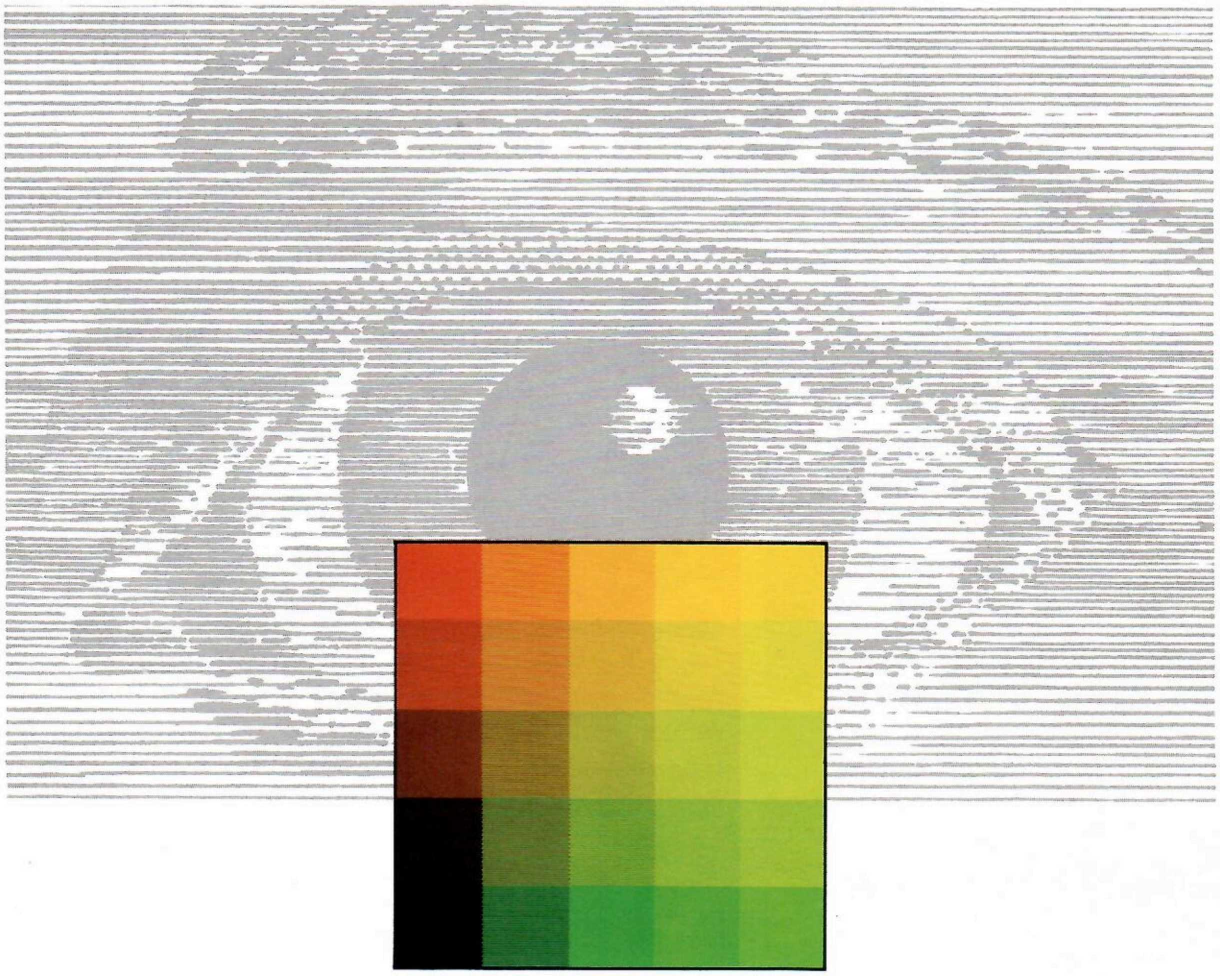
TEK LIQUID CRYSTAL SHUTTER

APPLICATION BOOKLET

THE EFFECTIVE USE OF COLOR AND DISPLAY TECHNOLOGY



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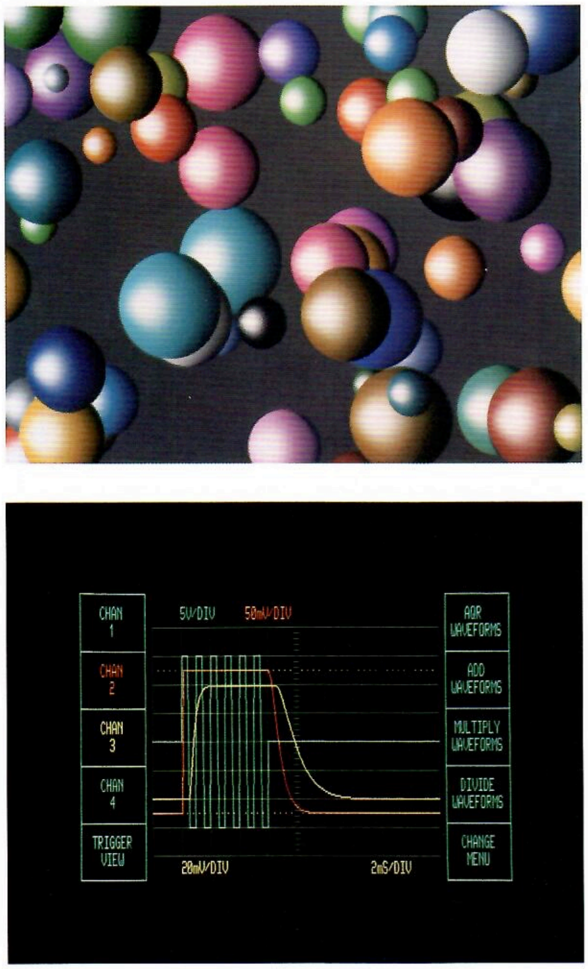

Figure 1. "Are shadow-mask and Liquid Crystal Shutter displays really competitors?"

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This application note reviews some basic attributes of human color perception and relates them to shadow-mask color technology and the new *Tektronix Liquid Crystal Shutter* (LCS) color technology. An understanding of the fundamental mechanisms of color perception provides a good criterion for the evaluation of display technologies for specific applications.

Color is a natural part of our visual imagery. Human color perception increases our information gathering and processing capabilities. For example, color can be used to distinguish between simultaneous events, to organize information into logical groups, or to call attention to important data. We can also use color to ignore information that is not pertinent to a particular application. We can associate a specific color with a particular class of events, such as yellow for attention or red for danger or warning. Color can also be used as an unambiguous signal indicating a particular occurrence or mode of operation. Ultimately, color has increased the number of ways information can be displayed, while reducing the number of ways it can be erroneously interpreted.

Clearly a large color palette, such as offered by shadow-mask displays, is required for the realistic reproduction of images. Shadow-mask technology, however, carries substantial penalties such as reduced resolution, misconvergence, Moiré patterns, limited contrast, and susceptability to desaturation by high ambient light