Nine Tools for Generating Harmonious Colour Schemes [1]

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Abstract. We survey a number of tools that have been developed for generating sets of colours according to commonly accepted rules for colour harmony. Informal manual techniques for generating harmonious sets of colours have been known and used for at least a century. Although superficially simple, they have not been precise techniques, as pigment-based and dye-based colouring techniques are not susceptible to accurate measurement, in terms of area of colour used or mathematical relationships between colours, and mathematical analysis does not appeal strongly to the design community. Now the historical separation between engineering and design has narrowed. First, the development of colour television brought numerical precision into colour specification. Secondly, in computers, the medium for colour representation and the tool for calculating colour parameters have been integrated. Consequently, it has also become feasible to derive sets of harmonious colours automatically.

1   Introduction

This research is part of a long-term investigation into techniques for selecting harmonious groups of colours for computer interfaces. The current focus is on designing an interface visualisation that facilitates exploration of a colour space. After a brief description of the background to the work, we present a survey of existing interfaces in tools for choosing colours using colour harmony heuristics.

1.1   Colour Selection Is Important

Colour is ubiquitous. We see its strong subliminal effects in many areas. For example:
- Advertisers are skilled in combining colours for effect. They imply urgency with light, saturated primaries, and sophistication with carefully selected tertiaries [1].
- Political parties - indeed whole political ideologies - are summed up by a single colour ("The Greens," and that 1950s clarion call: "Better dead than red")
- Colour-coding is used by many graphic artists to make a diagram's components more recognizable than if they were identified solely by shape or by name

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[1] in full colour at www-ist.massey.ac.nz/plyons/papers/Lyons and Moretti 2004 (Nine Tools).pdf

- In the workplace, colours are found to have significant effects on productivity. Greens are often used for their restful effect, but poorly chosen greens can induce nausea, and reduce productivity. Areas of strong colours can cause eye fatigue [2].

In general, interfaces with garish colours are undesirable; users should be able to concentrate on the task at hand, without being conscious of the appearance of the interface. That is, it should be perceptually visible, but cognitively invisible.

1.2   Colour Selection Has Become Even More Important

There are more colours available now than there used to be. Once, our environment was mostly made up of natural materials with inherently harmonious colours. Now it is largely manufactured; we are free, indeed *obliged* to choose, the colours of everything, including computer interfaces, from a range of thousands.

1.3   Colour Selection Is Difficult

Colour space is large. Even acknowledged masters of the area have trouble exploring it. Josiah Wedgewood, for example, performed over 10,000 experiments to find the best pale blue to contrast with the white decoration on his jasper ware [2]. Colour specialists specify colours in terms of a 3D colour solid with hue, saturation and brightness axes, but most non-specialists aren't familiar with 3D colour spaces, and have difficulty correlating a particular colour with a location in the space, and finding sets of points in the space that exhibit desirable colour relationships.

1.4   Colour Interactions Are Important

Colours never occur in isolation. Our perception of a colour is invariably influenced by simultaneous contrast, which is caused by the way our perceptual system exaggerates differences between adjacent parts of an image. For example, an orange background makes red areas appear yellower, and yellow areas appear redder [3].

1.5   Computer Programmers Are Not Colour Designers

GUI interfaces involve visual design, by definition. Their features differ in size and importance so they are often colour-coded for differentiation. Overlapping screen objects need to be clearly distinguishable. In addition, as interfaces are often used for long periods, poorly designed colour schemes will lead to user fatigue.

   Software developers are rarely skilled in considering all these factors. They are more likely to choose colours on the basis of their individual attractiveness. Not only are most system designers amateurs in designing for colour, but many senior designers "grew up" using software designed to run on 16-colour or 256-colour hardware. Worse, just about the time when designers started using 24-bit colour in applications, the World Wide Web rose to prominence. Web designers had to allow

for outdated user hardware, and they standardised on a 216-colour "websafe" palette [4], that delayed the universal use of full-colour interfaces.

