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Opponent color theory

Ewald Hering

Hering was the first to notice in the 1970s that there appeared to be two couples of “pure” colors with respect to each other: red and green, blue and yellow.

![Color circles](image)

*Figure 2. Visualization of four common types of color circles. The ordering of hues is preserved in each, while the position of the hues on the circle varies. The subtractive circle is used by painters, while a cyan-magenta-yellow circle (not shown) is used by most ink printing processes.*
# Opponent color spaces

## Opponent color space characteristics

- 1 luminance axis
- 2 chrominance axis based on the opponent color theory.

## Currently available opponent color spaces

**Device dependant (magenta-cyan axis)**

- $\text{YC}_b\text{C}_r$
- $\text{YIQ}$
- $\text{YCC}$
- $\text{YCC}$
- $\text{NCS}$

**Device independant**

- $L^*a^*b^*$
- $l\alpha\beta$
Proposed color space ideas

Desired features

- Opponent color space
- Similar in spirit to $l\alpha\beta$ and $L^*a^*b^*$
- Useful for graphics applications

Design choices

- Device dependant color space (directly from $R'G'B'$)
- Non-linear *luma* channel (instead of linear luminance)
Magenta-cyan vs red-green

Figure 1. Visualization of the oRGB decomposition of an (a) image into (b) luma, (c) yellow-blue, and (d) red-green channels.

Figure 4. Visualization of the chroma channels for (top) YCC, (middle) Iaβ, and (bottom) CIE L*a*b color spaces. Compared to our new oRGB space (Figure 1), these spaces do not have a true red-green channel.
Considerations on $R'G'B'$

Figure 7. (a) Orthographic view of RGB cube looking along white-black axis. (b) No affine transform will put red-white-green in line. (c) The $y$-axis will have red-magenta and green-cyan as its extreme values.

Figure 8. To take the red and green directions to the vertical axis, we compress angles on the blue side and expand them on the yellow side.
Proposed algorithm

Algorithm outline

1. From $\mathbf{R'}\mathbf{G'}\mathbf{B'}$ to $\mathbf{L'}\mathbf{C'}\mathbf{C'}$: linear transform to white-black, yellow-blue, magenta-cyan color space
2. From $\mathbf{L'}\mathbf{C'}\mathbf{C'}$ to oRGB: nonuniform rotation around luma axis to obtain red-green axis

Notes

The second step is a compression/decompression of angles depending on the quadrant to which the color attains.
**Proposed algorithm: mathematically**

**Steps**

1. \[
    \begin{bmatrix}
    L' \\
    C'_1 \\
    C'_2
    \end{bmatrix} = \begin{bmatrix}
    0.2990R' + 0.5870G' + 0.1140B' \\
    0.5(R' + G') - B' \\
    0.866(R' - G')
    \end{bmatrix}
\]

2. \[
    \theta_o(\theta) = \begin{cases}
    (3/2)\theta & \text{if } \theta \leq \pi/3 \\
    \pi/2 + (3/4) + (\theta - \pi/3) & \text{if } \pi \geq \theta \geq \pi/3
    \end{cases}
\]

3. \[
    \begin{bmatrix}
    C'_{yb} \\
    C'_{rg}
    \end{bmatrix} = R(\theta_o - \theta) \begin{bmatrix}
    C'_1 \\
    C'_2
    \end{bmatrix}
\]

where \( L'C'_1C'_2 \) is YCC and \( L'C'_{yb}C'_{rg} \) is oRGB.

![Diagram](image.png)
**oRGB properties**

**Properties**

- Similar to HSV/HSB
- It’s axes reflect common “color naming”
- $C_{yb}'$ and $C_{rg}'$ are in the $[-1, 1]$ range
- $L'$ is normalized ([$0, 1$])

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**Figure 9.**
Visualization of the gamut of our color space seen along the luma axis (a) before and (b) after nonuniform rotation. After rotation, the y-axis is a true red-green axis while the yellow-blue axis is the same.
Sample applications

- