



Adaptive color artwork

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HPL-2006-186
December 15, 2006*

variable data
printing, custom
publishing, color
printing, visual
performance

The words in a document are often supported, illustrated, and enriched by visuals. When color is used, some of it is used to define the document's identity and is therefore strictly controlled in the design process. The result of this design process is a "color specification sheet," which must be created for every background color. While in traditional publishing there are only a few backgrounds, in variable data publishing a larger number of backgrounds can be used. We present an algorithm that nudges the colors in a visual to be distinct from a background while preserving the visual's general color character.

* Internal Accession Date Only

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1. INTRODUCTION

The words in a document are often supported, illustrated, and enriched by visuals. This artwork printed with the text consists of graphic materials and rules. The graphic materials include photographs, illustrations, renderings, drawings, charts, graphs, logos, and other forms of artwork. Rules and boxing are used to organize disparate elements that might otherwise float in space or be confused with neighboring material.

When color is used, some of it—for example in graphs, logos, and rules—is functional, i.e., it is not an abstraction of a real world object color, it is used to define the document’s identity and is therefore strictly controlled in the design process. The result of this design process is a “color specification sheet.”

A traditional color specification sheet defines the identity color palette for various process variations, such as monochrome, duocolor, process, and process with spot colors. The most critical element is typically the logo, and the mapping for the various print processes is performed manually with much attention to preserve the logo’s character across processes, as can be appreciated from the example shown in Fig. 1.

Being so work-intensive, this design process is carried out for a single background color, namely that of the most commonly used media. In rare instances, this design work is repeated for a second background color, for example black, when the document is a product brochure or an advertisement.

In variable data printing, color is used much more dynamically to customize a document more closely for the intended target reader. For example, a baby formula brochure may use a pinkish color scheme for new parents of a girl and a cerulean scheme in the case of a boy, or a brochure for jewelry may be printed with a page background corresponding to the recipient’s birth stone color. When a logo appears on colored areas, the color specification sheet would need to be revised for each possible background color, which is expensive and not always feasible, because a larger number of color schemes may be used in a variable data job or campaign.

We will present an algorithm to nudge the colors in a logo—or any functional artwork—so that it is clearly distinct from a background color, while preserving the document’s general character. This can be achieved by simulating tinting—which is what designers traditionally do—or by minimally changing the lightness. We want the resulting artwork to be legible also when printed on a monochrome printer and when viewed by a person with deficient color vision. We will discuss the thresholds and show an example.

2. COLOR SPACE SELECTION

As shown in Fig. 1, in the U.S. artwork color is typically specified using the Pantone® system. This is not a colorimetric system and therefore is not a good starting point for an algorithmic approach. The first step is therefore to obtain from a table colorimetric values for each used color. This also holds for other non-colorimetric color systems, like for example the TOYO® Color Finder.

When a tabulation of colorimetric values is not available, a simulated color can be extracted from the PDF file by determining the alternate color space in the separation declaration and evaluating the type 1 or type 4 tint transformation in the same declaration with the tint value of each custom color (see the PDF reference manual¹ on page 267 for details). This will yield a CMYK or an RGB value.

When the artwork colors are specified in a device color space or calculated as above from a non-colorimetric color specification system, a color management system can be used to obtain colorimetric values. In certain cases, the colors are already specified colorimetrically, either as calibrated RGB, as CIELAB, or as ICC based.

Of the possible colorimetric color spaces, we would like to use one in which the dimensions correlate well with subjective color terms, because this will make it easy to translate typical graphic artist decisions into algorithms. A popular choice is

CIELAB in cylindrical coordinates, because L^* correlates well with perceived lightness, C^*_{ab} correlates well with perceived chroma, and h_{ab} correlates well with perceived hue.²

