Adjusting Simultaneous Contrast Effect for Dynamic Information Display

Suguru Ishizaki
Visible Language Workshop, Media Laboratory
Massachusetts Institute of Technology, Cambridge, Massachusetts

Abstract

Simultaneous contrast effect often confuses the viewer's understanding of the color coding scheme on information graphics, such as maps and diagrams. In particular, on a computer-based dynamic display, such as weather and air traffic, since background color and position of a graphical element are difficult to predict at run-time, we need to adjust the physical color of each element automatically so that all elements that are intended to appear the same color are perceived that way. This paper introduces experimental information graphics that automatically adjusts color differences based on Jameson and Hurvich's research The results suggest that adjustment of simultaneous contrast effect can increase the reliability of dynamic information display and the flexibility of its design.

Introduction

Simultaneous color contrast is a known phenomenon; humans perceive the same color differently on a different background color. In graphic design, this effect has been recognized, for it often confuses the viewer's understanding of the color coding scheme of information graphics, such as diagrams and maps. Consequently, graphic designers must select colors for information graphics carefully in order to minimize the simultaneous color contrast effect and maximize the reliability of message contents.

In a traditional *fixed* form of visual communication, such as print, film, and television, designers solve this problem by choosing colors with less simultaneous contrast effect, or by manually adjusting colors. However, in computer-based communication, where information and interaction can be dynamic, background color and the position of graphical elements are difficult to predict at run-time. Since simultaneous color contrast effect is unpredictable in computer-based visual communication, it limits the range of colors that can be selected by designers, compared to the range for traditional *fixed* media.

In this project, I have developed a software that adjusts the physical color of design elements automatically so that all elements that are intended to appear the same color are perceived that way. The purpose of this project has been to investigate how the automatic adjustment of simultaneous contrast can aid visual designers of computer-based information displays.

Simultaneous Contrast Effect in Visual Communication Design

In graphic design (e.g., publication, poster, or information graphics), the simultaneous color contrast effect is an important perceptual phenomenon that designers must understand from the perspectives of both esthetics and communication.

On the one hand, the simultaneous contrast effect can be actively utilized in order to increase the number of perceived colors with a limited number of physical colors. It allows designers to produce complex color harmony. The number of plates in printing can also be reduced; hence it can save printing costs. A road map is an example of the active use of the effect. In road maps, red and yellow are often used adjacent to blue and red to produce purple and orange respectively.

On the other hand, the simultaneous color contrast effect is manually adjusted to keep perceived colors constant. For example, in advertising, a corporate logotype that is placed on a background of varying colors (e.g., a colorful photograph) can be partially adjusted so that the perceived color of the logotype is uniform, thus maintaining the identity of the corporate color. Both usages have been emphasized in graphic design education and various exercises have been invented[2].

As described above, simultaneous contrast can be effectively used or adjusted to maintain constant color perception. However, in the design of information graphics, such as charts, diagrams, and maps, it has been recommended to select colors that minimize the simultaneous color contrast effect[7,8], or to use other techniques to reduce the effect. Some of the techniques developed include: the use of black lines in edges, the use of blurred edges, and the use of other cues (e.g., shape) in conjunction with color. Designers also often simply select colors which do not cause much simultaneous contrast based on their experience.

In the design of a computer-based information display, such as weather and air traffic, the visual design is far more restricted since information and interaction are dynamic. Although some of the techniques developed for traditional design (e.g., black line) can increase the reliability of the information display, the simultaneous contrast effect clearly limits the range of color compositions since designers also need to consider the esthetics and the semantics of the design.

Method

The simultaneous contrast effect has been known for a long time and there have been a considerable number of psychological studies since nineteenth century. After a series of experiments by Jameson and Hurvich in the 1960's, there has also been research based on the neurophysiological findings, and a number of models have been proposed and are being examined.

In this project, I have implemented experimental software based on the theory proposed by Jameson and Hurvich[1,5,6]. They describe the simultaneous contrast effect based on the opponent-colors theory. In the experimental program, three primary colors (red, green, blue) on a computer display are converted into three opponent primary colors, namely *r-g* (redness/greenness), *y-b* (yellowness/blueness), and *w-bk* (brightness) [3,4], and the effect is computed using the opponent primary colors.

In the context of visual design, I assumed a simple scenario where a designer selects a desired perceptual color with a particular background, which I call *reference color* and *reference surrounding color* respectively. Then, the problem is to compute physical colors for individual design elements on a display given their background colors, so that they can be perceived in the same way as the *reference color*. I call the colors used for design elements in information graphics *display colors* and their background *display surrounding colors*.

According to Jameson and Hurvich, *r-g* and *y-b* (chromatic components) of a surrounding area affect *r-g* and *y-b* of the focal area. Let $r\text{-}g_i$ and $y\text{-}b_i$ be the chromatic components of the effect (color difference) caused by the surrounding area, and $r\text{-}g_s$ and $y\text{-}b_s$ be the surrounding area, then:

$$r - g_i = -k \cdot r - g_s$$

$$y - b_i = -k \cdot y - b_s$$

where k is determined by experimental conditions (e.g., size of a focal area) [5].

