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'The Eye of the Beholder'— Designing for Colour-Blind Users

Colour-blind computer users see things differently from most people, but this is seldom considered in the design of software or web pages. This article offers a simple technique for simulating the differences, to help designers and developers avoid disadvantaging their users.

Introduction

Have you ever wondered how different the world could seem to someone with a colour-vision deficiency? Have you ever wondered whether they can understand your Web page, or follow the colour cues in your software?

If it is not your problem, you have probably never considered it. However, one man in 12 has some degree of colour-vision deficiency, or colour blindness (it is rare in women). The colour choices we make in software and Web design can make life more difficult for these people, if we are uninformed.

In good design, colour should never be the primary cue for information. The options should be clear without colour, and the colour is simply added as a means of emphasis.

Yet, colour becomes more and more a part of our everyday work, especially with computers increasingly supporting a greater range of colours. Often it is simply decorative, but colour cues are frequently used as the primary means of informing the user how to interpret information.

Published algorithms enable us to calculate how colours appear to individuals with certain types of colour vision deficiency. However, the mathematics is fairly complex, and designers and developers need an easier way to see how their choices impact colour-blind users.

This article offers a method for representing images as perceived with a colour deficiency, so designers can produce interfaces which avoid causing problems for their users.

Most colour-blind people have a deficiency with either red or green, and by focussing on the worst case scenario for these groups, maximum inclusiveness can be obtained.

'The basics of colour vision' introduces how colour vision works, in the simplest terms. 'Problems with colour vision' looks at how colour vision deficiency happens. The section on 'The colour transformations' explains the theory behind the palettes, and 'Using the new palettes' describes their application, and 'Lack of precision in colour displays' looks at some of the technical issues with monitors. The 'Glossary' covers the basic colour-vision terms, and words which appear there are in ***bold italics*** when they are first used.

The Basics of Colour Vision

We perceive colour via photosensitive cells in the eye, the rods and cones. The cones normally contain pigments tuned to receive wavelengths in three parts of the visible spectrum (Table 1). This gives us ***trichromatic*** vision. They can be referred to as *Red*, *Green* and *Blue*, although ρ (rho), γ (gamma) and β (beta) are sometimes used to avoid confusion with the common understanding of the colour names.

The wavelengths given are for peak receptivity, although they also receive light spread 100 nm or more either side of the peak, to a diminishing extent. Rods receive light at around 500 nm, but only as lightness.

The brain further processes the colour received by the eyes, and there are also further psychological issues,

Table 1   Comparison of Cone Names and Visible Spectrum Colours

Name	Alias	Symbol	Wavelength	Colour [1]	Proportion
rho	red	*r*	590 nm	yellow-orange	60%
gamma	green	*g*	550 nm	yellowish green	30%
beta	blue	*b*	440 nm	bluish violet	10%

but this article deals only with the initial stage.

Problems with Colour Vision

In a person who is a **dichromat**, one of the pigments is missing. This is usually red or green, although sometimes blue. A quarter of colour-blind people are dichromats.

For the other three-quarters, either the red-sensitive cones have had their tuning shifted towards the green part of the spectrum, or the green peak is shifted towards the red wavelengths. All three sets of cones still work, so they are still trichromats, but because

of the shift in sensitivity are referred to as **anomalous trichromat**s. The visual effect covers the continuum from normal trichromatic vision to dichromatic vision, so the common expression 'colour blind' is less appropriate to this group. (See Figure 1.)

Eight percent of Caucasian men are colour blind[1]. This is made up of 1% red-blind (**protanope**) and 1·1% green-blind (**deuteranope**) dichromats; 1% red-insensitive (**protanomolous**) trichromats, and 4·9% green-insensitive (**deuteranomolous**) trichromats. Only 0·002% of men are blue-blind (**tritanopia**—tritanomalous condi-

tions are not known) and 0·003% of men are totally colour blind. This article does not deal with these rarer conditions.

The red and green forms of colour deficiency are caused by a recessive gene on the X chromosome, and are therefore more common among men. Only 0·4% of women have any sort of colour vision deficiency, most of them being the red or green forms.