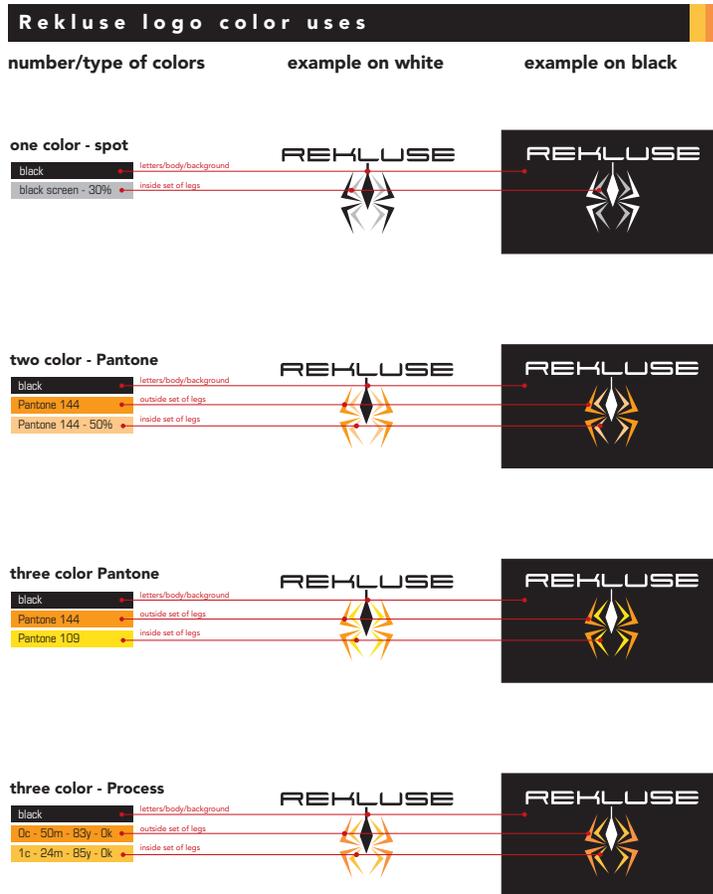


Fig. 1. Color specification sheet for a logo. The left column contains a row for each printing process. The center column shows the logo on a white background and the right column on a black background, with the red lines indicating the color to use for each element.

mark.

A more general process that scales well is to design a logo that works well with one neutral background. When a new background color is added, the logo’s colors are nudged so the logo is still clearly readable, but maintains its original character. Again, this can be extended to any visual element.

We now have to find out how to translate the concept of “nudging” into subjective color term changes, i.e., how to describe it in terms of changes of a color attribute perceived by a human. With our choice for the color space, the terms are hue, lightness, and chroma. The human visual system is most sensible to hue changes, therefore graphic artists strive to leave the hues constant so as to maintain the visual element’s “color character.” Should nudging be achieved by a change in lightness, chroma, or both?

The second most important criterion is the boundary integrity of the geometric elements comprising the visual elements,

Fig. 1 shows a logo, but the same discussion holds for color used in other functional visual elements, such as rules and descriptive statistics graphs.

3. GRAPHIC ARTIST’S INTENT

After the colors in a visual elements are available in the desired color space, we observe how graphic artists manually adapt the colors to a different background. Fig. 1 reveals the process when a logo is designed to concomitantly work on a white and on a black background. Graphic artists typically map a black element on a white background to a white element on a black background. For all other colors, they use a technique called “tinting,” where in the separation the color is not solid but half-toned to a percentage of coverage—for example using a Pantone Tints guide—so they obtain an intermediate lightness that shows well both on the white and the black background.

This process can be generalized to the concomitant design for a small number of different background colors, but it does not scale to a design for several background colors. Also, it does not lead to a rule for how to proceed when a new color is added to a background color palette, because it would require a completely new color scheme for the logo, which would defeat the logo’s purpose as a visual identity

i.e., the edges, must remain clearly visible. Because in the human visual system shape perception is sustained mostly by a modulation of the parvocellular pathway, which is the most likely site for a lightness channel, we postulate a criterion that there must be a lightness contrast between each geometric element and the background. When the lightness contrast is insufficient, the color's lightness is nudged above a threshold.

With this we have an algorithm that works from a color perception point of view, but this is not how a graphic artist would proceed, who as we saw before proceeds by tinting colors. Essentially, tinting consists in exposing some of the media's white background. This leads us to a second possible strategy for nudging a color, namely to blend it with the white background. This second criterion changes both the lightness and the chroma.

