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The Yin and Yang of Colors – how to calculate the exact Complementary Color to a specific chromatic Brand Color

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Abstract

This paper will test a research question about whether or not it is possible to calculate the exact Complementary Color to a specific Brand Color in different color systems. A method is proposed and tested in five different color systems: CIELAB, RGB, CMYK, Spectrum and HSB including device independent, device dependent, additive and subtractive color systems. In each color system, it is attempted to calculate the Complementary Color to an orange Brand Color (Pantone 151 C). The results are compared to the results from an online Adobe Creative Cloud Service, *Adobe Kuler* which was chosen because it seems to be widespread among design professionals when finding Complementary Colors. It is concluded that it is possible to calculate a Brand Color's exact Complementary Color by using the technical specifications of the Brand Color as a starting point for this paper's method. *Adobe Kuler's* suggestions for Complementary Colors are far from this paper's calculated Complementary Colors and it is proven that Adobe Kuler's Complementary Colors are not technically correct according to this paper's methods. The color difference between this paper's calculated Complementary Color and Adobe Kuler's Complementary Color is ΔE^*_{ab} 62.5, ΔE_{00} 43.5 and ΔH^*_{ab} 12.6.

Keywords: complementary color, brand colors, graphic design, Adobe Kuler

1. Introduction and background

When Graphic Designers, Art Directors and other design professionals create new visual identities to Brand Owners they enter a process in which they have to decide which colors they should choose to represent the company in logos, design line and the other elements of the company's visual identity.

When the primary Brand Color has been chosen it will often be accompanied with other supporting colors or secondary colors, which also will be specified in the corporate Brand Manual. In principle, these supporting colors can be divided into four main categories:

A. *Achromatic Colors:* This can be a supporting Black, White and/or Grey. This is the neutral choice that will keep the focus on the Brand Color. (e.g. LG, AP, Canon, Fujitsu, Huawei)
B. *Monochromatic Colors:* This can be a supporting color, which has another shade/chroma of the Brand Color. E.g. a blue Brand Color which is accompanied by a darker or lighter blue. This is a choice that amplifies the signal value of the Brand Color. (e.g. BlackBerry, NATO, PayPal,)
C. *Analogous Colors:* This can be a supporting color, which have another hue close to the Brand Color. E.g. an orange Brand Color can be accompanied by a yellow or red supporting color. This choice will create a harmonic, rich and almost monochromatic look but also bears the risk of having a lack of contrast. (e.g. KODAK, McDonald's)

D. *Complementary Colors:* This is a supporting color which is the "opposite" color of the Brand Color. E.g. an orange or yellow Brand Color can be accompanied with a blue color. This choice ensures the largest possible contrast between the Brand Color and the supporting Color. (e.g. AT&T, GÈANT, Walmart).

While the first three possibilities (A to C) largely are a matter of subjective personal preferences, including corporate values, then the latter possibility (D) is mostly an objective technical matter.

Some designers argue that if you need two colors in your pallet it should be complementary colors (Schmidt, 2013). Other designers evaporate;

> *Complementary colors balance each other as they are opposites [...] In their brightest intensities, they literally command attention, so they are especially effective when used in packaging, advertising, at point of purchase, banners, sports uniforms or other usage where exuberant and instant attention is important.* (Eiseman, 2000)

However, when a Designer wishes to use a Complementary Color, it can prove difficult to find the exact Complementary Color, the exact technical opposite color. While it would be relatively simple to find the complementary color to a basic color like Black, Red, Blue etc. then it may prove to be a greater challenge to find the exact Complementary Color to e.g. an aborigine purple or an olive green.

The Designer might turn to some sort of color wheel or color circle where it is possible to get an indication on which hue area the Complementary Color is placed. However, even though these color wheels are built to also showing the Complementary Colors then they are far too limited to provide the exact answer. Newton's color wheel from 1704 contains seven colors, Goethe's color circle from 1793 contains six colors, Munsell's color circle from 1915 contains ten colors/hues or fourteen color tones RAL's has thirty-six colors and NCS' has forty colors. Thus, it is not possible to find the Complementary Color for more than a few Brand Colors – those who are already placed in the color wheels.