levels. Alternative technologies, such as the Liquid Crystal Shutter, overcome these drawbacks but reduce the number of available colors. Yet, for most applications, a full color palette is neither required nor even desirable. Three examples discussed are test instrumentation, word processing and process control displays.

Color, when properly used, is able to improve the utility and appearance of almost all electronic instrument displays. Color perception, after all, provides a 'critical path' in the communication link between human beings and their environment. (See story on back cover: *HOW WE 'SEE' COLOR: FUNDAMENTAL MECHANISMS OF COLOR PERCEPTION.*) As we have witnessed, electronic instrument displays are increasingly using color to improve productivity in complex applications. But to obtain color, the user typically must give up something else. That 'something' is usually resolution.

Traditionally, loss of resolution has been "the price one pays for color," because until recently, shadow-mask color display technology represented the only practical means of producing color. However, the introduction of the new Liquid Crystal Shutter technology has changed the trade-off between resolution or color (Figure 1).

Matching Display to User: Task Analysis

Ultimately the function of all display devices is to convey information to the viewer. Yet the efficient transfer of information is largely dependent on the very nature of the information to be displayed. Similarly, the effective use of color is dictated by the application and its match to the visual needs and information requirements of the observer. Matching the display technology to the visual system of the user involves a simple series of steps or *task analysis.* In essence, the task analysis provides the methodology to match an instrument to user capabilities.

Step 1: Analyze Instrument's Requirements

The task analysis begins with an engineer making a careful and elaborate description of the objectives of the instrument: a 'philosophy' of the instrument application. Based on the instrument's task requirements, the engineer determines appropriate input and output functions and judiciously assigns some of these functions to the electronics and some to the user. (For instance, humans excel over machines in detecting critical signals against high-noise backgrounds, extracting complex and varying patterns or remembering solution strategies and 'short cuts.' Alternatively, instruments can store large amounts of information, perform repetitive functions and measure events beyond the sensory range of human experience.) Finally, the engineer perfects the interface between viewer and instrument.

Step 2: Choose Color or Monochrome

Technical improvements and cost reductions have made color a potentially powerful tool for improving the instrument/user interface. Yet, not all systems benefit from color, and misuse of color can even make the interface difficult to use. As a general principle, use what is known about color to enhance the interface, rather than using color because it happens to be technically feasible. Color must solve a problem!

Step 3: Identify Colors or Combinations of Colors

Although general guidelines, as previously indicated, are difficult to establish, one cardinal rule can be explicitly stated:

Use no more colors than necessary.

Using color as a means of simplifying an interface can be counterproductive when color is overused. (See Figure 2.) Except for the realistic reproduction of images, a large color space is not needed for an effective interface. In fact, the large color space offers the

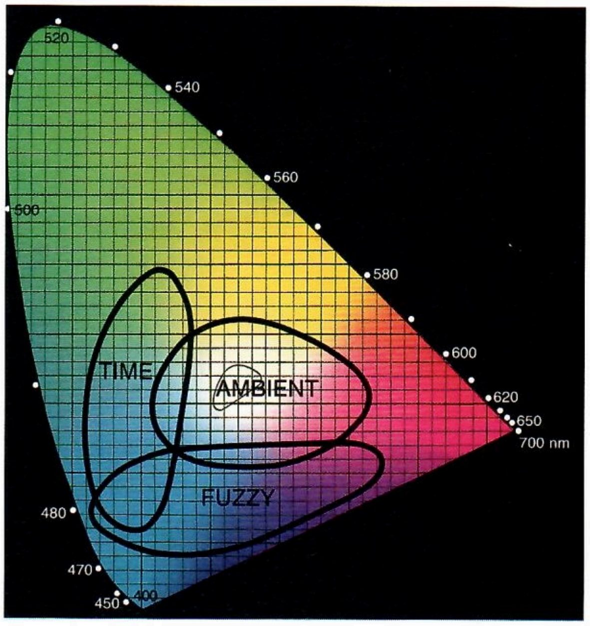


Figure 2. Two-dimensional representation of the color space of human vision (developed in 1931 by the CIE – Commission Internationale d'Eclairage). Contained within the diagram are all the colors to which the human eye can generate a unique pattern of response from the cones. Outlined areas indicate several groups of colors which should be used with caution. One group of colors – marked 'fuzzy' – constitutes the low visual sharpness blues and purples. Colors selected from this area will often appear fuzzy and out of focus. Additionally fine details portrayed in these colors lose their hue. A second group of colors are characterized by the danger of confusion when viewing time is short. The colors within the area marked 'time' cannot be readily held apart when assessed by a brief glance. The final area – denoted as 'ambient' – encircles the low saturation colors which are susceptable to washing out as the level of ambient light increases. These are also colors which show up misconvergence on a shadow-mask display.

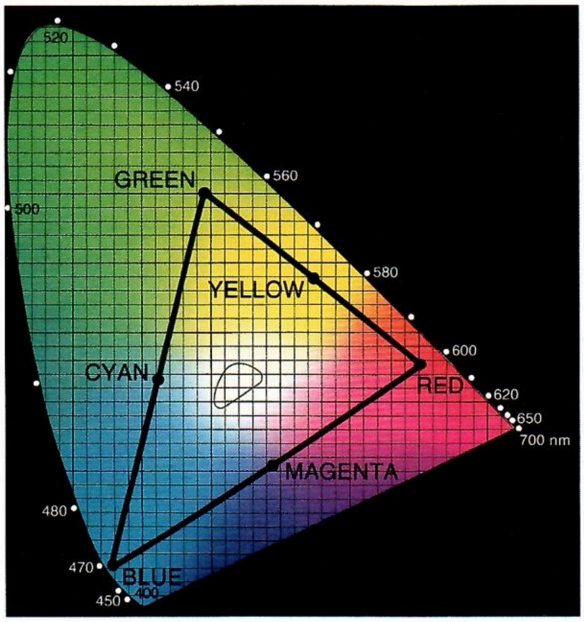


Figure 3. Realizable color space of a TV monitor. The nodal points indicate the colors of the red, green and blue phosphors while the area within the triangle denotes the colors obtainable by varying the proportions of the three phosphors: 'pale orange' for example, equals 70% red, 22% green and 8% blue.

designer a golden opportunity to misuse color. When color is used to draw attention, group common elements, locate critical features and perhaps to ignore marginal information, a palette of three to eight carefully chosen colors is sufficient.

Step 4: Select Display Technology

Finally, after the instrument has been analyzed, color or monochrome has been chosen, and colors and combinations of colors have been identified, a display technology best suited to the application and that meets the requirements of Steps 1–3 must be selected. Several color display technologies are available, each with its own advantages and limitations.

Shadow-Mask Technology: Realistic Color for Reproduction Of Scenes

The display designer, chartered with the design of a system capable of faithfully reproducing the colors present in a real scene, faces a particularly difficult problem. The normal CRT based color television set must match colors with combinations of different levels of three phosphors. Figure 3 plots a two-dimensional representation of the color space for human vision.

When a particular scene is reproduced on a TV display, only the colors contained within the triangle can be duplicated. An emerald green, which falls outside of the range of the TV phosphor set, will be reproduced as the 'nearest available green.' Clearly the designer of a television display, or the designer of any digital imaging device which must faithfully reproduce images, must have as large a color space as possible in order to encompass the largest number of displayable colors. The realism of the image will depend upon the obtainable color range.

The shadow-mask color CRT has been particularly successful as an image reproduction device, in part, due to the size of its color gamut. Alternative devices charged with the generation of realistic images will need to improve upon the shadow-mask display by displacing the nodal points of the phosphors towards the periphery of the color diagram.

Limitations

While the shadow-mask display has been particularly successful at realistic color reproduction, use of the technology in other display applications has revealed some severe limitations. The development of *TELETEXT* systems which produce alphanumeric and symbolic images on home television receivers provides an example: Such images are often very difficult to view due to both the nature of the visual mechanism for color perception and intrinsic problems associated with shadow-mask devices:

- Small details are not reproduced in the image due to the low resolution capabilities of the shadow-mask device.
- Not all colors are equally viewable. Saturated blues and purples appear fuzzy and unclear. Desaturating the colors improves their viewability but produces color fringing due to misconvergence.
- Fine, repetitive detail produces unwanted patterns of lines (Moiré patterns), reducing the 'viewability.'
- Increased levels of ambient light wash out the colors in shadow-mask displays. Two colors which are discriminable under low light may become indistinguishable at higher ambient light levels.

To summarize, a shadow-mask color display functions well in image reproduction, but it may not be the proper display medium for other applications. The preceding list of difficulties, while by no means exhaustive, points to a number of mismatches between the visual needs of an observer and the capabilities of a display.

Liquid Crystal Shutter: Optimum Color Display for Information Transfer of Data

The Liquid Crystal Shutter (LCS) provides a solution to the typical color vs. resolution tradeoff and overcomes the additional limitations of shadow-mask technology indicated above:

- With resolution based on the spot size of a monochrome CRT, the LCS display can provide sufficiently high resolution to avoid the loss of small details.
- All screen writing is achieved with a single electron beam, eliminating misconvergence problems.
- Because no shadow-mask is required, fine, repetitive detail does not produce unwanted Moiré patterns.
- The combination of color polarizers and a neutral polarizer in the LCS display significantly improves display contrast, making the LCS display especially viewable in high ambient light environments.

Although the LCS reduces the number of available colors, it eliminates the disadvantages of shadow-mask displays, making it an ideal color display technology for various instrument applications. As color is used to differentiate information, a carefully selected viewable palette is required. Two such LCS palettes, each designed for specific applications, are shown in Figure 4.

Matching Display to User: Examples

On the basis of completed task analyses, obvious applications for the Liquid Crystal Shutter include test instrumentation, word processing and process control.

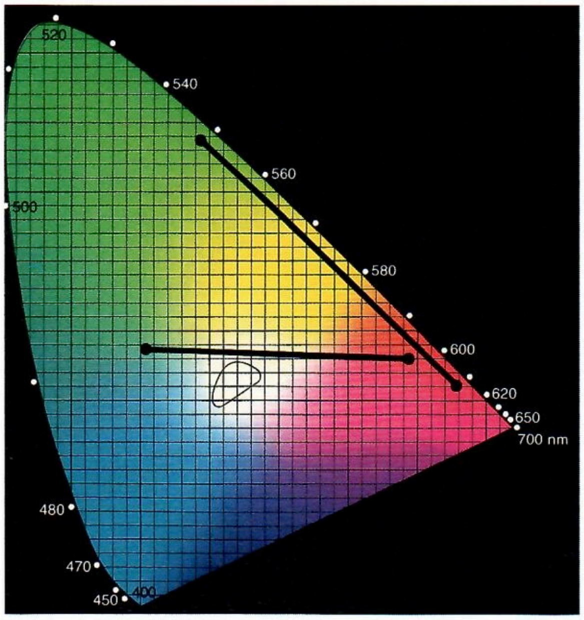


Figure 4. Two color ranges that are possible with the Liquid Crystal Shutter. One range extends along the edge of the visual spectrum from red through orange and yellow to green. Approximately 48 discriminable hues lie along this line. The second color line isolates a set of desaturated colors ranging from orange through white to cyan. Although a lesser number of colors exists along this line (approximately 32), the desaturated nature of the colors renders them highly viewable for prolonged viewing applications. Yet, the desaturation is not coupled with the problems of misconvergence or color purity variations found with a shadow-mask display.

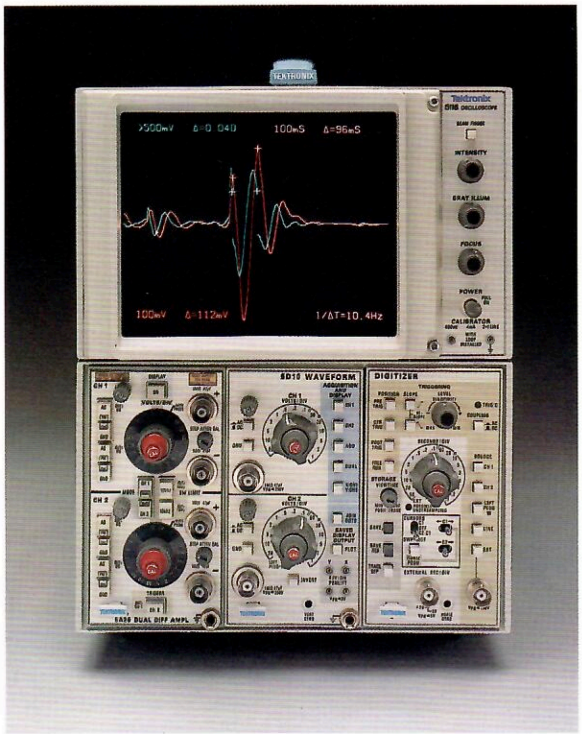


Figure 5. The Tektronix 5116 Color Oscilloscope.
Color 1 (Cyan) – Trace #1
Color 2 (Orange) – Trace #2
Color 3 (White) – Overlap of Trace #1 & #2
Color 3 (White) – Set-up Information

Test Instrumentation

The Tektronix 5116 Color Oscilloscope (Figure 5) provides a good example of the effective use of color on a test and measurement instrument. The need for color on a multi-trace oscilloscope is obvious as can be substantiated by anyone who has attempted to differentiate two complex waveforms from one another. Of equal importance for such oscilloscopes is the need for high resolution previously available only in a monochrome display. Because of the potential misinformation generated by misconvergence, the desaturation of colors by high ambient light levels, and reduced resolution, shadow-mask color display technology is rendered inappropriate for most oscilloscopes.

