Look around and consider what role color plays in the objects you see. I would argue that one of its primary purposes is to inform. Even in the natural world, color is a key way to tell if something is edible, dangerous, or one of a related set of objects. In the manufactured world, color is used extensively to label, to discriminate, to brand, or to otherwise identify objects and their components. It is an important part of illustration, cartography, and data presentation, from medical imaging to pie charts. This chapter describes the informative aspects of color in fields called visualization, information visualization, and illustration. Its principles also apply to the use of color in user-interface design.

Introduction

Color is a key component in information display. When used correctly, it can make a complex task or analysis simple; when abused, it can turn a simple presentation into visual chaos.

Visualization as a computational field explores ways to present visually the result of measurement and simulation. From simple
charts and graphs, to complex, multi-dimensional models; from fields as diverse as cartography, engineering, business and medical imaging—color is one of the parameters manipulated as part of information and data display.

Color in user-interface design follows the same principles as color in visualization—the color is used to identify components of the interface. Contrasting colors call attention, analogous (similar) colors group and blend pieces together. Making components legible and unambiguous is a critical part of user-interface design, and the right color design is a key part of this process.

Edward Tufte has published three marvelous books on information visualization, but only one, Envisioning Information, has a chapter on color. Tufte describes the fundamental uses of color as follows: to label (color as noun), to measure (color as quantity), to represent or imitate reality (color as representation), and to enliven or decorate (color as beauty). These principles provide the framework for this chapter.

Many of the positive (and negative) effects of color in visualization have a perceptual basis. Colin Ware’s book, Information Visualization: Perception for Design, describes many of these effects for color as well as for other perceptual phenomena.

Most great visualizations, such as those shown in Tufte’s books, are designed by skilled, even inspired, experts. The challenge for the field of computer-generated visualization is to assist ordinary people in creating such visualizations, or ultimately, to create such imagery automatically. It is unrealistic to expect the results to be as wonderful as the best of those designed by professionals, but they should be effective at conveying the desired information, and, at minimum, visually inoffensive.

**Good and Bad Uses of Color**

The goal in selecting colors for information display is, ultimately, to produce an image that is attractive and that conveys its message effectively. Anyone planning to use color in information display should thoroughly understand the principles of color design pre-
presented in the previous chapter. Color should be clarifying, not confusing. It should be tasteful, and it should be robust across media, viewing conditions, and viewers.

Tufte’s primary rule for the use of color is “do no harm,” as color used poorly can be worse than no color at all. Color can cause the wrong information to be most prominent, can cause text and other features to be illegible, and when overused, give the effect of many, unrelated pieces “screaming” for attention (sometimes called the Times Square, Los Vegas, or Picadilly Circus effect, depending on where you live). Figure 1 is a simple example designed to show these problems. Coloring each letter a different color (Figure 1(a)), makes the words nearly unreadable. Some letters pop out, others recede, and the “e” seems more associated with the frame than with the rest of the text. Identically colored letters may cluster, even in ways that cross word boundaries. Those that are too light are illegible. Coloring each word separately, as shown in Figure 1(b), respects the word structure, but now “careful” is emphasized over “color” (which may be appropriate). Figure 1(c) puts both words in red, where they stand out from the blue frame. Figure 1(d) uses the same blue as the frame, giving the most unified design; now, the color is entirely aesthetic—it could be black and read the same.

Map makers are masters of the effective use of color. Figure 2 is an example from the U.S. National Park Service showing the west end of St. Thomas in the Virgin Islands. This single example demonstrates all of Tufte’s principles. Color is used extensively to label, as indicated by the legend (color as noun). The shape and height of the terrain is suggested by the shading (color as quantity); water is blue, modulated by greenish sea grass; the land is brown, accented by a green mangrove stand (color as representation). The map is also pleasing to look at.

Figure 1.
Color creates emphasis and grouping. (a) Incoherent application of color to text obscures the words; (b) “careful” is emphasized; (c) the message is separate from the frame; (d) unified text and frame.
Map of St. Thomas, demonstrating multiple uses of color. (Courtesy of the National Park Service.)
with colors chosen to harmonize as well as inform (color as beauty). Figure 3 shows a fragment of this map rendered in shades of gray. While the roads and labels are legible, it is much less effective, and much less beautiful, than the full-color version.

