Advances in Computer Science and Engineering
Volume 5, Number 1, 2010, Pages 81-95
Published Online: August 29, 2010
This paper is available online at http://pphmj.com/journals/acse.htm

COLOR-ARRANGEMENT MODIFICATION FOR COLOR-BLIND WEB-PAGE READERS USING INTERACTIVE GENETIC ALGORITHM

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Abstract

This paper proposes a software system that arranges Web-page colors in such a way that it improves the readability of the page for color-blind readers. The system provides the most optimum color arrangement for an individual by using an interactive genetic algorithm. A prototype of the system has been developed as a Mozilla Firefox add-on. It has user assistance functions. For example, users who are not familiar with computer systems can evaluate new color arrangements using a star-rating system. A user can obtain a new color arrangement that is the closest to the original color arrangement from among candidate color arrangements. A subjective evaluation performed by fifteen subjects shows that it requires an average of 34 s to obtain a suitable color arrangement. Further, on a scale of one to four, two-thirds of the subjects rated the operability of the system to be three or more.

1. Introduction

Color blindness is the inability of an affected person to perceive differences among some of the colors that others are able to distinguish. There are a large

Keywords and phrases: interactive genetic algorithm, color arrangement, color vision, Web-page, CSS.

Received May 5, 2010

number of color-blind people throughout the world (approximately 2% to 3%); this number is greater than the number of disabled people. Meanwhile, because of the considerably widespread use of the Internet, people create their own Web pages to disseminate information. In this situation, it is highly desirable that anyone, including color-blind readers, should be able to acquire information from any Web-page. However, to this end, all Web-page designers need to have the knowledge of design that is color barrier-free.

Previous studies have developed systems [7-9, 14] that generate color arrangements according to personal preference on the basis of an interactive genetic algorithm (IGA) [2], which is one of the interactive evolutionary algorithms that use human evaluation [12]. Human evaluation is often necessary when the result of optimization should fit a user preference. These studies focus on obtaining color arrangements reflecting the preference of the designers. They do not take into account the preference of the Web-page readers. In contrast, in this paper, we propose a system that provides the best Web-page colors from the point of view of the readers, particularly, color-blind readers [13].

Our system helps color-blind readers to obtain the best color arrangement quickly and easily. Moreover, the system considers the intention of Web-page designers in such a way that the rearranged colors are as close to the original colors as possible. Furthermore, the system can be operated using user-friendly interface. The system proposes new color arrangements in a preview window and readers rate these arrangements using a star-rating system. A subjective evaluation carried out by fifteen subjects reveals that it takes an average of 34 s to select a satisfactory color arrangement, and that on a scale of one to four, two-thirds of the subjects rated the operability of the system to be three or more.

The rest of this paper is organized as follows: Section 2 provides an overview of the system. We outline the system and its applicability in the case where a reader encounters a Web-page that is difficult to read. Section 3 compares the proposed system with existing systems that use the IGA for color arrangements. Section 4 describes the manner in which the system analyzes and rearranges Web-page colors. Section 5 explains the method for obtaining the best color arrangement using the IGA. Section 6 shows the results of a subjective evaluation. Finally, Section 7 concludes the paper.

2. System Overview

The system proposed in this paper is invoked when a reader encounters a Web-page that is difficult to read. The system then proposes new color arrangements, and the reader rates all of them. After this proposal-evaluation process is repeated multiple times (the default is three times), the reader obtains a suitable color arrangement.

2.1. Processing steps

The following are the processing steps of the system:

1. A color-blind reader encounters a Web-page that is difficult to read.

2. The reader clicks on a part of the Web-page that requires color rearrangement.

3. The system analyzes the cascading style sheet (CSS) and retrieves color data (RGB values) of that part.

4. The system converts the RGB color values into HSL values.

5. The system proposes new color arrangements, which are obtained by using the IGA, and the reader rates these arrangements. After this proposal-evaluation process is repeated three times, the reader obtains the best HSL color values.