The Colour Transformations

The work described in this article relates to the most common deficiencies with red and green. These deficiencies are also very similar to each other, in terms of colour perception. It also deals with dichromatic vision, as that is calculable and represents the 'worst case' scenario. If one designs for dichromats, the lesser degrees of colour deficiency will be well accommodated.

Interestingly, a red or green deficiency does not simply affect how one perceives red or green. Any colours that vary from each other by the amount of red or green they contain will also appear different. In addition, because protanopes are less sensitive to light at the red end of the spectrum, colours in this area appear darker to them. Deuteranopes do not see this luminosity difference, as the other cones and rods compensate.

Another interesting aspect is that colours perceived by protanopes and deuteranopes are broadly similar, with just a slight greenish cast to the **protan** palette, and an orangey cast to the **deutan** palette.

In colour science, the visible spectrum can be represented in a diagram known as a *CIE chromaticity diagram*†. In Figure 2, the outer triangular shape represents visible wavelengths. The lines that are roughly horizontal through this space (confusion lines) indicate the colours that dichromats get confused. Every

Figure 1—Relation between trichromats and dichromats
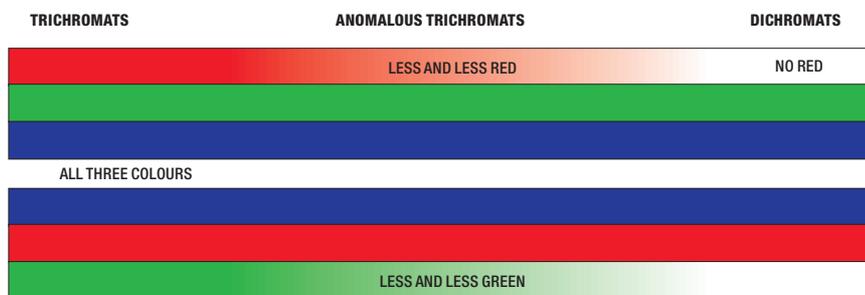
Figure 2—The CIE Yu*v* colour space, with confusion lines for protanopes (left) and deuteranopes (right) (included with permission from HCI Resources Network)

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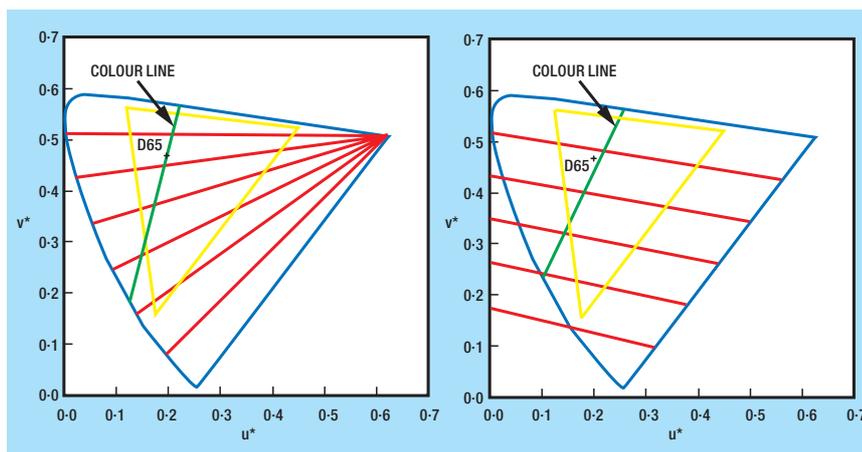
† The colours displayed on a computer monitor are a subset of this space, indicated by triangles in the diagrams.