Today's online universe has provided services like *Adobe Kuler* in which it apparently is possible to find a Complementary Color to any color (https://color.adobe.com). However, when you look at the color values it doesn't seem to be the exact technical Complementary Color, as proven later.

Therefore, it would be much more reliable if the Complementary Color could be found by calculation.

2. Research questions and methods

Since all Brand Colors can be described and specified in various color models with specific color code values (Pedersen, 2016) that means that every color has a unique technical specification. Thus, it should be possible to use this technical specification to calculate the unique technical specification of the Complementary Color.

By first defining the relationship between a color and its Complementary Color, a formula for calculating this is proposed. This formula will be tested in both device independent, additive and subtractive color systems: CIELAB, RGB, CMYK, HSB and Spectrum.

Throughout this paper Pantone 151 C (PMS151C) is used as an example of a Brand Color to which the Complementary Color shall be calculated. This color where chosen because it is a typical Brand Color and because it is out of CMYK gamut like more than half of all Brand Colors (Pedersen, 2016).

By interviewing five different professional designers from different companies on how they find their Complementary Colors today I found that they all used the online service *Adobe Kuler* (color.adobe.com). Therefore, this online service has been used to check whether or not this paper's suggestions correspond to Adobe Kuler's complementary color proposals.

All CMYK and CIELAB-values presented in this paper were found by using PANTONE COLOR MANAGER Software (version 2.1.0.249 for Windows) from which the official Pantone CMYK (CP) and CIELAB values where read out.

All calculated ΔH^*_{ab}, ΔE^*_{ab} and ΔE_{00} values were found by using these official Pantone CIELAB values and the CIELAB values from *Adobe Kuler* as basis for the calculations.

All HSB and RGB values were found by first adjusting Adobe Photoshop, Color Settings, Color Space to Absolute Colorimetric Rendering Intent and relevant ICC-profiles and later entering the official Pantone CIELAB values into the Photoshop's Color Picker after witch HSB and RGB values was read out.

3. Results and discussions

The word COMPLEMENTARY derives from the Latin COMPLEMENTUM which means, *"That which fills up or completes"*. We know this symbolic principle represented in Yin and Yang. Together Yin and Yang completes the whole and make a balance. Even though Yin and Yang seems opposite or contrary, they are in fact complementary, interconnected, and interdependent. Together they create the complete and make a balance. Yin is complementary to Yang and vice versa. Thus, in the world of colors, a Complementary Color is the specific color, which together with the primary color completes the whole and creates a balance – The Yin and Yang of Colors (Figure 1).

Figure 1: Two complementary colors in Yin and Yang

In the light of the above, the first task must be to define *the complete* and *the balance*. *The complete* can be considered as the entire color space and the neutral axis as the balance point. Depending on the color space chosen, *the complete* is either black or white and therefore the assumption is that a Color + a Complementary color = black or white or vice versa; if we subtract a color from the color space (from *the complete*), what restores the balance must be the Complementary Color. Therefore, it should be possible to calculate the complementary color to any Brand Color by using the technical specification of the Brand Color as basis for the calculation. Thus, a Complementary Color to a Brand Color can be defined as:

$$A^c = \{B\} - \{A\} \qquad [1]$$

where

$B = \{Color\ Space\}$

$A = \{Brand\ Color\}$

and where A is a proper subset of B

$A \subset B$

3.1 Finding the Complementary Color in the device independent CIELAB color space

Since the device independent color space CIELAB contains all visible colors including all Pantone, RGB, CMYK, RAL, NCS, Munsell colors etc. it would be possible and obvious to use CIELAB as a basis for calculating all Complementary Colors. However, this involves the risk of not noticing whether a device dependent color is placed within the gamut or not. Therefore, it is important first to investigate whether or not the current Brand Color can be reproduced in a device dependent color space. There is a probability that if the Brand Color is out of gamut for e.g. CMYK then the Complementary Color might also be out of gamut, as illustrated in the Figure 2.