6. The system converts the HSL values into RGB values.

7. The system replaces the old RGB values written in the CSS with the new values.

8. The reader goes back to step 2 if he/she wants to try again; otherwise, the reader terminates the system.

The system converts a RGB (red, green, blue) color representation to an HLS (hue, saturation, lightness/luminance) color representation since it modifies the saturation (S) and the lightness (L) values (see Section 5).

2.2. User assistance functions

The system provides two functions to support color-blind readers as they select suitable color arrangements. These functions include automatic selection and numerical display of brightness differences between characters and their backgrounds, and they enable readers to take decisions quickly and easily.

2.2.1. Automatic selection

This function enables quick selection of a new color arrangement that is the closest to the original. If a system user selects this function, then one color arrangement is automatically selected from the color-arrangement candidates proposed by the system on the basis of the length D defined by

$$D = \sum | L_i - L_i' | + \sum | S_i - S_i' |, \tag{1}$$

where L_i (L_i') and S_i (S_i') are the original (new) lightness and saturation values of the ith color. A small D indicates that the candidate is close to the original color arrangement. The system considers the arrangement of three colors. Therefore, $i \in \{1, 2, 3\}$. A user can select another candidate if there is a candidate that is better than the candidate proposed by this function.

2.2.2. Numerical display

The brightness differences between characters and their backgrounds are numerically displayed for all color-arrangement candidates in the preview window. Users can check the differences in figures. The World Wide Web Consortium (W3C) recommends that the foreground and background color combinations provide a sufficient contrast in brightness when the combinations are viewed by someone having color deficits [15], where the color brightness is calculated with RGB values as

$$\frac{R \times 299 + G \times 587 + B \times 144}{1000}.$$

2.3. Development environment

A prototype of the system, which is developed for the experiments described in Section 6 and is available at [13], is designed as a Mozilla Firefox add-on using JavaScript [6]. We also use a CSS, a style sheet language used for describing the look and the formatting of a document written in a markup language [10, 1], to modify the colors on the Web-page. The W3C recommends the use of the CSS [3].

3. Comparisons with Existing Systems

Table 1 compares the proposed system and the existing technologies. From the table, we observe that our system has the following three features.

1. The objective of our system is to modify the existing Web-page color arrangements. In contrast, the existing technologies are designed to help designers select color values that they prefer. In other words, the proposed system supports Web-page readers, while the existing systems support designers.

2. The proposed system deals with Web pages; therefore, it analyzes and modifies colors through the CSS language.

3. The system provides a star-rating system to support Web-page readers who are not familiar with computer systems.

Table 1. Comparisons with existing systems

	Proposed system	System in [8]	System in [9]	System in [14]	System in [7]
Objective	color-arrangement modification	color-arrangement design	color-arrangement design	design support	color-arrangement design for Web pages
Color representation	HSL RGB	HSL	RGB HSB L*a*b*	HSB	undisclosed
Analysis	CSS	no input[1]	image processing[2]	no input[1]	no input[1]
Output	CSS	undisclosed	undisclosed	undisclosed	CSS
Gene representation	real number	binary	binary	undisclosed	undisclosed
Evaluation	star rating (1 to 4)	slide bar (0.0 to 10.0)	click (1 to 5)	selection from 2 candidates	selection from at most 4 candidates

[1]Color values are randomly generated.

[2]Color arrangements of user-provisioned pictures are analyzed.

4. Accessing Web-page Colors

This section describes the way in which the system accesses and rearranges Web-page color arrangements.

4.1. Analysis

The proposed system uses the Document Object Model (DOM) to analyze and modify color values written in a CSS. The style sheet provides rules that define document presentation, such as the layout, colors, and fonts. Figure 1 exemplifies a CSS rule and its effective range. The DOM is an application programming interface (API) that allows programs and scripts to dynamically access and update nodes in

HTML, XHTML, and XML documents [5]. The DOM regards an HTML document as a hierarchical tree structure of nodes. Figure 2 shows a DOM tree, where the nodes in the figure correspond to those in Figure 1.