Task analysis of a typical storage oscilloscope capable of displaying two waveforms requires: three colors – one for each trace, and one for overlap and set-up information; high resolution; no loss of color discriminability in high ambient light; no chromostereopsis (appearance of various colors in different depth planes).

The Liquid Crystal Shutter with the orange, white and cyan (blue-green) color range matches these needs perfectly. A larger color palette would do nothing to improve the functionality of the instrument. The choice of the less saturated (orange, white, cyan) color range is supported by two specific considerations. First, these colors will not appear in different depth planes as will more highly saturated colors: for the accurate comparison of two traces one needs to see both at the same depth. Second, the orange and cyan colors are neutral in the sense that they convey no cultural meaning such as a warning signal (red) or a proceed indicator (green). In the same way, the ability to produce a white or neutral color where the traces overlap provides an intuitive descriptor of identical information sources.

Word Processing

In an application in which the display viewer spends long periods of time in intense interaction with a display, the quality of the viewed image is of great importance. A prime example of such an application is word processing in which the resolution requirements for sharp, high quality images have eliminated shadow-mask color display technology from consideration. Obviously a word processing system will benefit from the highlighting, and attention-drawing capabilities of color. For a system with a basic graphics processor, the ability to utilize color will markedly strengthen the usefulness of the instrument. As with the oscilloscope discussed previously, the word processor certainly has no need for the reproduction of realistic images and hence no need for a large color palette.

The Liquid Crystal Shutter solves the resolution problem and allows functional color without resolution penalty. In light of the current demand for positive image video – dark characters on a light background – the Liquid Crystal Shutter has obvious strengths: The traditional problem of Moiré patterns resulting from a mismatch in spot-size and shadow-mask pitch cannot occur on the Liquid Crystal Shutter display. Additionally, misconvergence and flicker are removed. Again, the cyan, white and orange combination appears to be an appropriate color range, since traditionally, word processing source document colors are black (text) and white (background). With the cyan, white and orange combination, white can form the background, and several levels of cyan, green, reddish-yellow and orange can be used for information differentiation on the screen.

Process Control

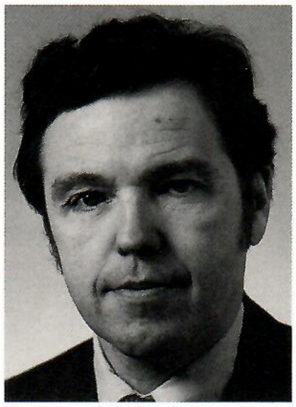
An application of the Liquid Crystal Shutter which capitalizes on a highly saturated color range of red-yellow-green is process control. Here a finite number of colors must signal specific events. Since highly saturated colors will immediately draw the viewer's attention, one can use the stereotypic meaning of colors and retain a highly saturated red for warning signals, a highly saturated yellow for functions in progress and a highly saturated green for normal operative states. Recall that colors in this red-yellow-green range can be readily discriminated with a brief glance. These colors on the Liquid Crystal Shutter are not subject to desaturation by high ambient light – which can render colors indiscriminable on a shadow-mask display.

Often the color display must replace an existing monochrome display which, in the case of a shadow-mask, means a reduction in viewable display area, the viewable area is limited to the dimensions of the shadow-mask. The Liquid Crystal Shutter, however, offers the identical area of the monochrome display.

Conclusion

Obviously the large color range afforded by a three-primary-color CRT allows the creation or reproduction of realistic full color images by matching the phosphor emissions to the range of colors present in the image to be reproduced. Yet, this large range of colors does *"not"* meet the visual needs for basic color systems designed to draw attention to critical items, group similar elements, locate low frequency events and so on. To a great degree we have taken the shadow-mask CRT to be *the* color display. However, we often fail to recognize that its drawbacks and limitations can be overcome by other display technologies designed specifically for information transfer as opposed to realistic imaging.

The *Tektronix Liquid Crystal Shutter* (LCS) is matched to the viewing needs of the human visual system. It provides the benefits of color without sacrificing resolution. The LCS overcomes the limitations of shadow-mask color display technology while offering a two-primary color palette. Yet, for most applications, including test instrumentation, word processing and process control, a full color palette has been shown to be neither required nor desirable. Designed specifically to meet information transfer requirements, the Liquid Crystal Shutter is ideally suited for various color instrumentation applications.