To summarise:
- colour selection is important for computer applications
- colour selection is difficult
- colour selection for interfaces concerns interaction more than individual colours
- computer application developers are not trained in colour choice or interaction
- computer applications developers have been inured to garish colour schemes

2   Computer-Aided Selection of Harmonious Colour Sets

Informal manual techniques for generating harmonious sets of colours have been known for at least a century [5, 6]. They are generally based on geometric relationships within a colour wheel. A set of colours will be harmonious if the members of the set are chosen: from a small range of hues near each other on the colour wheel (analogous harmony); from a full saturation base hue and the colours obtained by mixing the base hue with white (tints), black, (shades), grey (tones) (monochromatic harmony); from a range of greys (achromatic harmony) from a base hue and the hue directly opposite it on the colour wheel (complementary harmony); from a base hue and colours close to, and equidistant on the colour wheel from its complement (split complementary harmony); from a base hue and two others chosen so that the three colours form an equilateral triangle on the colour wheel (triad harmony), from a set of four colours equidistant around the colour wheel (tetrad harmony); from a set of colours disposed on an oval around the colour wheel (polyadic harmony). Such heuristics seem vague but are widely recognised as ways of achieving harmonious colour combinations [2-4, 6-11] Many writers attribute these heuristics to Johannes Itten [5] of the Bauhaus (1919-1933) design school, but most of them are common coin amongst artists, and they certainly antedate the Bauhaus. For example, Albert Munsell [6] published all of these heuristics, around 1905.

Fig. 1 shows two view of the L*u*v* colour solid [12], a 3D colour space like Munsell's, but mathematically tractable). Munsell held that an image would be harmonious if it was centred on grey (Itten also used this criterion at a descriptive level rather than as a rigorous mathematical technique). Munsell's criterion can be summarised thus:

$$\sum_{n=1}^{c} (CS_n \cdot A_n) = 0$$

Munsell based his colour harmony heuristic on a more sophisticated three-dimensional solid, based firmly in empirical measurements of human colour perception. (

where   c is the number of colours in the image
* CS_n, (the colour strength of colour$_n$) = saturation$_n$ x lightness$_n$*
*   A is the area of colour$_c$*
*   and the scales are chosen so that mid-grey has a saturation and lightness of 0*

For example, a small area of light, high saturation red (with a high CS) would balance a larger area of low saturation, dark green (with low CS). This approach is much more powerful than Itten's simple colour wheel heuristics, but it requires measurements of hue, saturation, lightness, and area for each colour in an image. The technique was largely ignored the twentieth century in favour of Itten's heuristics.

Engineering and design have converged significantly since Munsell's seminal work. Precision and mathematical tractability were brought into colour specification by the development of colour television, and computers have made the calculations trivial. Consequently, it has also become feasible to derive sets of harmonious colours automatically using Munsell's techniques. Here we report the results of a survey to determine the extent to which mathematical modelling of colour harmony has been incorporated into commonly available tools for generating harmonious sets of colours.
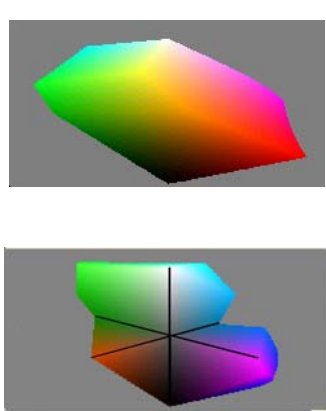
Fig. 1: External and cutaway views of the L*u*v* perceptually uniform colour solid.
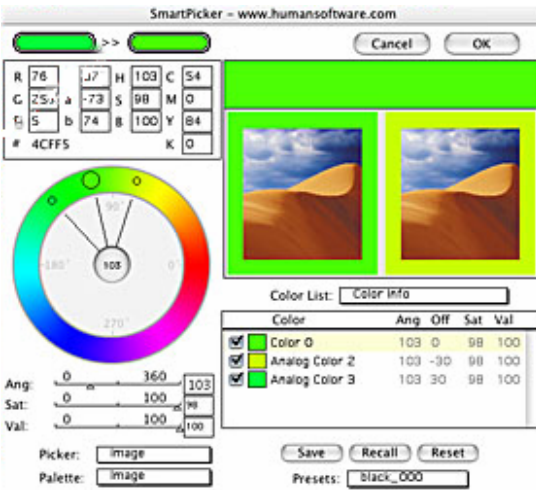
Fig. 2: SmartPicker, a CW/RW (Colour Wheel/Rotating Wireframe) interface