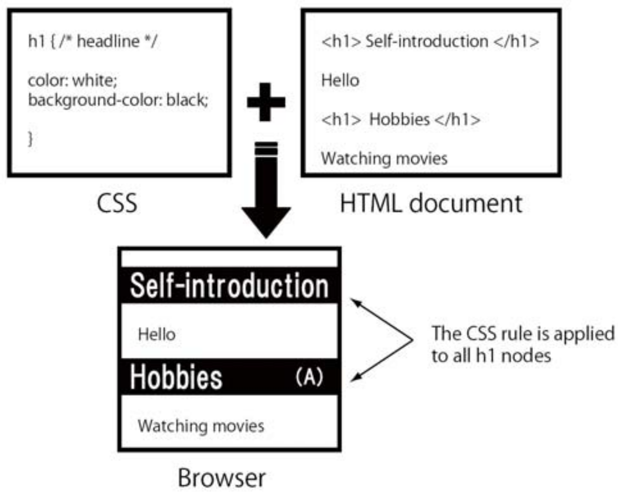

Figure 1. A CSS rule and its application.

The following describes the procedure (which is coded with JavaScript) for obtaining color values:

1. A system user clicks a place where colors should be rearranged.

2. The DOM tree is searched from the clicked node to upper-layer nodes until a CSS rule that specifies the color information of the node is obtained. For example, if place (A) on the browser in Figure 1 is clicked, then the tree is searched in the order of (A), (B), (C), and (D), as shown in Figure 2. If the definition of the character and background colors is not found, these colors are defiled as black and white, respectively.

3. The extracted CSS rule is analyzed to obtain the color values of the characters and the backgrounds.

The proposed system assumes that the color values are written in accordance with the CSS rules in the form of hexadecimal numbers (e.g., #ffffff), RGB values (e.g., rgb(255,255,255)), or Web color names (e.g., white).

4.2. Modification

Web-page colors can be modified by adding a new CSS rule. This is because a more recently added CSS rule has a higher priority. If a CSS rule is inserted, then the rule is applied not only to the clicked node but also to all nodes having the same name as the clicked node. For example, Figure 1 illustrates that if (A) is clicked, then all hl (headline) nodes are modified at the same time.

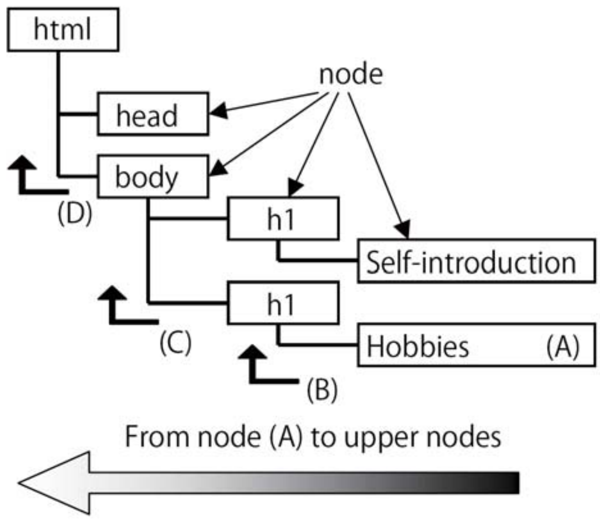

Figure 2. The DOM tree is searched for color information.

5. Finding Best Colors

Color-blind people are sensitive to saturation (S) and lightness (L); therefore, even small changes in the saturation and lightness values yield a large effect [11]. Accordingly, the proposed system optimizes S and L values with the IGA.

5.1. IGA

A genetic algorithm (GA) is a search technique used for finding exact or approximate solutions to optimization problems on the basis of the techniques inspired by evolutionary biology. The interactive genetic algorithm (IGA) is different from the GA in that the fitness of every individual is evaluated by human users and not by functions provided beforehand. Therefore, the preference of each user can be reflected directly in the solutions of the IGA. Figure 3 shows an IGA flowchart. In the figure, the dotted lines indicate the part in which a human user is involved.

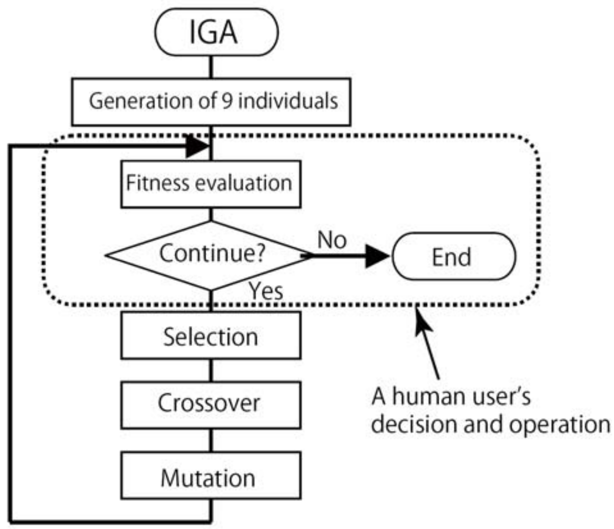

Figure 3. The next generation (nine individuals) is created through the selection, crossover, and mutation operations.

5.2. Representation

An individual consists of three colors. The first is a character color, the second is a background color, and the third is a background color right under the second color. Since we modify only the saturation (S) and the lightness (L) values of each color, six elements constitute a gene, which determines the fitness of an individual. The six elements are real numbers and take values in the range of 0 to 100. The hue (H) values of the three colors are fixed to their original values.

5.3. Operations

Every generation consists of nine individuals. The first nine individuals (i.e., the first generation) are created randomly, and the next generation is created through three gene operations (selection, crossover, and mutation) as shown in Figure 3. In the experiments in Section 6, the calculation is performed until the fourth generation is created. Table 2 summarizes the IGA parameters and their values for the experiments in Section 6.

5.3.1. Selection

By using the evaluation ratings of nine individuals, we select the three top individuals (the elitist strategy). The three individuals are included in the next generation. Next, six individuals, which are used for the crossover operation, are selected from the nine individuals. The selection probability is proportional to their ratings (the roulette wheel selection). In this case, an individual is allowed to be selected more than once.

5.3.2. Crossover

This operation is performed over the six selected individuals. For each individual *i*, its partner is uniformly selected from the rest of the selected individuals to execute the one-point crossing operation. The operation is performed with probability p_c (crossover rate), and the crossing point is uniformly selected. If the operation is performed, a new individual is created and is used for the mutation operation; otherwise, the original individual *i* is used.

5.3.3. Mutation

Lastly, the mutation operation is performed over each of the six individuals with probability p_m. In this operation, for all six elements e of an individual, a new element e', with which e is replaced, is uniformly selected from the range $[e - y_i, e + y_i]$, where y_i is the width used for the *i*th generation. The range decreases with an increase in *i* such that $y_{i+1} = r_c y_j$, where the contraction rate r_c satisfies the condition $0 < r_c < 1$.

Table 2. IGA parameter values used in the experiments

Parameters	Values
Crossover rate p_c	0.8
Mutation rate p_m	0.5
Contraction rate r_c	0.6
Mutation width y_1	40

5.4. User evaluation

A human user evaluates the fitness of each individual (i.e., how the user can read characters easily by using the color arrangement represented by the gene of the individual). Nine individuals are evaluated on five levels ranging from 1 to 5. For users who are not familiar with computer systems, the system provides a star-rating system. For example, "★★★✡✡" indicates a level-3 evaluation. In the system, the black and white stars are replaced with yellow and gray stars, respectively, since all color-blind people can easily recognize these colors [11]. Users can intuitively understand this graphical user interface (GUI) and every evaluation is carried out by clicking one of the five stars only once. In order to clearly distinguish between two stars ✡ and ★, the white star ✡ is replaced with a dot "**.**" just after evaluation. If an individual is not evaluated, its level is set to one. Figure 4 illustrates a preview window containing nine color arrangements.

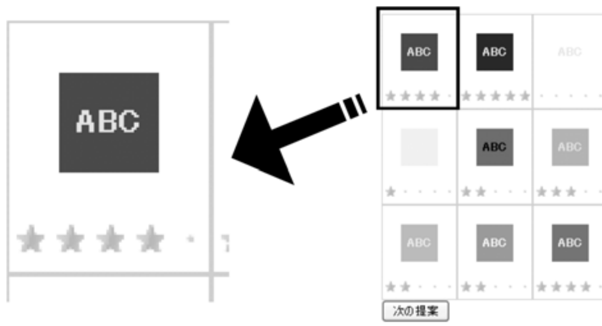

Figure 4. Star ratings for nine color arrangements.