We have implemented both nudging methods, changing just the lightness and tinting. Our management has preferred the first method, so for the remainder we just describe this method, assuming it is obvious how to implement tinting in CIELAB. In the next session we address the amount by which a color should be nudged.

4. CONTRAST THRESHOLD

In a previous paper³ we described how to change the color of text on a colored background so that reading performance is not impaired. We can use the same method also for color artwork. Fig. 2 illustrates how the lightness difference between background and foreground colors is assessed and a suggestion is computed. When the lightness difference is above a *threshold*, there is no discriminability issue.

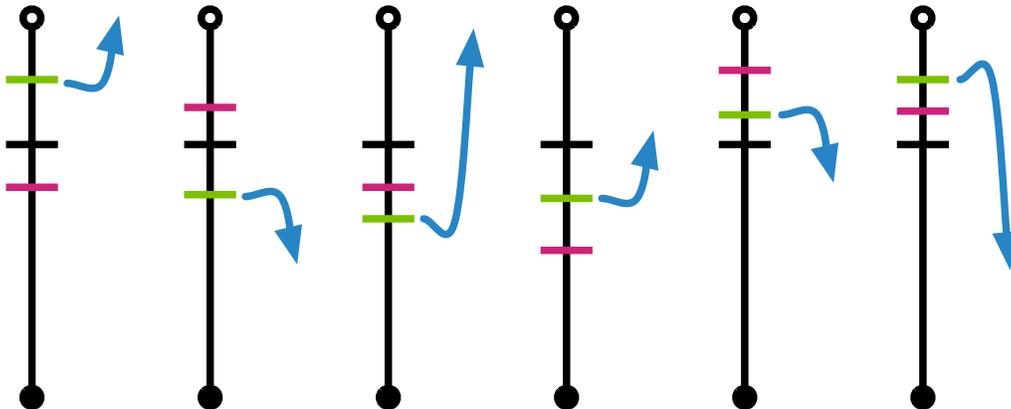


Fig. 2. An algorithm to adjust the lightness of a foreground color in relation to a background color. The vertical line represents the lightness axis and the black horizontal tick marks medium gray. The darker (violet) tick marks the background color, the lighter (green) tick at the arrow start the foreground color. The arrow indicates how the lightness of the foreground color is adjusted.

Note that in Fig. 2 medium gray is not half way the lightness range and we have introduced the concept of a lightness *bias*. Although the lightness range can grossly be divided in a dark half with values between 0 and 50 and light half with values between 50 and 100 lightness units, in practice, the best informal estimate for the effective mid-point between light and dark (bias) was 70 lightness units. Both the discriminability threshold and the bias are just empirical values that can change from application to application, but we believe they are typical for the real world.

With this information it is easy to understand Fig. 2, where the lightness for the foreground color is changed depending on its relative darkness or lightness with respect to the background color. The difference between foreground and background lightness is computed and compared to the threshold value described above. When the difference falls below this threshold, the lightness of the foreground color is changed depending on its position relative to the medium gray and the background color. The amount of the lightness change is calculated to push the new difference above the threshold. A

preliminary psychophysics experiment^{4,5} revealed that the threshold is somewhere between 25 and 30 CIELAB units.

The following code implements the algorithm in Fig. 2:

```
private final static double threshold = 29.0;
private final static double thresholdSmall = threshold / 3.0;
private final static double bias = 70.0;
public DiscriminableColor adaptiveColorOn (DiscriminableColor background) {
    ColorOpLch fgOp;
    DiscriminableColor fg, bg = background;
    double lightness = this.lightness();
    double deltaE = this.deltaE76 (bg);
    double deltaL = (abs (lightness - bg.lightness()));
    boolean darkenFG, aLot; double amount;
    darkenFG = ((lightness < bias) & (bg.lightness() > bias)) |
        ((lightness > bias) & (bg.lightness() > bias));
    aLot = ((lightness > bias) & (bg.lightness() > bias) & (lightness >
bg.lightness())) |
        ((lightness < bias) & (bg.lightness() < bias) & (lightness <
bg.lightness()));
    if ((this.chroma() < 10) & (deltaL < threshold)) {
        amount = threshold + (bias - 50.0);
        if (darkenFG) amount = -amount;
        if (aLot) amount = 2.0 * amount;
        lightness = min (max (lightness + amount, 0), 100);
    } else {
        if (deltaE < thresholdSmall) {
            amount = thresholdSmall * 0.5;
            if (darkenFG) amount = -amount;
            if (aLot) amount = 2.0 * amount;
            lightness = min (max (lightness + amount, 0), 100);
        }
    }
    fgOp = new ColorOpLch (lightness, this.chroma(), this.hue());
    fg = new DiscriminableColor (fgOp, n, this.descr + " adapted against " +
bg.descr);
    return fg;
};
```