Computer-generated visualizations are created from data. Figure 4 shows an MRI section of a head from the National Institute of Health’s Visible Human Project. Here, data taken in slices are visualized to reconstruct the original shape. In this grayscale representation, the result is recognizably a cross-section of a human head, with identifiable structures such as the brain and the sinus cavities.

There is no color information captured in an MRI; it simply captures the different densities of the materials scanned. The grayscale visualization maps the density scale to a lightness scale to create the image such that denser material is lighter (to mimic the appearance of x-ray film). Coloring the image in Figure 4 would mean replacing the grayscale values with colors, a process called pseudocolor. Such coloring is of dubious value, unless there is a clear mapping between a specific density and a feature of interest. Two pseudocolorings are shown in Figure 5. The blue-yellow gradient is visually inoffensive, possibly even appealing, but it is doubtful whether it conveys more information than the grayscale image. It has a similar lightness scale, even though it also changes hue. The brightly colored “rainbow” mapping is, alas, the more usual application of pseudocolor. Not only is it garish, notice how several small yellow and green “features” have artificially appeared around the cheeks. It is hard to imagine any form of visualization that would be improved by such a coloring—unfortunately, it is the default for many visualization systems.
This chapter focuses on effective uses of color as label and quantity. Labeling is the most fundamental use of color, as it can discriminate and cluster related features. Color as quantity is more complex. Much that is written about color and visualization concerns effectively mapping quantitative values to color. In many applications, this means finding color sequences, or color scales, to represent numeric values. Color as quantity also includes the use of color and shading to represent shape and size, as in the MRI example above, and also in 3D models and renderings, as will be shown below. Such visualizations are an application of the computer graphics principles (described in Chapter 10) to visualization.

Finally, color should be robust. Information presented in color should be visible to those with color vision deficiencies and to eyes of all ages. If rendered on multiple media, it must be legible on all. This implies both careful design and good color management.

To Label

Color can be used to identify or label objects in an illustration. Figure 6 shows a map of the area around Point Reyes, California. Color is used extensively to identify each feature. The major roads are red; the lesser roads are black. The area within the national park
is green; the water is blue—in both cases, the text is similarly color-coded. Cities are yellow, outlined in black to provide a contrasting edge to the light color. The major highways (101, 80, 580) are also outlined in black, which makes their red color appear darker, an example of simultaneous contrast. Figure 6(b) shows the same map in shades of gray. While legible, it is clearly much less effective without the labeling effect of the colors.

Color’s ability to label is a low-level perceptual phenomena—you don’t have to think about it. It is a classic example of a preattentive process; the visual system separates the colored objects from their background all at once, early in the visual processing. This can be demonstrated with following classic experiment. Take a page of numbers, such as shown in Figure 7, and count all the 7s. The amount of time to count them is proportional to the number of digits on the page. That is, to count the 7s, you must look at each digit to determine whether or not it is a 7. Now, color the 7s some distinctive color such as red, as in the second panel in Figure 7. In this case, the time it takes to count the 7s is proportional to the number of 7s on the page, independent of the number of other digits. This phenomenon is sometimes called *pop-out*, as the colored
Figure 7.
Count the 7s. Coloring them red makes them “pop out” from the surrounding numbers, and much easier to count.

digits “pop out” of the background. It is not necessary to use strong, primary colors for labeling and highlighting. The third panel of Figure 7, in which the 7s are much less vividly red, still exhibits pop-out.

Color also works well to group related objects, either by coloring them similarly, or by placing them on a colored background. Figure 8 shows an array of names and numbers representing a number of measured tristimulus values for different projected colors, which are measured for several different projectors. Coloring alternate rows makes it easier to associate each color name with its data, especially as the rows are long. Coloring sets of columns, as shown in the lower table, clusters all the measurements for each projector.