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HOW WE 'SEE' COLOR: FUNDAMENTAL MECHANISMS OF COLOR PERCEPTION

It is clear that our visual systems are designed to utilize color. A substantial body of physiological and psychophysical research has demonstrated that visual information is processed in terms of three processes. Initially the retinal *cones* translate light into electro-chemical energy. The critical element in this translation is the cone's photopigment. Three varieties of photopigment have been identified. Figure A plots the relative spectral sensitivity of each type of cone photopigment. The curves indicate the magnitude of the response of each type of cone to light of a given wavelength. Note that two of the cone photopigment types are sensitive to all wavelengths to which the eye is responsive, while the third responds only to short wavelengths. Historically, and inaccurately, the three types of light receptors have been called *red, green,* and *blue* receptors on the assumption that green, for example, was signaled by a preponderance of responses from the 'green' photopigment and no activity from the 'red' and 'blue' cones. In reality the so-called 'red' and 'green' cones actually respond to all wavelengths of light. They do, however, vary in their absolute response magnitudes and in relation to each other. The third class of cone – the historically named 'blue' cone – responds only to wavelengths below 520 nm. Thus light with a wavelength of 450 nanometers would evoke the strongest response from the 'blue', a weaker response from the 'green' and weaker still from the 'red'. *It is the relative response pattern of the three cone photopigments that provides the initial signal for color perception.*

Once a response pattern in the cones has been generated, the next step in the process of perceiving color is the brain's calculation of the perceptual characteristics of hue, saturation and brightness.

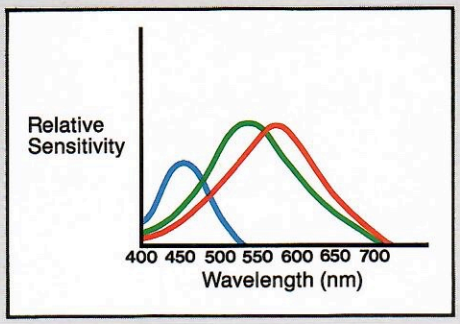

Figure A. Relative spectral sensitivity of each type of cone photopigment. The curves indicate the magnitude of the response of each type of cone to light of a given wavelength. Note that two of the cone photopigment types are sensitive to all wavelengths to which the eye is responsive, while the third responds only to short wavelengths.

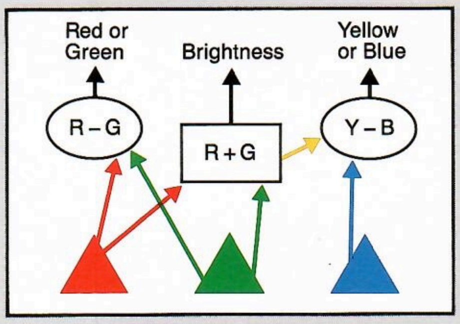

Figure B. Processes by which the response pattern from the cones is analyzed and segmented into two channels for color information and one channel for brightness information. As can be seen from the figure, the brunt of the analysis is performed by the 'red' and 'green' cones.

Figure B diagrams the processes by which the response pattern from the cones is analyzed and segmented into two *opponent* channels for color information and one channel for brightness information. As can be seen from the figure, the brunt of the analysis is performed by the 'red' and 'green' cones.

Brightness equals the summed response of red and green cones.

Hue derives from the red-versus-green opponent and the red plus green (yellow)-versus-blue opponent.

Saturation stems from the relative strengths of the brightness and opponent hue responses.

Consider a light with a dominant wavelength of 590 nm which provides the sensation of orange. The cone response consists of a pattern of 'red' and 'green' signals. The hue will be determined by the degree to which the 'red' exceeds the 'green'. Opponent hue responses yield the accompanying perceptions of brightness and saturation.

Color perception is a complex process, and we have only touched upon it. We hope, however, that designers will at least consider the basic principles, and be able to apply them when designing information displays that will present color information to the human eye and brain. This concept, then, captures the principle which must be followed in the design of effective displays. *Use what is known about color perception as the design guideline for a color display.*

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