5. RESULTS

Fig. 3 shows the result of applying this algorithm to the two background colors in Fig. 1, white and black. On the white background, the logo colors are the same as in the color specification sheet, but on the black background the spider's body is changed to gray instead of white. As mentioned earlier, the designer had only two background colors in mind, while the algorithm scales to any number of background colors and always nudges the colors consistently.

We can now apply this algorithm to a number of backgrounds. Fig. 4 shows how the colors are nudged when the artwork is placed on blue and pink background colors in the HP corporate palette with which the lightness contrast is low. The two backgrounds in the middle are maybe the ones that are unexpected, with no nudging of the spider body color on a light

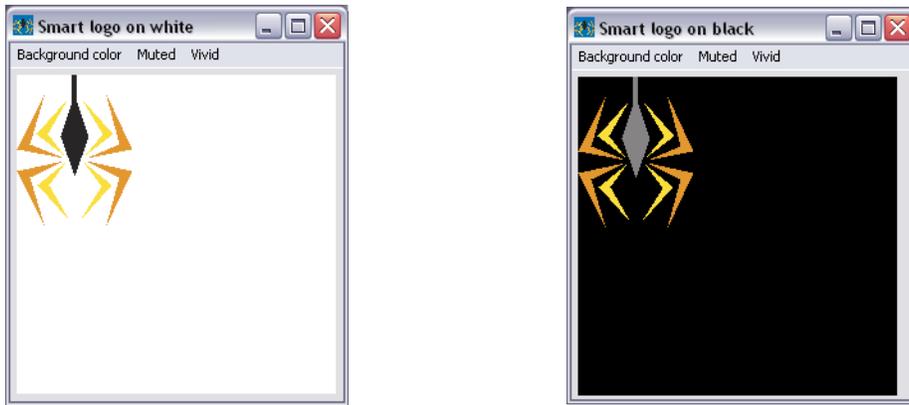


Fig. 3. Adaptive background color algorithm applied to the logo in the color specification sheet in Fig. 1 for a white and a black background. The colors are identical on for the white background, but on the black background the spider's body was just nudged to grey, instead of being changed to the complementary color.

blue background but a major change on the dark pink background.

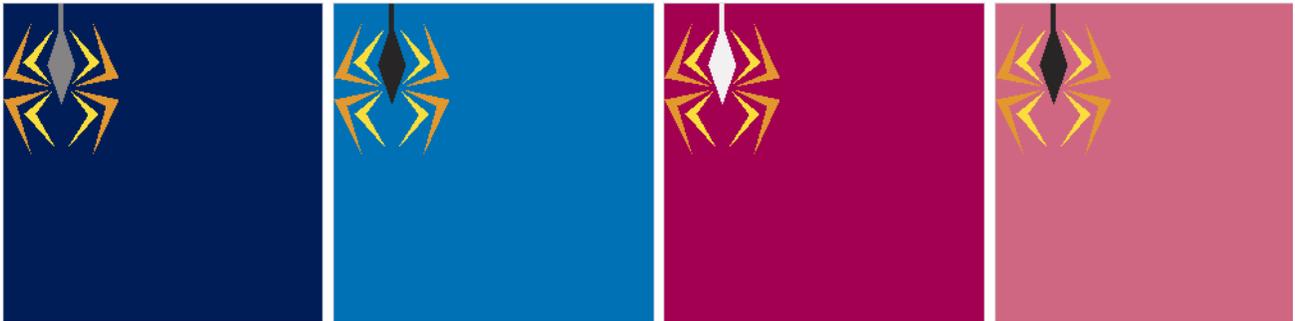


Fig. 4. On the darker blue background the spider's body color is nudged to grey, while on the dark pink background it is nudged to white. On the two pink backgrounds the leg colors have been nudged.