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<th>Y</th>
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Figure 8.
Color clusters either the rows (top table) or sets of columns (bottom table).
Color highlighting and labeling is most effective if there is a small number of different colors on a relatively neutral background. Otherwise, the display becomes cluttered and the information it presents becomes difficult to find. The principles of good design suggest that 2 to 4 key hues, plus tints, tones, and shades of the basic palette will provide a visually coherent design.

If color labeling is used such that the color uniquely conveys the information, it is subject to all the limitations of human memory. The rule of thumb for short term memory is 7, plus or minus 2. Note, however, that an experienced user could memorize many more mappings as long as they are distinguishable when seen in isolation. Colors used in this way should have distinct names. It is probably safe to assume that most people remember the color name more readily than the actual hue, and when discussing visualization, it is helpful to be able to name the visual attributes of the features of interest, such as “the red ones.” Color labeling that conflicts with information presented more explicitly, such as text, should be avoided. Figure 9 illustrates the “Stroop Effect,” which illustrates a fundamental conflict between reading and color labeling. Try saying out loud the color of each word in Figure 9. Since people “know” that the text color is less important than the text content, it takes a noticeable effort (and a measurable amount of extra time) to name the color of the text. Similarly, color labeling that conflicts with convention, such as labeling “stop” green, will cause confusion and errors.

![Color Palette]

**Figure 9.** The Stroop Effect. See how quickly you can name the color of the text (not the color it names).

**To Quantify**

Color scales are sequences of color values used to indicate relative quantity, such as those used in Figures 4 and 5. Time and time again, studies have shown that the only natural or intuitive color scales vary in lightness (value), or in saturation, often combined with a change in value (tints, tones, and shades). There are no perceptually-based hue scales. Yet naïve users and systems persist in trying to use hue scales for sequences of quantitative information. If this chapter can do nothing more than reduce the number of rainbow-colored visualizations like the one in Figure 5(b), it will be a success.
Once again, we turn to cartographers to see how to use color effectively. Cynthia Brewer has created a wonderful, interactive website called “The ColorBrewer” (www.colorbrewer.org) that shows how to map color to various types of numeric information. She categorizes the color scales as *qualitative*, *sequential*, or *diverging*. A qualitative scale simply labels, with different hues of similar lightness or value. A sequential scale indicates quantity, varying primarily in value and/or saturation. A diverging scale is essentially two sequential scales that cross-fade through a neutral color. She recommends that this neutral be mapped to a natural mid-point in the data, such as the mean for statistical data, or zero for signed data. Figure 10 shows an example of a qualitative, a sequential, and a diverging scale, taken from the ColorBrewer. These scales have a small number of distinct levels. Quantizing continuous data into meaningful discrete bins is another important component of creating an effective color scale.

![Figure 10](image-url)

Three different color scales. (From the ColorBrewer.)

Figure 11.
Screen shot from the ColorBrewer (www.colorbrewer.org) illustrating the use of the sequential scale from Figure 10.
Figure 11 contains an example taken from the ColorBrewer, demonstrating the use of the sequential scale in Figure 10, where numeric values are mapped from light to dark shades of green. The data in this figure has no particular meaning, but was designed to illustrate the color scales. Figure 12 shows a diverging scale used to visualize census data, in this illustration, the change in population density. In the diverging scale, the two halves of the scales diverge from a neutral mid-point in lightness steps of contrasting colors (purple and yellow), indicating gain or loss in population.

Scales like these map a single numeric sequence, or univariate data, such as the population data on shown in Figure 12, or the density values in Figure 5. Other examples of univariate data include temperature, height, speed—more generally, any monotonic sequence of numeric data. Multivariate data involves multiple, simultaneous numeric sequences. Assigning color to multiple variables, such as population density plus change in population, results in a multivariate map as shown in Figure 13, which shows population density plus change in population. The value of multivariate
A Field Guide to Digital Color

Figure 13.
This multivariate scale combines change in population with population density. Population change increases color saturation; population density is indicated by hue, which also changes in value. (From Mapping Census 2002.)

Reference.

mappings is that they allow one to more concisely display more information, and to discover relationships within the data. However, it is difficult to use color for multivariate data without causing confusion.

