Automatic Color Scheme Adjustment for Different Color Vision

Takuto Yanagida and Hidenori Mimura

Research Institute of Electronics, Shizuoka University
3-5-1 Johoku, Hamamatsu 432-8011, Japan
E-mail: takty@rie.shizuoka.ac.jp

Abstract

The authors propose a system which adjusts automatically color schemes for different color vision. Designing color scheme is difficult problem because it has two aspects, art design and accessibility, and they relate to each other. We formulate color scheme problem as a fuzzy constraint satisfaction problem, and implement a prototype system for proving the feasibility of our method.

1. Introduction

Information representation, such as floor maps and flyers in public spaces, traditional printings, and web pages, has two aspects on deciding its *color scheme*, combination of colors. One is the aspect of art design, where art designers exercise their abilities, and another is the aspect of media, by which information is conveyed properly to receivers. In the latter case, from the viewpoint of accessibility, difference of personal characteristics should be considered.

While physical objects have their own specific colors, elements in art designs can have arbitrary colors, which cannot uniquely determined when designers try to improve existing color schemes because art design and accessibility relate to each other. For example, when the contrast of a two-tone color scheme is to be improved, the combination of the two colors' parameters, brightness, saturation and hue, might explode. In addition, designers have to consider various *constraints*: to keep the image of original color scheme, to regard differences of *color vision*, etc.

Can we develop a supportive tool, which enables anyone to design color schemes which is easy-to-understand for everyone, aiming at floor maps etc.? In this work, we propose a system, which automatically suggests color schemes which satisfy both of art design and accessibility on information representation. With a technology of artificial intelligence, the color scheme problem is formulated as *fuzzy constraint satisfaction problems* (FCSP). This paper shows a prototype tool which automatically adjusts color scheme, based on the original one assigned by users or designers, satisfying the constraints mentioned above.

We have already submitted a paper on the detail of this work to the Japanese Society for Artificial Intelligence.

2. Color vision and color space

The difference of color vision gains sever problems for *reading* information representation using colors (Fig. 1), and it is caused by the difference of characteristics of cells in

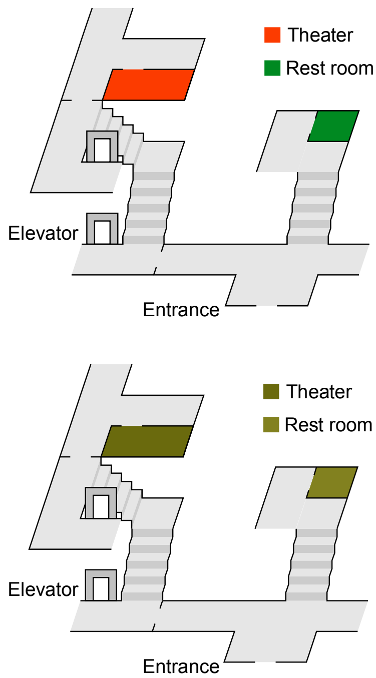

Fig. 1 The same floor map in different two color vision, trichromacy (top), and protanopia (bottom).

eyes. Human recognize color with *cone cells* on retinas. Cone cells can be classified into S, M, and L cones which respectively react to short, middle, and long wavelength. When all types of cones are normal, then color vision is called *trichromacy* (majority). When L cones or M cones are lacking, then color vision is respectively called *protanopia* and *deuteranopia*. Congenital red-green color deficiency (protanopia and deuteranopia) presents in approximately 5 percent of males and 0.2 percent of females, and in approximately 3 millions of Japanese people [1].

A color system means a system which consists of definitions and rules for representing color quantitatively [6, 8]. A color can be represented by combinations of independent three components. When these combinations are taken as vectors, three-dimension space for geometrical representation of color is called *color space* [6, 7]. In this paper, we use CIE 1976 L*a*b* color space, which aspires to perceptual uniformity, and is a uniform color space (Fig. 3). A color consists of lightness *L*,* and its position between red/magenta and green *a** and its position between yellow and blue *b**. *Color difference* corresponds to the distance of two points, and is calculated as follows:

$$\Delta E = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} .$$

Whether or not colors can be distinguished is determined by color difference among them.

3. Fuzzy constraint satisfaction

A fuzzy constraint satisfaction problem (FCSP) is a generic term for search problems

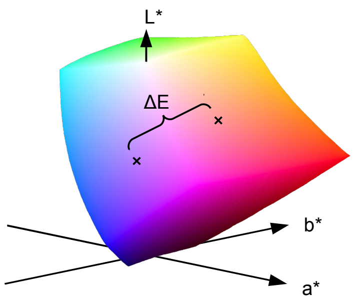

Fig. 2 L*a*b* color space. In this color space, a color difference corresponds to the distance of two color *ΔE*.

to find combinations of values that satisfy the given constraints. An FCSP introduces a soft constraint called a *fuzzy constraint*, which is not necessarily satisfied completely, but instead, its degree of satisfaction (*satisfaction degree*) should be considered. It consists of the following components: a set of *variables* $X = \{x_1, \ldots, x_n\}$, a set of finite *domains* $D = \{D_1, \ldots, D_n\}$, and a set of *constraints* $C = \{c_1, \ldots, c_r\}$. Each variable x_i is supposed to take a value from the domain D_i. a constraint c_k denotes a fuzzy relation with its membership function defined by

$$\mu R_k : \prod_{x_i \in S_k} D_i \text{ to } [0,1]$$
$$\text{for } S_k = \{x_{k_1}, \ldots, x_{k_w}\}.$$

In other words, the membership value is defined by an assignment $v[S_k]$ to the scope S_k. This value is called the *satisfaction degree* of the fuzzy constraint. S_k is called the *scope* of R_k. If $w=1$, 2, or 3, the constraint is called a unary, binary, or ternary constraint respectively.

Since an FCSP requires the satisfaction of the fuzzy conjunction of all fuzzy constraints, the satisfaction degree of the whole FCSP is defined as the smallest satisfaction degree of all the constraints as follows:

$$C_{\min}(v) = \min_{1 \le k \le r} (\mu R_k(v[S_k])) .$$

If $C_{\min}(v) > 0$, then an assignment v is called a *solution* of the FCSP, and a solution that maximizes $C_{\min}(v)$ is called an *optimal* solution. Therefore, an FCSP is regarded as an optimization problem that requires finding the assignment that maximizes the smallest satisfaction degree of the constraints.

4. Problem and method

Generally, increasing the color difference among combined colors which should be discriminated enhances the easiness of discrimination in color schemes. Therefore, we define the objective of our method as increasing color difference in color schemes in three color vision, trichromacy, protanopia, and deuteranopia as much as possible (Fig. 3). Color vision of protanopia, and deuteranopia is simulated by projecting the color space to planes with transformation equa-

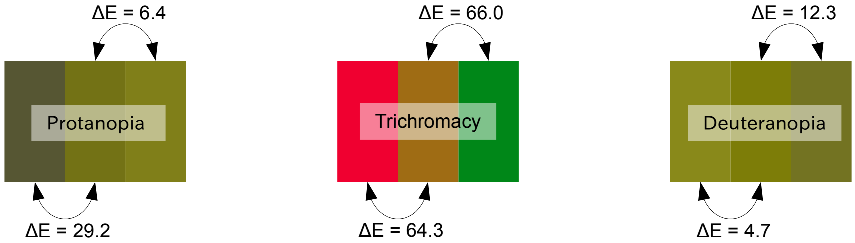

Fig. 3 Color differences among the colors of a color scheme in different color visions. ΔE denotes color difference. In the center, ΔE of the adjacent colors are enough, but in the left and right, ΔE of the different color combinations are small.

tions respectively [3]. In this work, a color scheme where color differences are increased as much as possible is the solution of color scheme problem. In addition, we take color conspicuity (how a color catches someone's eyes among multiple colors) [4] into account, and consider conspicuous colors should not be changed much for keeping the impression of original color schemes.

Applying the framework of FCSPs, we propose a method for adjusting color schemes to have enough color difference regardless of color vision, without destroying the impression of an original color scheme, the intention of its designer. The color scheme problem is formulated by mapping colors, pallets (possible colors), balance (relations meaning contrast etc.) to the elements of FCSPs (Fig. 4). The pallets consist of neighbor colors of each original color. Solvers of FCSP search combinations of colors in domains (pallets), and output a solution (improved color scheme) which satisfies constraints (color differences) as much as possible. Note that it is not trivial that we use pallets instead of all possible colors in the color space. An FCSP is a combination search problem, and thus, its search space should be small for getting quickly getting a solution. The pallets reduce the search space as well as keeping original colors.

5. Implementation

For proving the feasibility of our method, we implemented a system as a prototype of a tool in Java language. We adopted an FCSP library, Stlics [9], and two solvers, forward checking, which is one of the systematic solvers, and SRS 3, which is one of the stochastic solvers, contained in the library.

The system consists of two windows, color scheme window and control window. First, a user selects the number of used colors (two, three, fine colors, or two colors with a background color), and assign arbitrary colors (Fig. 5). Then, after specifying options, considered color visions etc., the user click the "Run" button (Fig. 6). In a moment, the tool shows a result, which is adjusted as to extend color difference.

