to apply such a rule. For a computer-assisted system to help with choosing groups of colours, it’s necessary to move away from the vocabulary imposed by the technology and find a means of expressing colour relationships that relates to the way people perceive colour.

The Hue-Saturation-Lightness (HSL) colour space - one of the more natural colour spaces - is the basis of the colour selector provided by the Microsoft Windows™ operating system. In this selector the double-cone HSL colour space has been represented in two dimensions, with the hue circle “rolled out” into a rectangle (Figure 1). This flattened representation loses the clarity of the circular color arrangement. Important relationships such as complements are obscured. It is also perceptually non-uniform; the perceived lightness of hues with equal lightness values vary wildly.

**Colour Harmony Heuristics**

Three elementary heuristics for selecting harmonious colours are:

- pick varying shades of one colour (monochromatic harmony)
- pick complementary colours
- pick nearby (analogous) colours

With the colour picker shown in Figure 1, it is possible to pick a group of monochromatic colours by moving only the vertical slider. Analogous colours can be chosen by moving the cross horizontally but because of the non-linearity of the displayed hues, it is difficult to find a particular colour – the relationships between the numbers and the colours are obscure. There is also no support for picking complementary colours.

**Artistic Colour Selectors**

Microsoft Office includes the fixed-colour selector shown in Figure 3 as well as the normal selector (Figure 1). This radial arrangement of colours is a minor improvement over the rectangular arrangement in Figure 1. Initially it seems simpler to use, but a new user soon finds that the selection of colours is very restrictive. There are only 144 colours available (127 and 17 greys) and even the lightest colours – those just around the centre – can be too strongly coloured for use as subtle backgrounds, and the dark colours are often not dark enough.

An improvement on this minimalist colour wheel is the Bob Stein’s Visibone arrangement [16] of the 216 web-safe colours shown in Figure 4. This was designed to make choosing analogous and monochromatic colour groups much more intuitive. While advances in technology have largely removed the need for such a severely restricted palette, the arrangement has proven most popular and is still used. A companion JavaScript application enables the users to interactively select up to eight colours and have these displayed as adjacent colour strips. The perceptual non-uniformity of the RGB colour space, which underlies this model, restricts the usefulness of this tool for accurate specification of relationships such as complementary colours.

**Multiple Colour Selectors**

As might be expected, specialised graphics programs have more powerful colour selectors but surprisingly, the
increased sophistication is primarily in the ability to select a single colour from colour spaces other than RGB. The Corel suite of graphics products is unusual in that it combines both the availability of colour spaces other than RGB and support for selecting groups of colours (Figure 5). In this colour selector, the user points the black triangle at a key colour and the program then fills in the other colours according to the selected geometric shape. While the number of colours is fixed by the chosen shape, the user is free to alter the shape of the figure, for example making the rectangle long and thin or more square. For each of the chosen hues, a range of alternatives is shown varying in some other parameter such as saturation (shown here), tint (amount of added white), shade (amount of added black) etc. The user then saves the set of generated colours as a palette.

This harmonious palette can then be used as the basis for the colours in a document. An automatic update facility would enormously extend the usefulness of this tool by allowing the dynamic recolouring of a complete design by selecting a new key colour in the palette generator shown in Figure 5. It could be argued that the features of this tool are artistic considerations that should be under direct control of the designer. For professional designers this is undoubtedly true. However the majority of those using desktop document preparation tools would probably value such a facility. One could envisage a system that would satisfy both groups. All coloured objects would be initially linked to positions in the palette and pick up the new colours if the palette is updated, but some or all links could be broken by the designer if this was artistically desirable.

Colour Styles
The facility just described is the colour equivalent of text styles in a word processor such as Microsoft Word™. Such a system is available in a restricted way in the consumer-level publishing application Microsoft Publisher™. This comes with a range of predefined colour schemes which the user can add to and alter (Figure 6). Each scheme has a
“main” colour and five accent colours. As highlighted in Figure 7, Publisher’s colour selector shows the scheme colours, non-scheme colours the user has added to the document and provides access to an extended single colour selector. This system has fewer colours than the schemes generated by the Corel palette generator, but any later changes in the main or accent colours, will automatically update every object that’s associated with the scheme colours (Figure 7). This system is simple, easy to understand and very effective - complete documents can be recoloured very quickly.