3   The Survey

While researching techniques for specifying sets of harmonious colours for computer interfaces, we searched for colour selection tools that take account of colour harmony heuristics. Here we survey features related to colour harmony in the tools we found.

Most of the applications show a colour circle overlaid by a rotary wireframe in the shape of one of the abstract schemes. We denote this interface style as **CW/RW** (Colour Wheel/Rotary Wireframe).

In most cases, the colour circle is affected by the three-primary-colour technology of CRTs; primary colours use one phosphor, secondary colours use two. Thus, unless the software normalises the brightness of the secondary colours (cyan, magenta, and yellow) they are significantly brighter than the primaries. This produces a set of light

coloured "spokes" representing the secondary colours, oriented at 120^0 with respect to each other. We say that such interfaces use an **unnormalised colour circle**.

None of the tools provide real-time update of a user-generated image, though several have a built-in selection of representative images that are updated when the user chooses a new set of colours

3.1   SmartPicker: A Typical CWRW Interface

SmartPicker [13] is a plugin for Photoshop that runs under MacOS 9 and X. It produces sets of colours conforming to analogous, complementary, split complementary, monochromatic, tetradic and triadic colour schemes via a CW/RW interface with an unnormalised colour circle. The points where the wireframe intersects the colour circle specify the components of a concrete colour scheme, and the user rotates the wireframe to choose a new set of colours.

In SmartPicker, slider controls are provided for specifying the lightness and saturation after the hue selection stage. The number of colours is restricted to three.
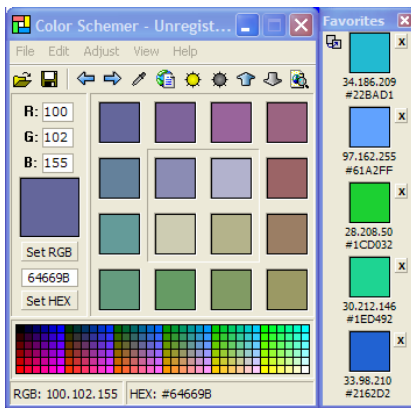
Fig. 3: The ColourSchemer interface produces a colour "wheel" tailored to a user-specified base colour in the top left corner of the 16-colour square
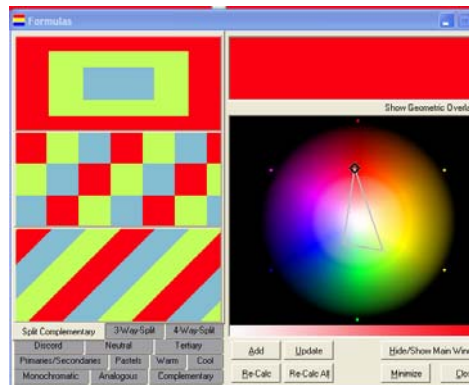
Fig. 4: ColorSchemes produces 13 types of colour scheme based on the choice of base colour from a wheel showing the surface of the colour space

3.2   ColorSchemer

Colorschemer [14] allows the user to specify a base colour, shown in the swatch on the left hand side, and at the top left of the square of colours in Fig. 3, It then fills in the remaining fifteen locations in the square with other colours related to the base colour by the rules of colour harmony. Eleven of the other colours are distributed in colour-wheel-order order around the square, with the top left hand corner occupied by the base colour, and the four central positions occupied by lighter and darker versions

of the base colour, and lighter and darker version of its complement. The user can thus easily select a colour scheme based on one of the standard colours schemes. However, the number of colours in a colour scheme produced by the system is restricted to three or four. If more colours could be chosen, they would not harmonise.