6. Subjective Evaluation

6.1. Conditions

In the experiments, we use a color simulation monitor that can reproduce colors perceived by P-type (protanopia) and D-type (deuteranopia) people, where the P-type people have a color vision deficiency caused by the complete absence of red retinal photoreceptors and the D-type people have a color vision deficiency in which the green retinal photoreceptors are absent, moderately affecting the red-green hue discrimination. According to [4], approximately 90% of the color-blind people are either P-type or D-type people.

Fifteen subjects (age group: 20 to 25 years) perform subjective evaluations using the proposed system and the color simulation monitor in the following order.

1. The subjects select the most unreadable Web-page from 18 pages twice; i.e., the selection is made when the monitor is set up to simulate the P-type color vision and the D-type color vision. The CSSs of the 18 pages are written such that the color arrangements of all pages are unsuitable for the P-type or the D-type people.

2. The subjects modify the color arrangements of the selected pages by using the proposed system.

3. The subjects check whether sentences written on the page are readable after modification.

4. The subjects answer the questionnaire in Table 3.

Table 3. A questionnaire for subjective evaluation

No.	Questions	Evaluation
1	Is the selected page readable?	1 to 4
2	Is the modified page readable?	1 to 4
3	Can you get information after modification?	yes or no
4	Is the system easy to operate?	1 to 4

6.2. Results

6.2.1. Readability

Figures 5 and 6 show the experimental results of subjective evaluations for the first three questions given in Table 3. Figures 5 and 6 are the results for the P-type and D-type color visions, respectively. From the two figures, we observe that all subjects confirmed that the modified page was more readable than the selected original pages and that they could easily read the information written on the modified pages. There were six subjects who selected the same page as the most unreadable page. The character and background colors of the page were brown (# 4e4510) and green (# 005110), respectively; therefore, the brightness differences were 16. After modification, the brightness differences of the modified pages were 71, 32, 22, 43, 63, and 78. The maximum value (i.e., 78) was more than three times larger than the minimum value (i.e., 22). Therefore, this shows that the brightness difference depends largely on personal preference.

6.2.2. Operability

Figure 7 shows the results for the operability of the proposed system (the fourth question in Table 3). Eleven out of fifteen people (73%) rated the operability of the system as good (i.e., 3 or 4). However, four subjects, who did not rate the operability as good, commented that the GUI operation was troublesome.

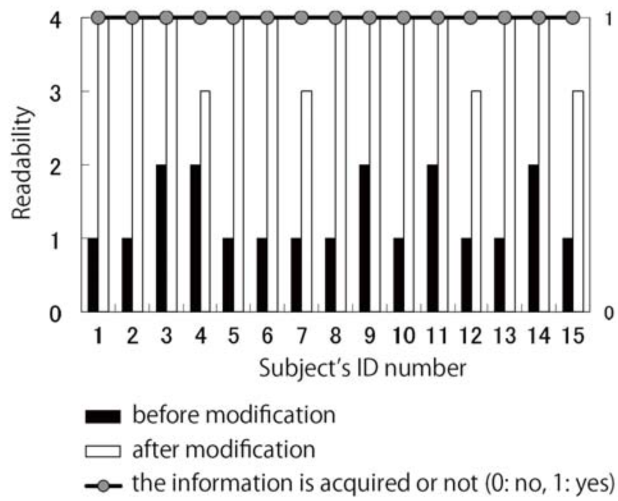

Figure 5. Readability improvement for the P-type people.