Standard *Protan* *Deutan*
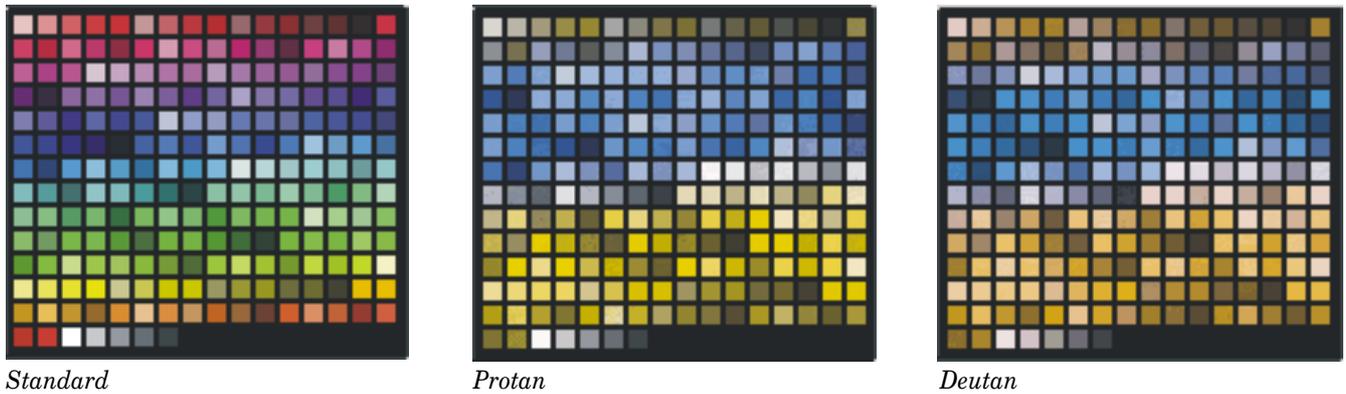
Figure 3—The look of the Web-safe palette, and how it compares to the transformed palettes

colour along a given line looks the same as all the other colours along that line. The point at which the Colour line crosses them represents the perceived colour for that confusion line.

The position of any colour relative to these lines can be calculated. The relation between colours in a CIE chromaticity diagram and colours for given monitor phosphors is known, so RGB equivalent values can be generated for a monitor with known chromaticity coordinates[3]. It can, in theory, be done with as many colours as one cares to calculate (within the gamut for the monitor), but the work in this article is based on the standard 216-colour† web-safe palette[4, 5].

Values were calculated according to established algorithms[3], and palette files were created from the

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† There are 216 colours considered 'safe' to use on Web pages, because they are common to most of the computing platforms available. When other values are used, any system running 256 colours will substitute the specified colours for those it has available. Backgrounds will change colour, and flat colours in gifs will dither. Using the Web-safe palette gives better visual control over what the end user sees. The web-safe palette includes all colours (and no others) which have RGB values made up of 0, 51, 102, 153, 204, and 255 (or 33, 66, 99, CC, FF in Hex).

‡ Please note that printed colour may look quite different from screen colour, and these printed images will not be a totally accurate reproduction of how the colours look on screen. For more clarity, see the images on the Web site.

Standard

Protan

Deutan
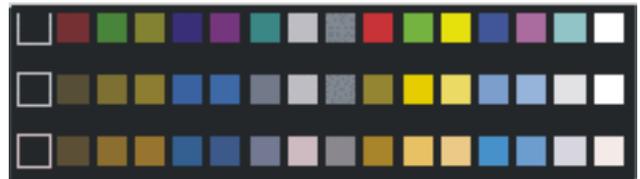
Figure 4—The transformation when applied to the 16-colour palette

results in the **.pal* format (as used by Paintshop Pro). Figure 3 gives a visual representation of how the palettes compare‡ for the 216 colours. Figure 4 shows the corresponding transformation of the old Windows 16-colour palette.

A striking feature of these two transformed palettes is how similar they are. The transformations are all roughly divided into yellows/ochres, and blues. The protan palette seems to have the slightest greenish cast, whereas the deutan palette has a slight orange cast. Both red and green vanish from the palettes, as well as purples and oranges.

One can work out easily whether a given RGB value falls into the yellows or blues group. In general, if the Red value is greater than the Blue, it appears in the yellows group, and if Red is less than Blue it appears in the blues group. A colour generally appears neutral when Green equals Blue, more or less regardless of the value for Red.

The transformed Web colours are available as **.pal* files and/or **.gifs* which can downloaded from the colour pages at http://www.labs.bt.com/people/rigdence/colours/. Certain pages within the site also 'list' the Web colours visually, alongside their transformed colours, so that a direct comparison may be made. They are shown all together, and are divided into blues, yellows, and neutrals as well.