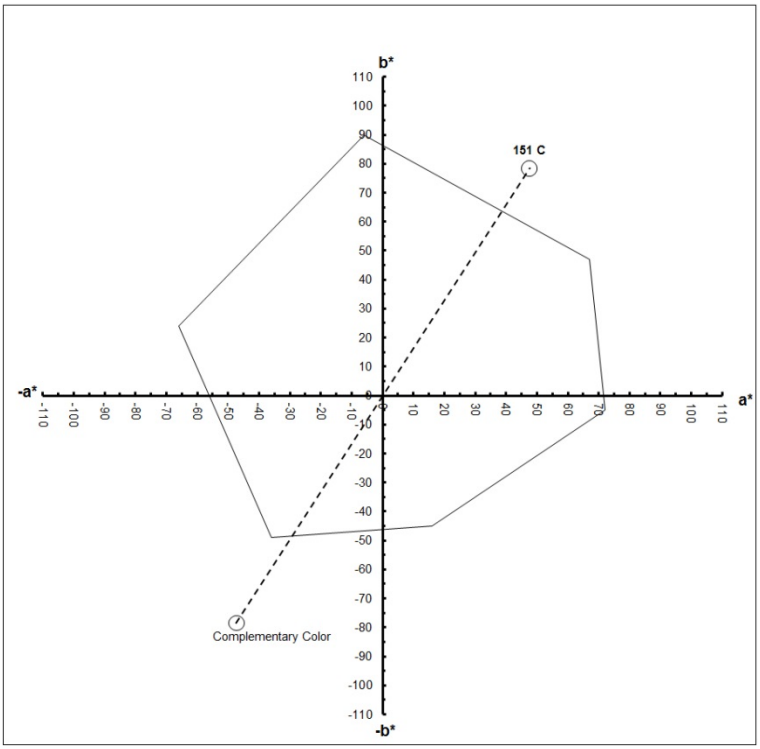

Figure 2: CIELAB ab diagram showing the Brand Color Pantone 151 C and the calculated Complementary Color both being out of CMYK gamut (FOGRA 39)

According to the Pantone Color Manager software Pantone 151 C has the following CIELAB values: L^* 69.68, a^* 47.27, b^* 78.51.

Therefore, the Complementary Color can be determined as:

$$A^C = \begin{Bmatrix} L^* & 100 \\ a^* & 0 \\ b^* & 0 \end{Bmatrix} - \begin{Bmatrix} L^* & 69.68 \\ a^* & 47.27 \\ b^* & 78.51 \end{Bmatrix} \quad [2]$$

$$The\ Complementary\ Color\ A^C = \begin{Bmatrix} L^* & 30.32 \\ a^* & -47.27 \\ b^* & -78.51 \end{Bmatrix}$$

Table 1: A practical example of finding the complementary color in CIELAB

COLOR SPACE {CIELAB}	–	BRAND COLOR {PMS 151C}	=	{COMPLEMENTARY COLOR}
L^* 100	–	L^* 69.68	=	L^* 30.32
a^* 0	–	a^* 47.27	=	a^* -47.27
b^* 0	–	b^* 78.51	=	b^* -78.51

In the device independent CIELAB color space the coordinates of the two colors shows that they have the same distance to the center of the neutral axis, as illustrated in Figure 2.

The distance between the Brand Color and the Complementary Color is 187.5 ΔE^*_{ab}

3.2 Finding the Complementary Color in the device dependent RGB

In the classic illustration showing the additive color system we see that cyan is the Complementary Color to red. This can be evidenced by:

Figure 3: The additive color system

$$A^C = \begin{Bmatrix} R & 255 \\ G & 255 \\ B & 255 \end{Bmatrix} - \begin{Bmatrix} R & 255 \\ G & 0 \\ B & 0 \end{Bmatrix} \quad [3]$$

$$The\ Complementary\ Color\ A^C = \begin{Bmatrix} R & 0 \\ G & 255 \\ B & 255 \end{Bmatrix} = CYAN$$

According to Adobe Photoshop Pantone 151C has the following AdobeRGB values: R:236, G:131, B:23. Thus we have the following equation:

$$A^C = \begin{Bmatrix} R & 255 \\ G & 255 \\ B & 255 \end{Bmatrix} - \begin{Bmatrix} R & 236 \\ G & 131 \\ B & 23 \end{Bmatrix} \quad [4]$$

$$The\ Complementary\ Color\ A^C = \begin{Bmatrix} R & 19 \\ G & 124 \\ B & 232 \end{Bmatrix}$$