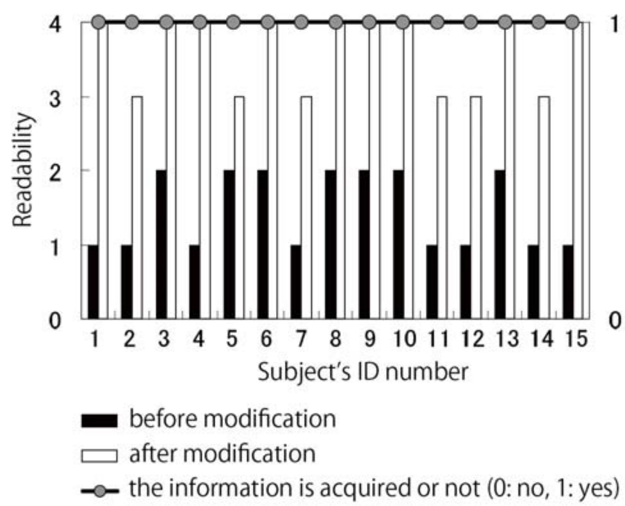

Figure 6. Readability improvement for the D-type people.

The four subjects were familiar with the character user interface (CUI) operation; therefore, they wanted convenient CUIs, such as shortcut functions. Every subject used the system twice (since the experiment was designed for two color-vision types). It took 34 s on an average to finish the modification process when the subjects used the system for the first time. However, the average time decreased to 10 s for the case in which subjects used the system for the second time.

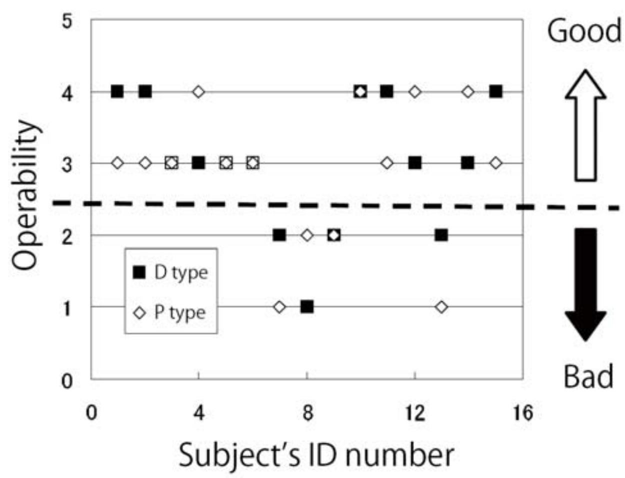

Figure 7. Operability of the proposed system.

6.2.3. Other findings

We obtain the following two interesting results:

• 33% of color arrangements selected by the subjects agreed with those selected by the automatic selection function. This result suggests that people may not always select the color arrangement that is the closest to the original.

• The W3C recommends that the brightness difference between the foreground and the background colors should be at least 125 [15]. However, our experiment shows that 60% of the modified pages did not satisfy this recommendation. Therefore, people may not always require a large brightness contrast.

7. Conclusions

In this paper, we have proposed a software system that arranges Web-page colors in such a way that it improves readability of the Web-page for color-blind readers. The system has been designed such that the preference of each reader is directly reflected in the modified pages through the use of the interactive genetic algorithm. Automatic selection and numerical display functions were introduced to enable readers to take decisions quickly and easily. The former is used to obtain a new color arrangement that is the closest to the original, and the latter numerically displayed the brightness differences between characters and their backgrounds. For color-blind readers not familiar with computers, the system provides an easy-to-understand star-rating system; using this system, users can evaluate each color arrangement by clicking once on one of the five stars. A subjective evaluation was performed by fifteen subjects with a color simulation monitor that could reproduce colors perceived by P-type (protanopia) and D-type (deuteranopia) people. We obtained the following experimental results:

• All subjects confirmed that the page modified with the proposed system was more readable than the original page.

• Eleven out of fifteen people (73%) rated the operability of the system as good. It took 34 s on average to obtain a modified page when the subjects used the system for the first time. For subjects using the system a second time, the average time decreased to 10 s.

• 33% of the color arrangements selected by subjects agreed with those selected by the automatic selection function. This indicates that people might not always select the color arrangement that is the closest to the original.

• 60% of the modified pages did not satisfy the W3C recommendation that the brightness difference between the foreground and the background colors should be at least 125. Therefore, people might not always require a large brightness contrast.

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