Color vs. Black-and-White in Visualization

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Introduction

Color is a powerful aid to visual data representations, if used appropriately. It can be used to code qualitative or quantitative, single- or multi-parameter data. However, many of the large number of possibilities can degrade the representation rather than improve it. Because of this risk the use of color has become very controversial. However, the increase in color graphics capabilities and in the demands put on visualization techniques (such as increasing size and dimensionality of data) has increased the interest in the use of color even among long-time traditional opponents.

This panel addresses the issue of the use of color, as compared to monochromatic displays, in visualization. Panelists will

- Present the advantages and disadvantages of color displays, and those of monochromatic displays;
- identify situations where color can improve the representation, and those where it will degrade it; and
- suggest guidelines on how (and when) to use color.

Panel Participants

Haim Levkowitz is an Assistant Professor of Computer Science and a founding faculty member of the Institute for Visualization and Perception Research at the University of Lowell, in Lowell, MA. His research interests include graphics, imaging, color, human-computer interaction, and computers in music and sound, in particular as related to visualization and perception.

From January 1982 until June 1989 he was with the Departments of Radiology, and of Computer and Information Science, The University of Pennsylvania, and with the Department of Radiology and the Division of Cardiology, The Children's Hospital of Philadelphia, all in Philadelphia, PA. Dr. Levkowitz received his Ph.D. in Computer and Information Science from the University of Pennsylvania. He is a member of IEEE, ACM, SIGGRAPH, SIGART, and SIGCHI.

Richard A. Holub received the Ph.D. degree from the University of Wisconsin in 1977 for research in visual information processing. After several years of postdoctoral work, he joined the faculty of Boston University where he taught computer engineering and conducted visual research. In 1983, he joined Eikonix Corp., where he became Chief Color Scientist. He remained with Eikonix through its acquisition by Kodak in 1985. In 1990, he joined the Compugraphic Division of AGFA Corporation as Technology Consultant for Color Science and Imaging Architecture.

Gary W. Meyer is an assistant professor of computer and information science at the University of Oregon. His research interests include color reproduction and color selection for the human-computer interface, perceptual issues related to synthetic image generation, and the application of computer graphics to scientific computing.

Dr. Meyer has been a member of the technical staff at Bell Telephone Laboratories. He received a BS from the University of Michigan, an MS from Stanford University, and a Ph.D. from Cornell University. He is a member of IEEE, ACM, SMPTE, SID, and OSA.

Philip K. Robertson is a Principal Research Scientist at the CSIRO Division of Information Technology's Centre for Spatial Information Systems in Canberra, Australia. He leads the Centre's Visualisation Systems Group, which undertakes collaborative research and development projects with university and industry partners. He also lectures in Computer Science at the Australian National University, and is a member of the University's Centre for Information Science Research. His research interests cover conceptual and computational approaches to visualization, including visualization methodologies, perceptual color interfaces and modeling, and parallel and multi-dimensional algorithms in image processing and graphics.

Dr. Robertson holds a BE and MSc in Electronic Engineering, and a Ph.D. in Computer Science from the Australian National University. He is a member of ACM, IEEE and the APRS, and a member of the editorial board of IEEE Computer Graphics and Applications.

Panelists Statements

Richard A. Holub: Color IS Essential for Gamut Visualization

In publishing applications the visualization of gamuts of color reproduction devices benefits intrinsically from the use of "true" color. In the course of the presentation, the foregoing assertion will be supported by illustrations.

The gamut of a color reproduction device or medium is the subset of perceivable colors which can be reproduced by the device. A common requirement in printing and publishing is the reproduction of color images captured from one medium (such as positive reversal film) on another medium (such as ink on paper). This process is known as *cross-rendering*. Modern prepress systems also utilize high resolution, color video display terminals for interactive image processing.

All three media alluded to above have very different gamuts, as can be appreciated from the study of solid models. It is advantageous to model gamuts in a device independent and visually uniform space. Either of the CIE's 1976 spaces (CIELAB and CIELUV) are well suited for this purpose, especially in their cylindrical coordinate forms. The latter utilize the variables Hue Angle, Chroma, and Psychometric Lightness.

A device independent space offers a common coordinate system in which to consider gamuts of devices whose internal coordinate systems may be as different as RGB and CMYK. It can be shown, for example, that the relative lightnesses at which maximum saturation of certain colors occurs are different for VDTs and paper printers. As we trace the evolution of our efforts to understand gamuts and cross rendering, we show how inadequate the two dimensional chromaticity diagram is at conveying this fact.