Using the New Palettes

There are two basic approaches to using these palettes:

● apply them to images, to approximate how they appear to protanopes and deuteranopes; and

● use the understanding of the transformed palettes to select colours which work together safely for the Web site's navigational scheme.

For the first approach, the basic Web-safe palette is loaded or applied to an image or screen capture. Save the files into a convenient directory. In PaintShop Pro, choose **Colors - Load palette…**, and select *web-safe.pal*. 'Nearest colour' should be used for flat-colour images such as gifs, and 'error diffusion' for photographs†. (Other commercial paint programs have similar functions.)

Two copies are then made of the image. To one copy, apply *protan.pal* in the same way, but this time select the dialogue option 'Maintain indexes'. Apply the *deutan.pal* file to the second copy. The resulting images are a visual approximation of how it would look to a protanope or deuter-

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† This will also show how the image will look when viewed on a 256-colour monitor, if it has not already been checked.

Using standard palette   *Using protan palette*   *Using deutan palette*

Figure 5—Example transformations of a photograph

anope. Figure 5 gives an example of how this would work on a photograph.

It is important that the Web-safe colours are in their correct index positions, in order to correlate with the transformed palettes. If in doubt, re-map to the Web-safe palette supplied with the others.

For the second approach, the designer starts with the sort of colour scheme they are considering, based on the non-functional requirements of the site, aesthetics, and the general 'feel' being sought. They can then look at the corresponding colours in the transformed palettes, and use that information to help them choose the most suitable colours in the primary palette which will also 'work' in the transformed palettes.

For example, for the colour site where these files are kept, a primarily monochromatic colour scheme was chosen. By using a mid-tone colour for the navigation panel, a colour could be chosen for unfollowed links which was contrasting enough to be readable there as well as in the main page. To be easily distinguished from a green unfollowed link, the followed links colour was chosen from among cooler colours, while still toning with the main colour scheme. Figure 6 illustrates how these compare.

The colour differences in the lighter shades are marginally more visible to anomalous trichromats, while the mid-tone and darker shades are more consistently confused.

Multiple colours will create greater difficulty in finding shades

that are adequately different from each other when transformed. Early work suggests that only up to four colours may be chosen which can be clearly differentiated. When more colours are used, make sure their differentiation is less important.

Keep in mind cultural meanings also, when choosing how to represent information with colour.

The two essential points to remember are:

● Make sure that any text has a good luminosity (brightness) contrast with its background, for readability. Do not put a mid-tone against a mid-tone. Large areas of text for reading need to ensure greater contrast than text in a navigation bar.

Figure 6—Sample colour selection based on a monochrome palette, showing how it looks normally, followed by how it appears with the protan (bottom left) and deutan (bottom right) palettes
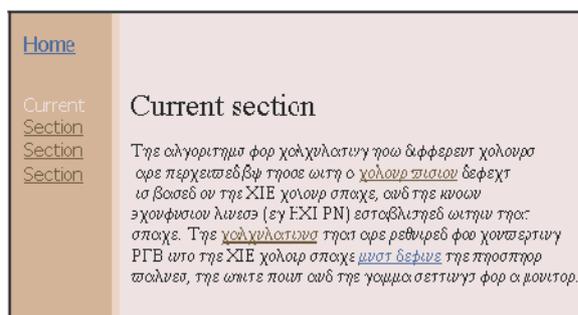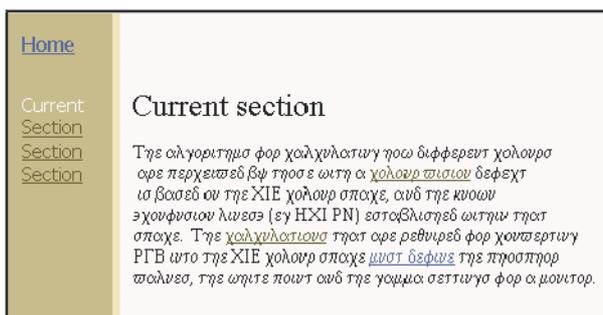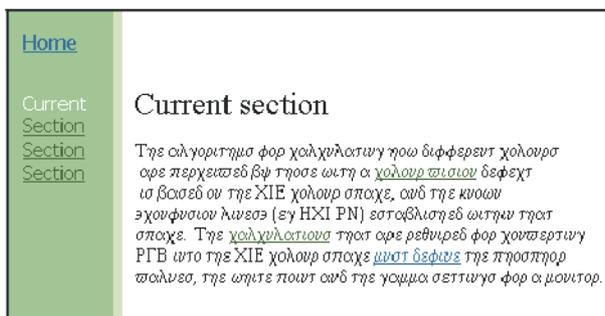
● Make sure that the colours chosen for followed and un-followed links are far enough apart. It is safest if they fall on either side of the colour division in the palette, so that one colour is transformed into the blues group and the other one is in the yellows group.