Now, let $r\text{-}g_f$ and $y\text{-}b_f$ be the chromatic components of a *reference color*, $r\text{-}g_s$ and $y\text{-}b_s$ be the chromatic components of the *reference surrounding color*, $r\text{-}g_{f'}$ and $y\text{-}b_{f'}$ be the chromatic components of the *display color*, $r\text{-}g_{s'}$ and $y\text{-}b_{s'}$ be the chromatic components of the *display surrounding color*, then we can compute $r\text{-}g_{f'}$ and $y\text{-}b_{f'}$ such that the chroma of the design elements are perceived in the same way as the reference color:

$$r - g_{f'} = r - g_f - r - g_s + k \cdot r - g_{s'}$$

$$y - b_{f'} = y - b_f - y - b_s + k \cdot y - b_{s'}$$

Similarly, the brightness of the surrounding area affects the brightness of the focal area. Let R_f be the brightness of the focal area that is perceived by a viewer, $w\text{-}bk_f$ be the achromatic component of the focal area, $w\text{-}bk_s$ be the achromatic component of the surrounding area; then we can obtain R_f as follows:

$$R_f = (w - bk_f^n - l \cdot w - bk_s^n) / (1 - l^2)$$

where $n = 1/3$ and l is determined by experimental conditions (e.g., size of a focal area)[6].

Let $w\text{-}bk_f$ be the achromatic component of the *reference color*, $w\text{-}bk_s$ be the achromatic component of the *reference surrounding color*, $w\text{-}bk_{f'}$ be the achromatic component of the *display color*, $w\text{-}bk_{s'}$ be the achromatic component of the *display surrounding color*; then we can compute $w\text{-}bk_{f'}$ in such a way that the brightness of the design element is perceived in the same way as that of the *reference color*:

$$w - bk_{f'} = (w - bk_f^n - l \cdot (w - bk_s^n - w - bk_{s'}^n))^{1/n}$$

In addition, when the *display surrounding color* is not uniform (e.g., map, photograph) the average of the surrounding area can be used for the computation[6]. I have also observed that the value of k is a function of *reference color* and *reference surrounding color* as well as the size of target; and the value of l is influenced by the value of k and the size of target. However, in the current system, those functions are manually appropriated for each application. Further investigation is necessary to find more general functions.

Application and Discussion

The automatic adjustment of the simultaneous contrast effect can be applied to various domains of information design. In this project, I have implemented two examples of experimental information displays that use automatic adjustment. The results have been evaluated informally by professionally trained graphic designers. Viewing distance was roughly determined based on the normal use of information graphics (approximately 500 mm).

The first example is a display of butterfly migration. The display is designed to show two types of butterflies discovered in the area around Mediterranean sea over a period of time. The system plots squares (approximately 7×7 mm each) in places where significant numbers of butterflies are discovered. Geography is shown by using a satellite map in which the color varies from desert (pale yellow) to ocean (deep blue) to forest (green). The display also uses text to show the temperatures and names of places. In this type of display, since the background colors of design elements may arbitrarily vary, the simultaneous contrast effect becomes unpredictable.

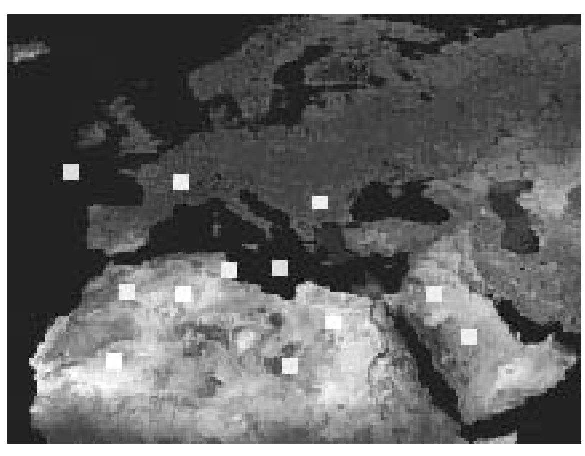

Figure 1. Screen snapshot of a butterfly migration display

The colors of the squares are adjusted based on a reference color that is selected with a background color. In other words, the color palette used in this system uses a color perceived by the viewer by taking its background into account, whereas a typical color palette simply takes the physical color of the selected cell. The surrounding color of each square is averaged (colors in approximately 5 mm around the edge are sampled) and the physical color of the square is computed so that it can be perceived in the same way as the reference color. For text, an average color of a rectangular area that contains a character is considered as a surrounding color and individual characters are separately adjusted.

A grayish orange, which is the color of one type of butterfly, is used to indicate that butterfly. This grayish orange considerably changes in appearance depending on its background (e.g., map) without the adjustment. Using the automatic adjustment program, the range of perceived color of the squares becomes closer to the *reference color* (color of the butterfly). Although there are still noticeable differences, the adjusted display is clearly an improvement over the one that is not adjusted.

The adjustment improves the display in several ways. It corrects the perceived size differences of individual squares caused by brightness contrast. The perception of depth caused by size difference is also adjusted and all the squares are perceived on a flat surface. The adjustment also emphasizes the sense of group (which is important in visual communication) of squares that belong to the same category. The adjustment is particularly effective when two categories of butterflies are plotted on the display.

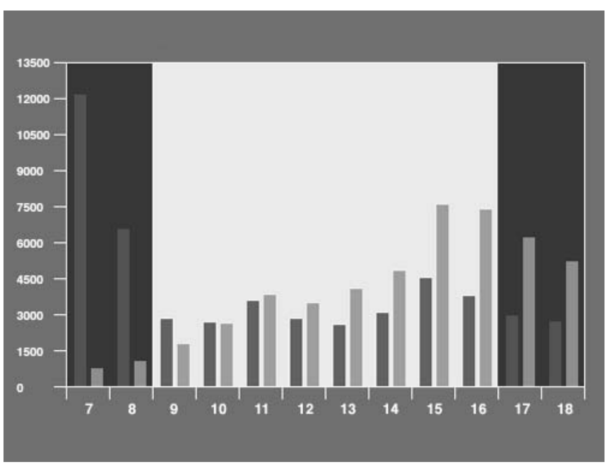

Figure 2. Screen snapshot of a bar graph representing pedestrian traffic in a train station

The second example is a bar graph typically used in business graphics. The system is designed so that the colors of the bars and the background can be altered by hand or by a dynamic change of information. The particular example I have implemented is a graph of pedestrian traffic in a train station. This graph is designed so that both the number of people entering and exiting the station can be compared according to time (every hour). The bar graphs that show the number of people entering the station and exiting it are color coded orange and green respectively. Blue and pale yellow are used for the background to differentiate morning/ evening and during a day. Without the adjustment, the colors of the bars displayed on different backgrounds are perceived differently.

This example has given additional proof that the adjustment improves the visual design of the information display. The adjustment also solves the problem of thickness differences among bars caused by brightness contrast. It improves the sense of group among the bars that belong to the same category as well; hence the sense of transition, which is not obvious otherwise, becomes emphasized.

It has been observed that the problem caused by simultaneous contrast effect is stronger in the design of bar graphs compared to that of butterfly migration. This indicates that the effect is more obvious in color compositions with flat colors than those with arbitrary color surfaces (i.e., map). As a consequence, flat color compositions may require more precise color adjustment than that used in the experimental program.

Conclusion

The experimental use of the automatic adjustment of the simultaneous contrast effect in the visual design of computer-based communication are reported. Experimental software that adjusts the simultaneous contrast effect on a computer display has been developed based on Jameson and Hurvich's research, and the applicability of automatic adjustment in visual design has been examined.

Two application examples, *a butterfly migration display* and *a bar graph of pedestrian traffic in a train station* were implemented and the results have been discussed. The results have shown that automatic adjustment improves the visual design of information display in several ways: we have observed that the sense of group is improved, the perception of illusional depth is corrected, and the size difference caused by brightness contrast is adjusted. Although the program does not perfectly adjust the simultaneous contrast effect, this experiment has shown that automatic adjustment does extend the flexibility of visual design of computer-based information graphics.

In this project, the emphasis is placed on examining how the automatic adjustment of the simultaneous contrast effect can aid visual designers. Thus, the accuracy of the adjustment has not been emphasized. This project also has not considered the relationships between simultaneous contrast and motion, form, and mode of appearance of color (i.e., surface color and illuminant color). These issues will be considered in future research.

Acknowledgment

This research has been done at the Visible Language Workshop, Media Laboratory, Massachusetts Institute of Technology, under the direction of Professor Muriel Cooper. We thank members of the Visible Language

Workshop for their help. The world map data was provided by Tom Van Sant of Geosphere, Inc. This work was sponsored in part by ARPA, NYNEX, Alenia, and JNIDS.

References

1. Agoston G. A., *Color Theory and its Application in Art and Design*, Springer-Verlag, 1987, pp 181-209.
2. Albers J., *Interaction of color*, Yale University Press, 1971.
3. Jameson D. and Hurvich L. M., "Some quantitative aspects of an Opponent-Colors Theory.II. Brightness, saturation, and hue in normal and dichromatic vision," *J. Opt. Soc. Am.* Vol. 45 No.8, 1955, pp. 602-616.
4. Jameson D. and Hurvich L. M., "Some quantitative aspects of an Opponent-Colors Theory. IV. Psychological Color Specification System," *J. Opt. Soc. Am.* Vol. 46 No. 6, 1956, pp. 416-421.
5. Jameson D. and Hurvich L. M., "Opponent chromatic in duction: Experimental evaluation and theoretical account," *J. Opt. Soc. Am.* Vol. 51 No. 4, 1961, pp. 46-53.
6. Jameson D. and Hurvich L. M., "Theory of brightness and color contrast in human vision," *Vision Res.* **4**, 1964, pp. 135-154.
7. Marcus A., *Graphic Design for Electronic Documents and User Interface*, ACM Press, 1991, pp. 77-96.
8. Tufte E., *Envisioning Information*, Graphics Press, 1989, pp. 81-95.