Table 2: A practical example of finding the complementary color in AdobeRGB

COLOR SPACE {AdobeRGB}	–	BRAND COLOR {PMS 151C}	=	{COMPLEMENTARY COLOR}
R: 255	–	R: 236	=	R: 019
G: 255	–	G: 131	=	G: 124
B: 255	–	B: 023	=	B: 232

In the device dependent RGB color space the center of the neutral axis is R:128, G:128 and B:128. The distance of each RGB value to this axis is the same; the Brand Color's R:236 is 108 away from the neutral axis' R:128 like the Complementary Color's R:19 is 108 away from the neutral axis' R:128. And the same goes for the G-values and the B-values.

3.3 Finding the Complementary Color in the device dependent CMYK

In the classic illustration showing the subtractive color system we see that red is the Complementary Color to cyan. This can be evidenced by:

Figure 4: The subtractive color system

$$A^C = \begin{Bmatrix} C & 100 \\ M & 100 \\ Y & 100 \end{Bmatrix} - \begin{Bmatrix} C & 100 \\ M & 0 \\ Y & 0 \end{Bmatrix} \qquad [5]$$

$$The\ Complementary\ Color\ A^C = \begin{Bmatrix} C & 0 \\ M & 100 \\ Y & 100 \end{Bmatrix} = RED$$

In practical use it can be discussed whether or not the fourth process color Black should be a part of the equation since the subtractive color system only have three primaries; CMY. It is proposed that when black is not a part of the Brand Color then it shouldn't be part of the Complementary Color. Otherwise the Complementary Color would contain 100 % black. However, if the Brand Color have a significant black component (e.g. a dark green C:90 M:30 Y:90 K:30) then the Complementary Color should contain black as well (A^C: an aborigine purple C:10 M:70 Y:10 K:70).

According to Pantone Color Manager Software, Pantone 151 CP (Coated Paper) has the following CMYK values: C:0 M:60 Y:100 K:0. Thus we have the following equation:

$$A^C = \begin{Bmatrix} C & 100 \\ M & 100 \\ Y & 100 \\ (K & 100) \end{Bmatrix} - \begin{Bmatrix} C & 0 \\ M & 60 \\ Y & 100 \\ (K & 0) \end{Bmatrix} \quad [6]$$

$$The\ Complementary\ Color A^C = \begin{Bmatrix} C & 100 \\ M & 40 \\ Y & 0 \\ (K & 100) \end{Bmatrix}$$

Table 3: A practical example of finding the complementary color in CMYK

COLOR SPACE {FOGRA51}	–	BRAND COLOR {PMS 151 CP}	=	{COMPLEMENTARY CMYK}
C: 100	–	C: 000	=	C: 100
M: 100	–	M: 060	=	M: 040
Y: 100	–	Y: 100	=	Y: 000
K: 100	–	K: 000	=	((K: 100 (0))*

* in this case Black is not a part of the Brand Color and therefore not a part of the Complementary Color

In the device dependent CMY(K) color space the center of the neutral axis is C:50, M:50, Y:50, (K:50). It is seen that the Brand Color's M:60 and the Complementary Color's M:40 have the same distance to this center's M:50. They are both 10 away from the center.

3.4 Examination of the calculated Complementary Colors versus Adobe Kuler's suggested Complementary Colors

To examine how the previous calculated Complementary Colors corresponds with the Complementary Colors that designers find through *Adobe Kuler*, Pantone's reference values where entered into *Adobe Kuler* and *Adobe Kuler's* results was compared with the calculated results.

When entering Pantone 151C's corresponding AdobeRGB values (R:236, G:131, B:23) into *Adobe Kuler* it will propose a Complementary Color with the RGB values: R:23, G:183, B:236.