If a univariate color scale is a path in a color space, then multivariate data could be mapped to a plane (two variables), or to a volume (three variables), applying some rules for color mixing. For example, one could put one variable on lightness and one on saturation. Unfortunately, this example is the only 2D scheme based on perception. All other color-mixing models must be learned. Figure 13 puts saturation along one dimension—the other dimension changes in both hue and value, with green being implied as the mixture of yellow and blue (as in dyes or paints, not lights).

Estimating the ratio of colors in a mixture is difficult, even for experts. So at its best, using a color to visualize multivariate relationships only works effectively for highly quantized data, where each mixture is distinctly different from the others. In effect, it becomes a mnemonic for a labeling scheme, rather than a true analysis of mix-
ture. Note that there are only three levels of each dimension in Figure 13, so the total mapping is only nine colors.

Another, possibly better, way to combine colored data is spatially. For example, three different sequential scales could be combined using stripes or other patterns within each region, making it easy to identify the precise quantity of each component. Any colored patterns are subject to the effects of simultaneous contrast and spatial frequency, so again, this approach is good only if the number of different colors is small.

Technologists familiar with RGB color often try to map three data values to red, green, and blue to produce a coherent visualization. For example, in the multi-spectral imaging community, different spectral bands (none of which are actually visible radiation) are mapped to each primary, then combined into a full-color image. While the resulting images can be very beautiful, I believe this approach is as fundamentally flawed for conveying information as the rainbow mapping of univariate data—there is nothing intuitive about RGB mixture, in spite of the way the cones function in the retina. The only time this approach will be helpful is if a specific numeric triple (or volume of triples around it) is of significance, and can be made to create a distinct hue to label its occurrence.

**To Indicate Shape and Size**

In many instances of visualization, the goal is to represent shape, which is most easily done by shading to mimic light falling on a 3D object. Tufte calls this color as quantity also, but I find it a distinct application from the color scales discussed in the previous section. The shading to indicate hills and mountains in Figure 1 is an example of this in cartography.

The field of computer graphics converts data to perceived shape. The techniques described in Chapter 10 for realistic imagery can be applied to simulated or sampled data for visualization given a surface description of the data. For example, the rendering of a marble statue in Figure 2 in Chapter 10 used data taken from a real statue, but visualized it using computer graphics rendering.
Figure 14.
Architectural visualization. This is a rendering of a model of the staircase at one end of the Cornell University Theory Center Building. (Image by Ben Trumbore, Cornell University Program for Computer Graphics.)

One of the first applications of computer graphics was to design and visualize mechanical parts. Computer aided design (CAD) is now used in fields from architecture to drug design. For example, Figure 14 is an architectural rendering created at Cornell University around 1990, when such images were found only in research institutions. Now, architects routinely use such models and rendering to visualize how a building will look before it is built. The company Autodesk, for example, which sells software for 3D modeling and rendering, has a gallery of such images on its website (www.usa.autodesk.com).

Volumetric data sets create values at each point in a 3D space without any explicit surface description. Volumetric rendering is the branch of computer graphics that creates images from such data. A volumetric model can be transformed and viewed from all directions, like any 3D graphics model. Figure 15 shows tiny fragments of surgical gauze modeled by embedding them in a solid block, then alternately photographing and slicing away sections. The re-

Figure 15.
Tiny fragments of surgical gauze reconstructed from microscopic slices. (Image courtesy of Resolution Sciences Inc.)
sulting data are then combined into a volumetric model and rendered to show the shape of the object.

This type of technique can be used for many forms of analysis. Often, the object is not physically cut; the slices are created non-invasively using MRI or CAT scanning technology. Figure 16 shows a reconstruction from CAT scan data of a human foot.

The perception of shape, like the detection of edges, is caused by variation in brightness. Changing hue alone does not give an impression of shape, which can lead to some confusion about the notion of using “color” to indicate shape. More precisely, it is the shading (which is, technically, changes in color) that indicates shape. Changing hue as well, however, can add clarity by labeling, emphasizing, and mimicking nature. For example, Figure 17 is the foot in Figure 16 rendered only in shades of gray. The overall shape is still quite visible, but the colored version more clearly distinguishes the skin from the bones. In addition, the brighter hues at the silhouette edges tend to emphasize them, making the different shapes more distinct.