It is possible to realize much more saturated purples and magentas in reversal films than on paper. The advantage of visualizing in a (approximately) perceptually uniform space is that one has insight as to how to map colors from one medium to the other so as to preserve relational information or visual differences. This can be appreciated more directly by comparing gamuts with a computer graphical package which supports solids modeling in true color than by building, for example, "foam core" models in black and white.

Gary W. Meyer: Some Problems with Color as a Visualization Tool

Color is widely used in scientific visualization as a coding technique to help analysts interpret their data. While there is no question that this enhances the ability to see trends and to identify extreme points, there are also limitations as to how well this technique can be applied. This talk will point out some of the problems that can arise in using color as a visualization tool. In particular, it will focus on the use of color to display the value of a single continuous variable on a three dimensional surface.

Perceptually uniform color spaces are the best available tool for selecting a color scale to encode a continuous variable. One must remember, however, that the data on which these uniform spaces are based was obtained under tightly controlled conditions. Some of the parameters held constant include 1) the size of the color samples, 2) the spacing between the color samples, 3) the luminance and chromaticity of the background on which the color samples were compared, and 4) the luminance and chromaticity of ambient light in the test environment. Given these limitations it is possible to create a color swatch key across the bottom of the image that is perceptually uniform. It is impossible, however, to maintain this uniformity in the interior of the image because of color contrast effects.

In rendering a three dimensional object, the brightness dimension of the color is used for shading. This means that only chromaticity can be used to encode a parameter since the length of the color vector in 1931 CIE XYZ space is used for color intensity variations which convey the shape of the object. A uniform chromaticity diagram can be used to select a scale of chromaticity variations with uniform perceptual spacing. The use of brightness to convey shading also means that planar surfaces will be equiluminant (for purely diffuse reflectance). This means that the edges between color contours will be difficult to detect because the chromatic spatial frequency response of the visual system does not exhibit low frequency roll off as does the achromatic spatial frequency response. Finally, because of color adaptation effects, one must be careful in using colored light sources to illuminate the objects on which the color encoded parameter is being displayed.

One additional thing to keep in mind is that approximately eight percent of the male population and less than one percent of the female population suffer from some form of anomalous color vision. Complete dichromatism afflicts approximately two percent of the male population and a fraction of one percent of the female population. Color scales that appear different to dichromats and are thus better in displays designed for them differ at least in luminance and preferably do not lie on the same confusion line in the chromaticity diagram. The best such color scales would be more or less orthogonal to the confusion lines. The fact that dichromatic vision is a more restrictive form of defective color vision than anomalous trichromatic vision means that a display designed for a particular type of dichromat will also work for the same type of anomalous trichromat.

Philip K. Robertson: Color by Design

Color is but one aspect of visual information. It can help to distinguish certain factors, such as different materials by observing hue discontinuities, or clarify others. Or it can help to confuse, such as when grey shades used to depict surface shape are color-mapped.

But *color vs Black-and-White* is not the only, or even necessarily a major, display design decision. Rather the overall approach to display design, and how the variables of interest are to be represented, is more important. Without such overall display design, the use of color is chancy.

Black-and-White (or monochrome) displays can certainly be more effective in conveying certain kinds of information; witness the power of Black-and-White images in photography or drawing. The information may be complex, subtle or abstract, but the constraint of representation effectively focuses attention on the information to be conveyed. We know little about how to exploit effectively this power of paucity in computer-synthesised displays, but we would do well to try to understand it better.

Color may also be very effective by omission, for example to distinguish. Separating data objects and control objects in a user interface can be critical if planned interaction is to be achieved. Similarly separating two data sets, or two phases of an interaction sequence, or "active" and "inactive" components of a display, or modeled from measured data, or one from several, can be very effectively performed by depriving one of its color.

Color can also make a nonsense of interpretation. Color-coding saw-tooth data representations, often used in the geosciences to emphasize gradients, can create a psychedelic chaos that is unintelligible. And color incorrectly modeled from device to device can introduce perceptual discontinuities where no data discontinuities exist; this is very commonly observed in transparencies taken from an image that looks smooth on a CRT screen. Color interpolation can also introduce anomalies. And of course the aforementioned coloring of Black-and-White shading variations is just one of several natural occurrences of lightness variations that mean nothing if color-coded.

Three issues, then, must be considered for color to be effective for improving data interpretation: first, the context of the use of color should be determined by the design of the display and not by chance or experiment; second, color should be used in a manner that is stimulated by our use of color for decoding real-world information; third, control over color production systems must allow reliable generation of colors specified in a device-independent coordinate framework.