3.3   ColorSchemes

ColorSchemes [15] uses a variant of the CW/RW interface (Fig. 4). The circular view is more than a circle of hues; it shows the complete exterior of a spherical colour solid. From the centre of the circle to half the radius, the interface shows the sphere from above, with the white pole at the centre. Beyond that point, it shows the "skin" of the lower half, stretched so that the black pole forms the circumference of the circle. The user interacts with this display by choosing a base colour, and the software displays a set of (full saturation) colours that correspond to the user's choice of one of colour scheme from a set of eleven. A wireframe corresponding to the chosen scheme can be superimposed on the colour circle by selecting "Show Geometric Overlay," and the user can changes any of the colours in the scheme by repositioning any of the vertices of the wireframe A sampler shows the selected colours in a geometric pattern that, in the opinion of the authors, effectively disguises the harmony of the colours.

Fig. 5: The HP Colour Wheel displays a swatch with a large region of a base colour and smaller regions of harmonious colours corresponding to a particular colour scheme (here, a tetradic scheme)
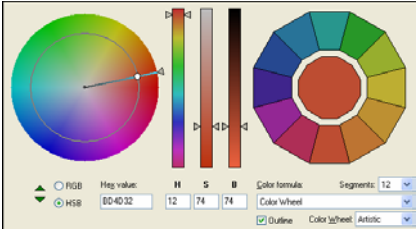
Fig 6: ColorImpact's wheel allows simultaneous alteration of hue and saturation, with instant feedback on sliders and a colour palette.
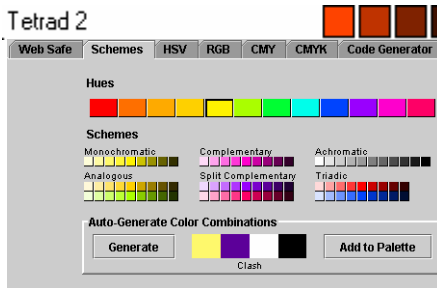
3.4   HP Colour Wheel

The HP Colour Wheel [16] is an applet that displays an unnormalised CW/RW image with complementary, split complementary, analogous, triadic, and tetradic colour schemes (see Fig. 5). The user can rotate the wireframe around the circle and a set of colours corresponding to the colour will be displayed in the area to the right of the colour circle. Sliders alongside the colour wheel allow the user to change the saturation and brightness of the colour set that is generated as a whole. There is no facility for changing the brightness or saturation of individual colours.

3.5   ColorImpact

ColorImpact [17] has a CW/RW interface with an elegant control (the small white circular handle shown in Fig 6 where a radial line and a black circle intersect) that allows both the hue and saturation of a base colour to be specified simultaneously. Although a number of interfaces provide a visualisation that allows simultaneous specification of hue and saturation, the explicit representation of both polar coordinates (the radial line shows the angular coordinate and the black circle shows the length coordinate) works as a visual feedback mechanism that lends a feeling of control that is out of all proportion to its simplicity. The elegance of the interface is further enhanced by immediate feedback between this control and the Hue and Saturation sliders; the colour wheel does not alter brightness, so there is no interaction between the handle on the colour wheel and the brightness slider.

The application generates a polygonal palette – the number of sectors can vary between three and thirty-six – containing colours harmonised with the base colour calculated according to a "formula." The formulae incorporate the usual complementary, split complementary, monochromatic schemes, and a number of others that are more ambitious. However, these are not presented in the context of the colour space (even a simplistic colour wheel), and it is difficult to correlate a "formula" (see Tetrad 2, below) and the heuristic that was used to generate it.

Fig. 7: ColorWrite's interface presents colours from various colour schemes; the user can add colours from any of these schemes to a palette.