FrontPage™, Microsoft’s web design tool, incorporates a similar facility. It provides “themes” for the textual elements and navigation graphics on a web page. Changing the theme can change the text font, colour and style and regenerate the navigation graphics. However, themes have a non-extensible predefined set of textual and graphical elements. A more general solution would be to allow the user to associate any design element with a dynamically extensible set of “scheme” colours.

Direct Manipulation Colour Selectors

Colours selected out of context look quite different in situ depending on their area and on the adjacent colours. The ability to experiment with colour schemes is thus necessary for all but the most talented designers.

Direct manipulation interfaces - one of the major advances in human-computer interaction - have yet to be widely applied to colour selection. However, several immediate-feedback colour selectors have been prototyped that recolour objects as the user moves the mouse on a colour wheel. These give a very intuitive interface that is a dramatic improvement over the usual “delayed-effect” colour selector dialogs.

The Colour Harmoniser

The systems discussed have three key features:

1. binding scheme colours and interface objects
2. no predetermined limit on the number of colours in a scheme
3. dynamic feedback on colour changes – to promote experimentation

It is not difficult to bind scheme and interface colours, or to change interface colours dynamically (though the interface for associating colours and objects could become unwieldy as the number of both increase).

The second feature is more problematic, for two reasons. Firstly, if the scheme has many colours, it becomes difficult to manually select sufficient harmonious colours, and secondly, the likelihood of undesired or unintentional interactions between the colours increases.

Visibility Constraints on Colour Selection

As the number of objects increases, so the number of colour interactions increases, especially if objects overlap. For example, if the text shown in Figure 8 is to be readable, the colour difference between the caption text and the button must exceed some minimum value. The button must be distinct from the background, but colour of the button and the colour of the word MENU can be identical as there is no positional overlap. The word MENU isn’t as distinct on the darker background but this could be intentional, and as the text is larger, the contrast doesn’t need to be as high for readability. For a general colour-scheme-selection system, there appear to be three major classes of colour interaction between interface components – colours must be identical, colours must be distinct, and colours are mutually unconstrained.

If interface components are categorized in the above manner, a RAD application could calculate the colour values using a generalization of Munsell’s postulates. The application has access to the object’s areas and colours and could easily handle the calculations associated with each object’s chroma, value and area.
It is essential for the algorithm to operate in a perceptually uniform colour space such as Munsell’s. However, there is no mathematically tractable mapping between his space and RGB. Instead the system could use the perceptually uniform CIE-LUV and CIE-LAB colour spaces [17], which have mathematically tractable transformations to and from RGB.

**Aesthetic Hints**

Using the above information (distinct, identical and mutually unrestricted), a system could calculate harmonious colours satisfying the distinctiveness constraints. There are, however, reasons for allowing the user to alter the chosen colour scheme. For example, the automatically chosen colours may be unsuitable for the purpose; bright pink and dark green are probably inappropriate for a corporate website. Alternatively, the colours chosen may give undue prominence to unimportant objects in the interface.

Therefore the user needs to be able to guide the system by providing hints as to the relative importance of objects. It is then possible to extend the constraint relationships so that objects are coloured both harmoniously and appropriately. The colours could be altered by moving the complete scheme (represented as a rigid geometrical shape, similar to the rectangle shown in Figure 5) within the colour space. As the space is perceptually uniform, all the constraints would be preserved. This technique is discussed more fully in [18].

Modern RAD tools allow the developer to bind in new components that modify and extend the program development environment. A colour scheme selection component would allow the RAD environment to dynamically and immediately recolour interface elements as the designer or the system modifies the colour scheme.

**CONCLUSION**

The selection of groups of colours that are harmonious is problematic with virtually all colour selectors currently available. Those that do support the selection of integrated colour schemes are limited, either in scope or the potential for dynamic interaction and control. Several key factors have been identified that could be incorporated into a semi-automatic colour group selector. This would provide a way of choosing harmonious colour schemes for complex interfaces that would enforce colour distinctiveness constraints and also promote experimentation by the designer.

**REFERENCES**

17. Colorimetry. 2nd ed. CIE Publ. No 15.2. 1986, Vienna: Central Bureau of the CIE.

**NOTE**

This paper, with the diagrams in colour, can be downloaded from http://colourharmony.massey.ac.nz