Then double-check their effectiveness by taking a screen capture of your choices (as in Figure 6), and applying the transformed palettes to them.

Postscript on Colour Displays

A prevalent concern about doing this kind of work in the past has been the lack of precision involved. The colours on every computer monitor are going to be slightly different, according to the gamma setting and the colours of the RGB phosphors. This makes it impossible to come up with a single 'true' RGB value for any specific real-world colour, and makes it difficult to manage accurate colour reproduction on screen.

However, in practical terms, RGB is used to define colour in software and on the Web, without concern for the chromaticity values. Modern monitors are becoming more similar than they used to be, as manufacturing becomes more standardised. Therefore, in spite of a lack of real precision, these transformations are a valid and practical means of ensuring that an interface does not cause problems for colour-blind individuals.

References

1 HUNT, R. W. G. Measuring Colour. Ellis Horwood Ltd, Chichester, 1987.

2 TRAVIS, DAVID. Effective Colour Displays: Theory and Practice. Academic Press, 1991.

3 HCI Resources Network. Colour Vision Deficiencies. Retrieved May 1998 from the World Wide Web: http://www.hcirn.com/atoz/atozc/coldef.html.

4 WEINMANN, LYNDA; and HEAVIN, BRUCE. <Coloring Web Graphics.2>. New Riders Publishing, 1997. Browser-safe colours also explained on Lynda's Web page at http://www.lynda.com/hex.html.

5 SIEGEL, DAVE. Images on the Web— Use the Netscape Colour Cube. Retrieved from the World Wide Web, Nov. 1998: http://www.dsiegel.com/tips/wonk10/images.html.

6 POYNTON, CHARLES. Poynton's Color FAQ: 19. Is RGB always device-dependent? Retrieved from the World Wide Web, June 1998: http://www.inforamp.net/~poynton/notes/colour_and_gamma/ColorFAQ.html#RTFToC19.

Glossary

trichromat   a person who has three colour reception pigments functional to some degree.
dichromat   a person who has only two of the three pigments functional.
anomalous trichromat   a person who is a trichromat, but one pigment is dysfunctional, or anomalous.
pro-   Latin for 'first', and referring to red (first of the trio RGB).
protan   relating to problems with red reception.
protanopia   condition where the red (first) pigment is missing, 'red blind'.
protanope   dichromat with protanopia.
protanomaly   'red insensitive' anomalous condition.
deu-   Latin for 'second', and referring to green (second of the trio RGB).
deutan   relating to problems with green reception.
deuteranopia   condition where the green (second) pigment is missing, 'green blind'.
deuteranope   dichromat with deuteranopia.
deuteranomaly   'green insensitive' anomalous condition.
tri-   Latin for 'third', and referring to blue (third of the trio RGB).
tritan   relating to problems with blue reception.
tritanopia   condition where the blue (third) pigment is missing, 'blue blind'.
tritanope   dichromat with tritanopia.
tritanomaly   theoretically the 'blue insensitive' anomalous condition, but the condition is not known to exist.

Biography

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Christine Rigden is part of BT's User Centred Design Group. Her work involves all aspects of designing interfaces for usability, but particularly developing guidelines for the conceptual design of software user interfaces and Web sites. She also offers interface evaluations and design tutorials. Christine joined BT in 1988 as a Drawing Office assistant, working in graphic design. She was sponsored to the BT Women's Bridging Course (Chelmsford) and subsequently to the University of Essex as a mature student, and graduated in 19994 with a B.Sc. (Hons.) in Information and Business Systems Technology.