Fig. 8: The wireframe in Life Software's CW/RW Colour Wheel is extensible; it allows the user to select a range of lightnesses. The grey lines at 9 and 12 o'clock are artefacts

3.6   ColorWrite

Colorwrite [18] presents the user with a range of full-saturation hues (Fig. 7). When the user selects a hue, the software generates six colour schemes. The monochromatic range, for example, comprises nine colours with the same hue as the user's base colour, and a range of lightnesses. Other schemes follow a similar pattern, except that analogous and split complementary schemes have two ranges of colours in addition to the base hue. There are other tabs in which the base colour can be specified in HSV, RGB, etc. units.

After experiencing a number of other, colour wheel-based applications, it was interesting to test ColorWrite, which, lacking a CW/RW interface, forces the user to model the behaviour of the colour selection heuristic cognitively. The underlying behaviour of the two types of application is of course the same; a CW/RW system, doesn't really rely on the rigidity of a rotating wire shape to define a consistent relationship between positions on a colour wheel. Nor does the application sample the colours at the ends of wireframe when it comes to rest. CW/RW applications replace pondering with perception. It is surprisingly unsettling to be forced to return to pondering, and the user feels that the application is running by "magic."

3.7   Life Software Color Wheel

Life Software's Color Wheel [19] has an interesting feature that makes it more intuitive to use. At heart, it is a CW/RW system with an unnormalised colour wheel (Fig. 8), but unlike the others, its colour wheel represents two dimensions of the colour space, lightness and hue[2], *and* the user can extend the wireframe (so that the colours chosen are full-saturation hues) or contract it (so that the colours are light, low saturation colours, typically called pastels[3]). This makes the software more intuitive to use than some of the other colour choice interfaces – even though the number of colours chosen is restricted to three.
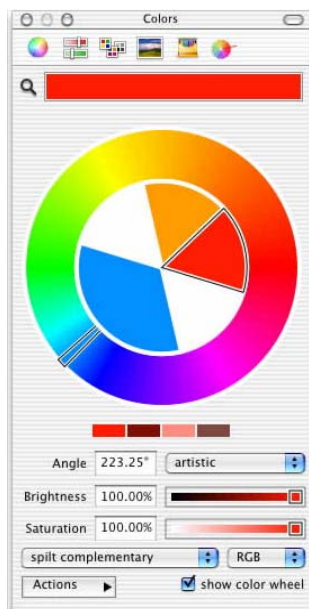
Fig. 9: Painter's Picker can replace Apple's MacOS colour picker
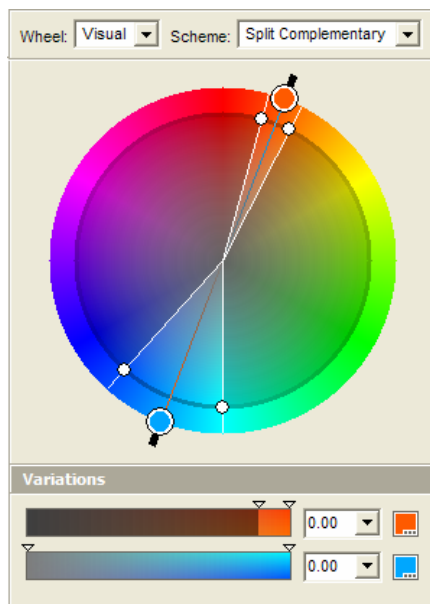
Fig. 10 Color Wheel Pro can be configured to specify hue ranges

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[2] The lightness range is not complete; all the colours displayed have a minimum value of 255 for at least one of R, G, and B, so only hues and tints are displayed; there are no shades.