Making Color Robust

Color used to convey information must be robustly designed to accommodate all viewers and all environments where it is shown. This doesn’t mean that all color representations must work everywhere and for everyone, but the techniques that make color robust often create designs that serve everyone more effectively.

There are two basic categories of problems that need to be solved to make color robust. The first is accommodating viewers with
anomalous color vision, or colloquially, people who are “color blind.” The second category is accommodating media, such as the differences between display and print. Some problems in this category can be alleviated by the correct use of color management, but if colors are far outside the target gamut, no automatic gamut-mapping algorithm will preserve the information content of those colors.

**Designing for Color Vision Deficiencies**

Somewhere around 10% of the population, mostly men, has some form of anomalous color vision. To understand how best to make color robust for such individuals, we need to review some principles from Chapters 1 and 2. Color is encoded in the retina by the cones. This can be represented by the color matching functions, which capture the results of a “standard observer” matching each wavelength with some standard set of primary colors. Someone with anomalous color vision would create a different set of color matching functions than someone with normal color vision.

Color vision problems can be grouped by dimension. Anomalous trichromats see three dimensions of color, but through a significantly different set of color-matching functions (there is some variation among all observers). Dichromats see two dimensions of color, and monochromats only one. For the purposes of color information display, the variation provided by anomalous trichromats can probably be ignored, unless it is important to analyze subtle variations in hue. Monochromats are extremely rare. Most of the 10% mentioned above are dichromats.

The problems caused by dichromatic color vision are best described in terms of the opponent color model, which was presented in Chapter 2. This model, shown again in Figure 18, transforms the short (blue), medium (green) and long (red) cone responses to red-green, yellow-blue, and achromatic color channels. Dichromats fail to see color along one of the two opponent color channels.

The most common color vision problem is a genetic failure in the red-green color processing channel. People with this problem do not see redness or greenness in any color due to some failure in the
medium or long cone processing. This makes discriminating red from green difficult, of course, but also blue from cyan, yellow from orange, or brown from gray. Monochromatic light at 500 nm, which would appear a bright, intense, green to normal observers, appears white. Intense red colors may appear black.

There are two basic forms of red-green vision problems, depending on which of the M and L cones is defective. A person with a defect in the M cone is called a protanope, whereas a deuteranope has a defective L cone. A weakness on the yellow-blue channel, caused by a defect in the S cone, is also possible, but is so rare that it is often ignored as a design constraint; such people are called tritanopes.

Even though dichromatic color vision seems to be caused by a failure in one of the cone photopigments, most dichromats process luminance information from all three cones. As a result, their perception of brightness is similar, if not identical, to that of persons with normal color vision. Maintaining sufficient luminance contrast is important for legibility for all viewers, and even more so for those with color vision deficiencies. As a result, the primary rule for making color robust for information visualization is the same as that for good design: Maintain sufficient value contrast so that the design can be correctly interpreted when reduced to shades of gray.

Another basic rule for making information display robust for all observers is to reinforce the color encoding with position, shape, and size information. This degree of redundancy is not always convenient, but should be provided in proportion to the importance of the information. A stop sign, for example, is not only red—it is hexagonal in shape, is located in a standard place with respect to the intersection it services, and is labeled “STOP” in white, high-contrast letters.

Brettel, Viénot, and Mollon published an algorithm in 1997 that can be used to simulate dichromatic color vision for RGB additive color. A chapter on their work is included in Color Imaging, Vision and Technology, edited by MacDonald and Luo. The Vischeck website (www.vischeck.com), run by Robert Dougherty and Alex Wade of Stanford University, uses these algorithms and their extensions to visualize the effect of “colorblind vision” on websites and color images.

Reference.
Color and Media

Information display is traditionally designed for a specific medium. Maps and the examples in Tufte’s books are created specifically for print. User interface designs are created for displays, and so on. Changing to a star-shaped model, where one design that includes colors from many sources can be output on many different media, is even more difficult than for image reproduction.