This shows that Adobe Kuler doesn't use this paper's proposed method since the two sets of RGB values don't add up to 255. According to Adobe Kuler *the complete* is: R:259, G:314, B:259 (R:236+23=259), (G:131+183=314), (B: 23+236=259) which in all three cases exceeds her maximum of 255 in the RGB color space. Thus, Adobe Kuler's proposed Complementary Color is not the exact technical Complementary Color to this Brand Color.

When entering Pantone 151C's CIELAB values into Adobe Kuler we find that there is a huge difference between the calculated Complementary Color and Adobe Kuler's proposed CIELAB values for the Complementary Color.

Table 4: Comparison

Pantone's reference CIELAB values for PMS 151C			→	Calculated Complementary Color		
	L^*	a^*	b^*	L^*	a^*	b^*
	69.68	47.27	78.51	30.32	-47.27	-78.51
Pantone's reference CIELAB rounded values entered into Adobe Kuler			→	Adobe Kuler's Proposed Complementary Color for PMS151C		
	L^*	a^*	b^*	L^*	a^*	b^*
	70.00	47.00	79.00	72.00	-16.00	-44.00
Numerical differences between the two Complementary Colors				ΔL^* 41.68	Δa^* 31.27	Δb^* 34.51
Color Differences				ΔH^*_{ab} 12.6	ΔE^*_{ab} 62.5	ΔE_{00} 43.5

3.5 Finding the Complementary Color in the visual spectrum

In the visual spectrum the spectral reflectance of the Complementary Color will be the inverse of the spectral reflectance of the Brand Color.

$$A^C = \{\text{Equal Energy (1)}\} - \{R_\lambda \text{ (the spectral reflectance of the Brand Color)}\} \qquad [7]$$

In the example below, this formula have been implemented in Microsoft Excel and subsequently measurement of the Brand Color (PMS 151C) has been conducted with a spectrophotometer (X-Rite SpectroEye) calibrated and set in accordance to ISO 12647-1:2013

nm	Brand Color Spectrum	Compl. Color 1 - Brand Color
380	0,0305	0,9695
390	0,0267	0,9733
400	0,0276	0,9724
410	0,0323	0,9677
420	0,0351	0,9649
430	0,0336	0,9664
440	0,0320	0,9680
450	0,0316	0,9684
460	0,0321	0,9679
470	0,0324	0,9676
480	0,0364	0,9636
490	0,0516	0,9484
500	0,0867	0,9133
510	0,1259	0,8741
520	0,1477	0,8523
530	0,1565	0,8435
540	0,1655	0,8345
550	0,1939	0,8061
560	0,2740	0,7260
570	0,4287	0,5713
580	0,6049	0,3951
590	0,7207	0,2793
600	0,7704	0,2296
610	0,7911	0,2089
620	0,8033	0,1967
630	0,8123	0,1877
640	0,8214	0,1786
650	0,8285	0,1715
660	0,8339	0,1661
670	0,8347	0,1653
680	0,8347	0,1653
690	0,8334	0,1666
700	0,8332	0,1668
710	0,8342	0,1658
720	0,8325	0,1675
730	0,8311	0,1689
740	0,8311	0,1689
750	0,8311	0,1689
760	0,8311	0,1689
770	0,8311	0,1689
780	0,8311	0,1689

