The purposes for using color in computer graphics are for aesthetics, to establish a tone or mood; for searching; for identifying areas as being associated; and for coding. With care, color can be effectively used for these purposes, but careless use of color can make the presentation less useful or less attractive than a corresponding monochrome presentation. In one experiment, meaningless introduction of color reduced user performance to about one third of what it was without color. Color should be employed conservatively, not garishly. Any decorative use of color should be subservient to its functional use, so that the viewer does not misinterpret decorative uses of color as having some underlying meaning. This implies that the use of color, like all other aspects of a user-computer interface, must be tested with real users to identify and fix problems. Many systems also allow the user to modify how color is used.

Users tend to like color, even when there is no quantitative evidence that it helps their performance. While some cost-conscious buyers may thus scoff at color, we feel anything that encourages people to use computers is important!

A conservative approach to the use of color is first to design for a monochrome display, to ensure that color is purely redundant. This will avoid potential problems for color-deficient users, or if the application is also used on a monochrome display.

Many books have been written on the use of color for aesthetic purposes; we state here just a few of the simpler rules that will help produce color harmony. The
Several cautions are in order. First, color codes can easily carry unintended meanings. Bright and saturated colors will stand out more strongly than dimmer, paler colors. Displaying the earnings of company A as red and those of company B as green might unintentionally suggest that company A is in financial trouble, because of our learned associations of colors with meanings. Two elements of a display that are the same color may be seen as related (they have the same color code), even if they are not. This problem is often seen when color is used both to group menu items and to distinguish display elements, such as different layers of a printed circuit board or VLSI chip. Green display elements can be incorrectly associated with green menu items, etc.

A number of color usage rules are based on physiological rather than aesthetic considerations. For example, because the eye is more sensitive to spatial variation in intensity than spatial variation in chromaticity, lines, text, and other fine detail should vary from the background not just in chromaticity, but in brightness (perceived intensity) as well. This is especially true for colors with blue in them, because relatively few cones are sensitive to blue. This means the edge will be hard to distinguish between two equal-brightness, colored areas that differ only in the amount of blue.

Blue on black has very little color or brightness difference, and is thus a particularly bad combination. Similarly, yellow on white is relatively hard to distinguish, because the two colors are both quite bright.

The eye cannot distinguish the color of very small objects, so color coding should not be applied to small objects. In particular, judging the color of objects that subtend less than 20 to 40 minutes of arc is error-prone. An object that is 0.1" high, when viewed from 24" (a typical viewing distance), subtends this much arc. This corresponds to about seven pixels of height on a 1,024-line display with a vertical height of 15". The clear implication is that the color of a single pixel will be quite difficult to discern.

It is also good to avoid reds and greens with low saturation and luminance—close to gray in a color space—as these colors are confused by males who are red-green color deficient, the most common form of color deficiency.

The perceived color of an area is affected by the color of the surrounding area. The effect is particularly problematic if colors are used to encode information. The effect is minimized when the surrounding areas are some shade of gray or are relatively unsaturated colors.

The color of an area can actually affect the perceived size of the area. Cleveland and McGill discovered that, given equally sized red and green squares, the red square will be perceived as larger than the green square. This could readily cause the viewer to attach more importance to the red square than to the green.

The most fundamental rule of color aesthetics is to select colors according to some method, typically by traversing a smooth path in a color model and/or by restricting the colors to planes or hexcones in a color space. This might mean using colors of constant lightness or value. Furthermore, colors are best spaced at equal perceptual distances in whatever subspace they are drawn from.

A random selection of different hues and saturations will usually appear quite garish. Alvy Ray Smith, of Pixar, performed an informal experiment in which a 16 x 16 grid was filled with randomly generated colors. Not unexpectedly, the grid was unattractive. Sorting the 256 colors according to their H, S, and V values (hue, saturation, and value, from the HSV color model) and redisplaying them on the grid in their new order gave a remarkable improvement to the appearance of the grid.

More specific instances of these rules suggest that if a chart contains just a few colors, the complement of one of the colors should be used in the background. With an image containing many different colors, a neutral (gray) background should be used. This is both harmonious and avoids calling attention to the background. If two adjoining colors are not particularly harmonious, a thin black border can be used to set them apart. This also provides stronger information for the achromatic (black/white) visual channel, which facilitates shape detection based on the black outline.

Color can be used for coding. Christ found that color is usually a more effective nominative code (to distinguish between different items) than shape, size, and intensity. Cleveland and McGill found color to be a poor ratio code (to represent relative magnitudes). Ware and Beatty found that color is effective for showing that objects are clustered (belong together), but is not effective as a ratio code.
Large areas of highly saturated colors, when stared at for many seconds, temporarily overload the cones. When the viewer looks elsewhere or when the displayed image changes, an afterimage of the large area will appear. This effect is disconcerting and may cause eye strain.

Also, large areas of different colors will appear to be at different distances from the viewer, because the index of refraction of light depends on wavelength. The eye will change its focus as the viewer's gaze moves from one colored area to another; the change in focus gives the impression of differing depths. Red and blue, which are at opposite ends of the spectrum, have the strongest depth-disparity effect, with red appearing closer and blue more distant. Hence the use of blue for foreground objects simultaneously with the use of red for the background is unwise.

Given all these potential perils and pitfalls of color usage, is it surprising that one of our first-stated rules of color use is to use color conservatively? More background on the use of color in computer graphics can be found in the literature.7-9

We wish to thank the authors who contributed to this special issue. We expect you will find the articles interesting and useful. Thanks also go to the many reviewers who continue to provide invaluable service to the IEEE Computer Society through their anonymous and highly technical reviews.

References
4. C. Ware and J. Beatty, paper to be published in Human Factors.