The principles of device-independent color and color management can be applied to help support cross-media information display. As in image reproduction, they make the color transformations across media more stable and predictable, but algorithms sufficient for transforming images may be less successful when applied to color for information display. For example, color scales that generate uniform steps on one medium may be transformed so that the steps become uneven, or two values become identical. Similarly, while most gamut mappings generally preserve relative lightness, they may darken or lighten extremely out-of-gamut colors, thereby reducing contrast.

Color used in information display has semantic content, which is usually expressed by color relationships. These are difficult to preserve simply by mapping each color independently as a point in some color space. An ideal system for supporting cross-media design (a topic for future research) would make it possible to explicitly specify and constrain the underlying relationships so that they could be explicitly preserved. For colors used as labels, color names could provide an appropriate level of abstraction; the name “dark red” for example, could be mapped to an appropriate color on all media, avoiding accidental transformation into the color “brown.” Colors used in color scales could be represented as paths through some device-independent color space. Mapping algorithms that preserved the path relationships could then be designed. Specifying color scales as paths is already included and published in Brewer’s work.

A simple example of this approach, suitable for application to charts and graphs, was implemented at Xerox PARC as part of the work on the Xerox Color Encoding Standard in the late 80s. A small
set of named colors (red, green, blue, yellow, black, white, and gray), were recognized by all printer and display drivers. The mapping to device primaries was determined by the specific driver, and optimized to that device. Even black and white printers implemented these color names, choosing distinct textures or line patterns for each one so that the color encoding was still visible.

Encoding color semantics in the device driver is probably not the right implementation strategy for modern computer system architectures; however, allowing a level of indirection for color specification somewhere in the color reproduction path is a powerful way to make color used in information display more robust across media.

A Final Example: The Colors of Emission Nebula

One of the powers of using computers to create digital images is to visualize natural phenomena that are normally impossible to see. Emission nebula are glowing clouds of gases consisting primarily of ionizing hydrogen and oxygen. The emissions may be fueled by the energy from young stars, which are created inside the nebula, or, the nebula may be the lingering results of a super nova. Seen through a telescope, they are faint, fuzzy patches in the night sky—but glowing hydrogen and oxygen should be brightly colored, as they emit nearly monochromatic red and green light, respectively.

This final section describes two different efforts to visualize the colors of emission nebula, as illustrating how art and science can be combined to make effective use of color in information display. The first example is by Thor Olson, a color engineer and avid night sky photographer. The second is the simulation created by the San Diego Super Computing Center for the Hayden Planetarium. The description here will be brief, but both images are backed by excellent web sites, which describe their creation and context.

Figure 19 is a visualization of the Veil Nebula, created by performing careful colorimetric rendering of measurements taken through a telescope using narrow band filters. The technique of using narrow filters enables a careful analysis of the spectral distribu-
Figure 19.
Colorimetrically accurate rendering of the Veil Nebula. (Image by Mike Cook and Thor Olson. For more detail, see www.nightscapes.net.)

tion of the light produced by the nebula at each point on the image. The process used by Olson to render the picture applies the principles of colorimetric color reproduction to map the spectral description to the sRGB color space. While this process was made as accurate as possible, some estimations were needed due to limitations in the data, and the process that produced the best colors for the gases created pinkish stars. As a result, the stars were color corrected separately, to make them appear white.

The resulting image shows more of the green oxygen emissions than most renderings of this phenomenon, and is potentially most enlightening for those seriously interested in the composition and hypothetical appearance of such nebula. The coloration is more subtle, however, than that often published in pictures of this nebula, which are simply photographs taken through telescopes. In such pictures, the film response, not a simulation of the human visual response, produces the colors. Other standard methods for producing color photographs of nebula involve combining several images that represent emissions in different parts of the spectrum, mapping them to red, green, and blue, and combining them to form a sort of

Reference.
pseudo-coloring. The result is often very colorful and attractive, and can be informative if the pseudo-color highlights significant spectral features.

The colorimetric color reproduction methods used to create Figure 19 were published at the Color Imaging Conference in 2002. Detailed information about this image, as well as other technical information about night sky photography and many lovely examples, can be found at www.nightscapes.net.