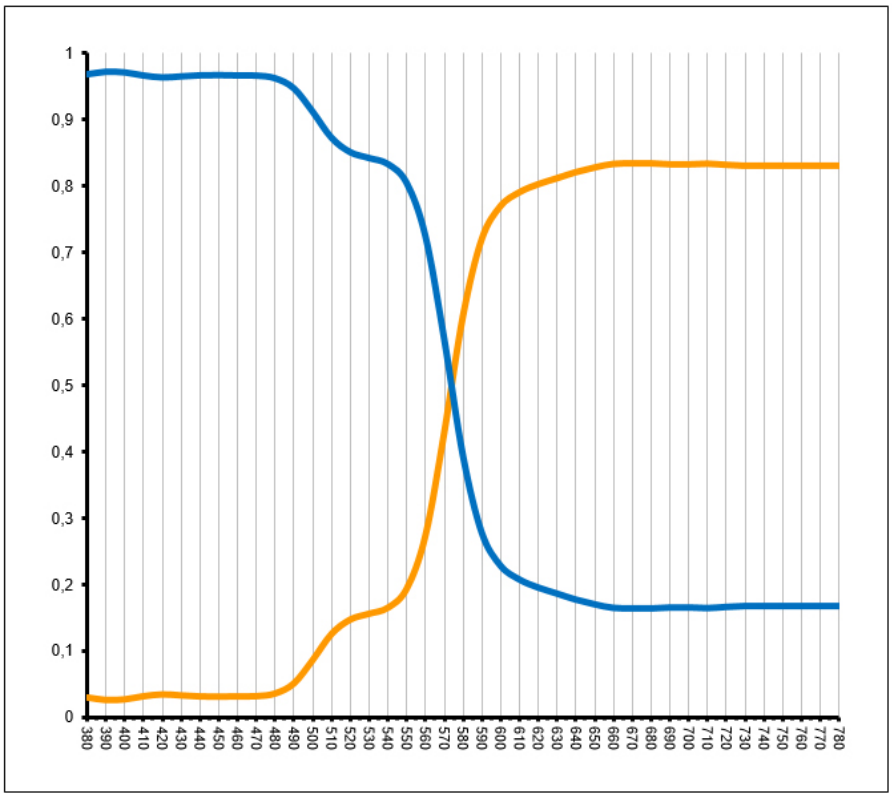

Figure 5: Orange curve: Spectral distribution of the orange Brand Color (Pantone 151 C)
Blue curve: the Complementary Color to the orange Brand Color (1 minus the spectral distribution of the Brand Color)

3.6 Finding the Complementary Color in Color Systems with Hue Angles

In color systems where colors are defined as metric hue angle degrees the previous presented model is not direct applicable.

In the HSB color space (Hue, Saturation, Brightness) the color is placed on a 360° circle while the Brightness and Saturation are defined as percent. Thus, if we use the previous presented model we will get an invalid result:

$$A^C = \begin{Bmatrix} H & 360° \\ S & 100\% \\ B & 100\% \end{Bmatrix} - \begin{Bmatrix} H & 31° \\ S & 100\% \\ B & 100\% \end{Bmatrix} \quad [8]$$

$$The\ Complementary\ Color\ A^C = \begin{Bmatrix} H & 329° \\ S & 0\% \\ B & 0\% \end{Bmatrix} = Black$$

In this case the complementary color to an orange would be calculated to be a black, which makes no sense. We have to leave the Saturation and Brightness as they are and concentrate on the Hue angle. Here, it is important to recognize that the Complementary Color always will be positioned on the exact opposite half of that of the Brand Color.

Therefore, the distance between the Brand Color and the Complementary Color will always be 180° and therefore 180° must be added or subtracted to the value of the Brand Color depending on the numerical value of the Brand Color.

When the Brand Color's hue angle is ≥ 180° then 180° must be subtracted from hue angle.
When the Brand Color's hue angle is ≤ 180° then 180° must be added to hue angle.

$$A^C = \{Brand\ Color° \pm 180°\} \quad [9]$$

EX.1: $A^C = \{31° + 180°\} = 211°$
EX.2: $A^C = \{211° - 180°\} = 31°$
EX.3: $A^C = \{92° + 180°\} = 272°$

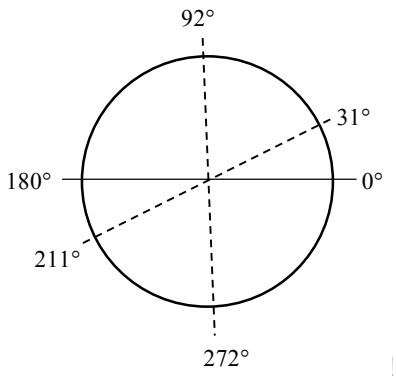

Figure 6: A 360° hue circle with two Color's hue angles and their matching Complementary Colors

4. Conclusions

It can be concluded that it is possible to calculate a Brand Color's exact Complementary Color by using the technical specifications of the Brand Color as a starting point for this paper's proposed method.

Adobe Kuler makes suggestions for Complementary Colors that are not technically correct according to this paper's methods and they are far from this paper's technical calculated Complementary Colors although they are in the same hue area.

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