[3] though real pastels incorporate some of the highest concentrations of pigment in any painting medium, and can thus be more highly saturated than most paints

3.8   Painter's Picker

The oddly named Painter's Picker [20] is an alternative to the Apple Color Picker in MacOS X. It does not explicitly show a colour scheme wireframe but it is essentially a conventional CW/RW system (Fig. 9). Its main distinguishing features are its MacOS compatability, its fourteen colour schemes and two types of colour wheel, one based on the RGB primaries, another on artist's RYB primaries. Though the latter does not orient the CMY secondaries at 120^0 to each other, the wheel is still unnormalised; the secondaries are brighter than the primaries, for technical reasons explained earlier.

3.9   Color Wheel Pro

Color Wheel Pro [21], (Fig. 10) is a more than usually customisable CW/RW interface. Three features set it apart. First, each "colour" chosen is a range of hue, lightness and saturation. Secondly, the wireframe shape of a scheme is capable of some customisation. For example, the angle subtended at the centre of the colour wheel by a pair of analogous colours can be varied from 0^0 to 120^0. Thirdly, the colour scheme is presented on a realistic image at a realistic size (*much reduced in the adjacent inset*). This combination of controls generates a set of colour regions from which the user can select individual colours, or colour ranges which can be used as a gradated fill. The system automatically chooses a range of saturation and lightness for each colour region. The user may increase or decrease the range.

4   Discussion

The use of colour wheels for colour harmony derives from the spectral model of *light* that Newton developed as a result of his famous prism experiments [22]. But *colour* is a complex psycho-perceptual construct: in the retina, ganglia transform signals from S, M, and L[4] retinal cones into values on orthogonal red-green, blue-yellow, and light-dark axes. Further processing in the visual cortex converts these into a sensation that requires three dimensions - hue, saturation and brightness – to characterise it adequately [2, 12].

   Although the colour-set selectors reviewed here often incorporate separate controls dedicated to saturation and brightness, most of them use an underlying model of the colour universe that is one dimensional[5]. Indeed, the help system for Color Wheel Pro, the last application surveyed, includes this interesting assertion:

   Color theory analyzes only the relationships of pure colors, it does not take color lightness and saturation into account. While your color scheme can use any tints, shades, and tones, color theory pays attention only to the hue component.

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[4] Short-, medium-, and long-wavelength-sensitive (loosely, blue-, green-, and red-sensing) cones
[5] A colour *wheel* with no information encoded in its radial dimension - as in most of the surveyed applications – can perhaps be thought of as a 1½D representation.

The developers of most of the applications surveyed seem to labour under the same misapprehension. Such a simplification based on Itten's theories of colour harmony[6] was perhaps justifiable when designers and artists used brushes. However, now that the design medium is the computer, Albert Munsell's earlier and more sophisticated theory [6] that accounts for saturation, lightness and area of colours, is viable.

All of the surveyed applications that display colour wheels are non-linear, because their colour wheels are unnormalised. In addition, they do not account for the fact that the human perceptual system does not accord all full saturation hues the same brightness. Ideally, all full saturation hues would occur on the equator of a spherical colour solid. In fact, Munsell's experiments showed that full saturation yellow, red and blue are (respectively) brighter, darker, and darker than full saturation green. And full saturation yellow, red and blue are respectively more, less and less saturated than full saturation green. Thus a *perceptually uniform* colour solid is a rather bulbous-looking blob. Only if the colour space is represented as this shape will the neat geometrical wire frames reliably generate harmonious sets of colours.

It is our view that the tools surveyed fall short in several respects. They do not allow for technologically-generated inconsistencies in the colour wheels they use. Their visualisations do not display the full three-dimensional structure of the colour universe. Consequently they do not make it easy to position colour choices in the three-dimensional colour space, or to change colour choices in real time. Although most of them allow the user to visualise colour harmony heuristics as simple wire frames, they do not maintain a constant relationship between point-to-point distances on a wireframe and colour differences as experienced by humans. None will update a user-supplied image in real time, though several have a selection of built-in images that they recolour each time the user tries a new set of colours.

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[6] Itten was clearly aware that colour harmony heuristics could be based on the geometry of 3D colour spaces, but in his discussions he ignored the implications of this almost completely.

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