Figure 20 is a frame from an animated visualization of the birth of an emission nebula, produced by the San Diego Super Computing Center together with the American Museum of Natural History for the Hayden Planetarium. The visualization shows cosmic gases and dust condensing to form clumps, which eventually become new stars. A detailed physical simulation was used to create the time-varying volumetric model that was rendered for the visualization. As in Figure 19, the red comes from ionized hydrogen and the green from ionized oxygen, though
the colors in this visualization were not colorimetrically simulated, but were manually selected. The yellow and orange colors are simply mixtures of the red and green that appear in the same volume of space. The deep blue is entirely artificial—it represents the dust cloud, which would normally be black or dimly lit by the light of distant stars. In the early stages of the animation, there is only dust, which would make dull viewing if accurately rendered. Another enhancement was to make the stars appear larger as they became closer. Physically, they would only become brighter, as the distances are too great to see an increase in size, but this looked wrong. People’s experience with moving objects at more normal distances and the fact that brighter stars make bigger dots on photographic film due to overexposure made the sequence look “more realistic” if the stars got bigger.

Figure 20 was designed to be shown in the Hayden Planetarium, which is part of the American Museum of Natural History in New York City. Seven projectors are used to produce the images on the planetarium’s dome. Dome projection, however, scatters light from adjacent surfaces, which desaturates the image. To compensate for this effect, the scientists at the Super Computing Center increased the saturation of the rendering. The result is a spectacularly colorful picture, which print can only approximate. Images from the simulation, plus a more complete description of the simulation process, can be found at www.vis.ucsd.edu.

**Summary**

Color in information display should follow Tufte’s principles, the primary one of which is “do no harm.” Color can emphasize, cluster, and label. Some combinations can indicate quantitative sequences of numbers. It is an important part of indicating shape through shading, where a smooth change in brightness can give the appearance of light falling on a 3D object. The shading need not be realistic to have its effect; the shading used by cartographers for terrain, for example, is highly stylized.

Many articles on color for information display are actually about color scales. While it has been stated many times already, let me
repeat one more time: Changing hue is a terrible way to indicate numeric sequences. There are no intuitive hue scales, only learned ones. There aren’t even very many good learned hue scales. Thermometer scales make red “hot” and blue “cold,” but black-body radiators are hotter at blue than at red. And while many learn the order of the rainbow (and hence of the spectrum) colors in grade school, which is “bigger” depends on whether you think in wavelength or frequency.

Like color design, effective use of color in information display must be learned through a combination of principles and experience. This chapter has tried to emphasize good examples, which were taken primarily from cartography. For those looking for other good examples, the National Park Service has placed their collection of maps in digital form on the web, and makes them freely available (www.nps.gov/carto/). The U. S. Census Bureau makes their publications available on the web also (www.census.gov). Like the Park Service maps, they have been put in the public domain and can be freely used.

This chapter is structured on Tufte’s principles for the use of color, which have been applied by others to the problem of visualization. The “Evolution of a Numerically Modeled Storm” is a classic example of visualization created at the National Center for Supercomputing Applications. An article by Baker and Bushell describes how they used Tufte’s principles to enhance their visualization of a storm system.

The emission nebula examples are included because they blend scientific simulation with the art of making effective images. Even the colorimetrically accurate simulations of human vision used by Olson had to be augmented by special treatment of the star field. The shapes and colors produced for the Hayden Planetarium were the result of a massive simulation effort, which modeled as accurately as possible a process impossible to see—the simulation covers thousands of years. The resulting images, while colored according to good scientific principles based on the light created by the simulation, also included concessions to the mass-presentation venue of a public planetarium.

Reference.

Tufte’s final fundamental use of color is to enliven or decorate. Good illustrations are beautiful, which is why people collect maps and make posters of the route map of the London Underground. The value of aesthetics is often questioned in “practical” disciplines like science and engineering, however, some of the principles that make color design more attractive, such using a limited palette (eliminates confusion), with a range of tints and tones (to provide luminance contrast), make color more effective as well. An attractive illustration will be looked at more carefully and remembered longer, which is, after all, the primary goal of information display.