As expected, on orange and ochre background (see Fig. 5) colors the spider's legs would disappear in the background and need to be nudged to make them slightly lighter or darker. Note, however, that the color character is still preserved.

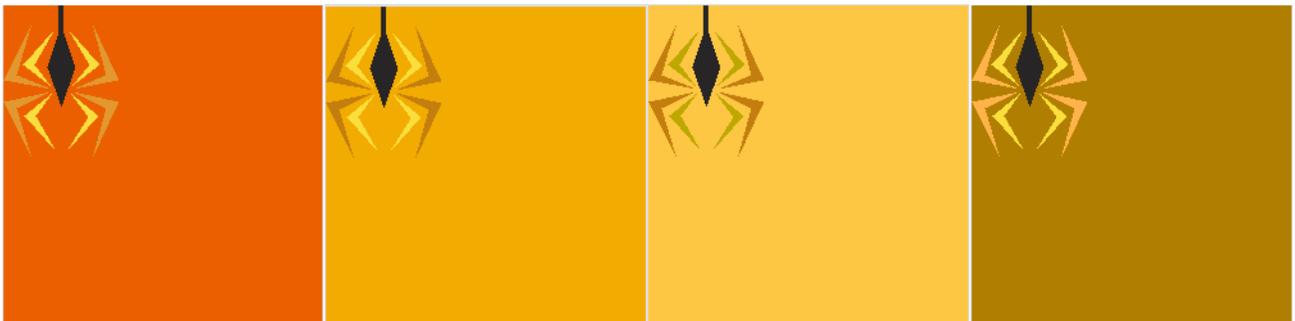


Fig. 5. On the orange and ochre backgrounds the leg colors have been nudged, but the logo's overall color character has not changed.

As we noted at the end of the introduction, we have decided to consider the lightness contrast because we also wanted to ensure sufficient contrast for readers with deficient color vision. In reality for the more common cases of (anomalous) protanopia and deuteranopia, this is necessary only in the case of colors on the confusion lines. The colors could be remapped to simulate what protanopes and deuteranopes see and the color contrast can then be evaluated. When there is sufficient color contrast, the requirements for the lightness contrast could be relaxed.

A further refinement could be to take into account also simultaneous contrast. When an element of a visual has a complementary color with respect to the background, it could be muted to preserve the overall color contrast.

6. CONCLUSIONS

We have presented an algorithm to nudge the colors in color artwork so that the artwork remains distinct from any arbitrary color background, while maintaining its general color character. This algorithm is useful in variable data printing, where each copy of a document is customized for its recipient, and a logo or descriptive statistics graph can be automatically placed on a background of an unexpected color. We have listed an example implementation and shown the application to a logo.

7. REFERENCES

1. Adobe Systems Incorporated, *PDF Reference, sixth edition: Adobe Portable Document Format version 1.7*, 2006; download from http://www.adobe.com/devnet/pdf/pdf_reference.html
2. G. Wyszecki and W.S. Stiles, *Color Science: Concepts and Methods, Quantitative Data and Formulae*, 2nd edition, John Wiley & Sons, New York, 2000
3. G.B. Beretta, "Color Aspects of Variable Data Proofing," in IS&T/SPIE Symposium on Electronic Imaging Science & Technology, *Internet Imaging VI*. Proc. SPIE Vol. 5670. San José 16-20 January 2005
4. S. Zuffi et al., "A color selection tool for the readability of textual information on web pages," in *Internet Imaging VII*. Proc. SPIE Vol. 6061. San Jose 2006
5. C. Brambilla et al., "Web-based vs. controlled environment psychophysics experiments," in *Image Quality and System Performance IV*. Proc. SPIE Vol. 6494. San Jose 2007