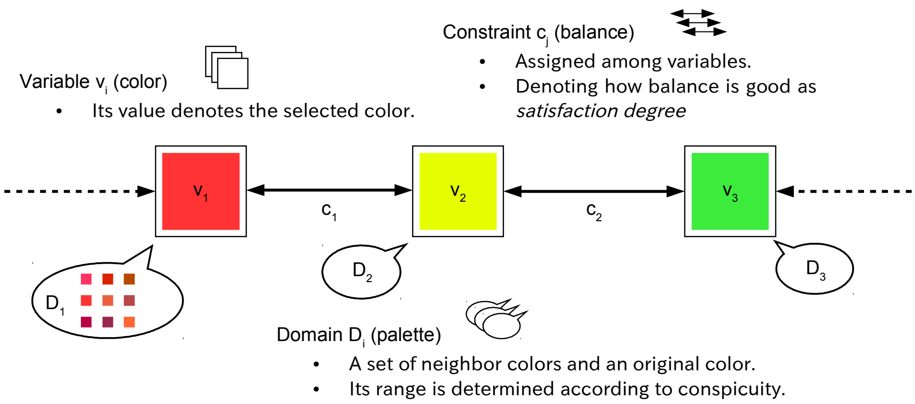

Fig. 4 A color scheme problems formulated as a fuzzy constraint satisfaction problem

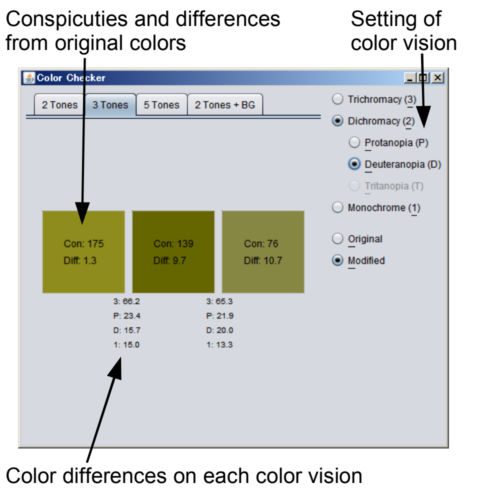

Fig. 5 A screen shot of the color scheme window of the implementation of the tool.

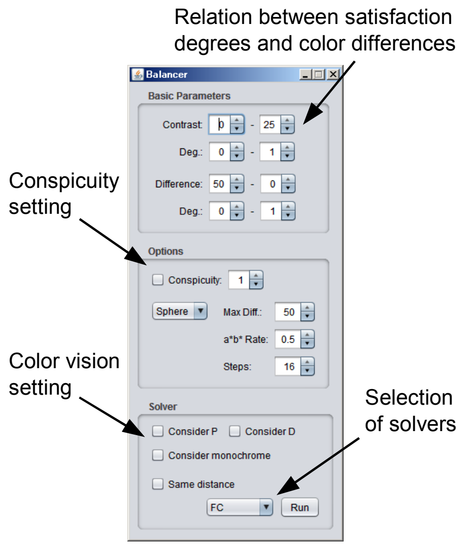

Fig. 6 A screen shot of the control window of the implementation of the tool.

6. Conclusion

We formulated the color scheme problem considering the difference of color vision as a fuzzy constraint satisfaction problem, and showed the implementation of a prototype of the automatic color scheme adjustment system. In addition, we verified our method and system could work properly, adjust color scheme for multiple color visions.

References

[1] Japanese Ophthalmological Society : Eye Diseases—Congenital Color Vision Deficiencies, 2003, Available at http://www.nichigan.or.jp/public/disease/hoka_senten.jsp (accessed July 2, 2010)
[2] Gernot Hoffmann: CIELAB Color Space. http://www.fho-emden.de/~hoffmann/cielab03022003.pdf
[3] Viénot, F.; Brettel, H. & Mollon, J. D.: Digital Video Colourmaps for Checking the Legibility of Displays by Dichromats, Color Research and Application, Vol. 24, pp. 243-252, 1999.
[4] Harumi Saito, Masahiro Watanabe, and Yoko Asano: Effective Use of Color Conspicuity for Re-Coloring System, Correspondences on Human Interface, Vol. 12, No. 1, pp. 33-38, 2010. (in Japanese)
[5] Ruttkay, Z.: Fuzzy Constraint Satisfaction, Proceedings of the 3rd IEEE Conference on Fuzzy Systems, Vol. 2, USA, pp. 1263–1268, 1994.
[6] Noboru Ohta: *Shikisai Kougaku*, Tokyo Denki University Press, 2nd Edition, 2001. (in Japanese)
[7] Hideyuki Tamura: Computer *Gazo Shori*, Ohmsha, 2002. (in Japanese)
[8] Takao Matsuda: *Shichikaku*, Baifukan, 1995. (in Japanese)
[9] Takuto Yanagida and Yasuhiro Sudo: Stlics: A Library for Fuzzy Constraint Satisfaction Problems, 2009, Available at http://www.nvrc.rie.shizuoka.ac.jp/takty/interest/stlics.en.html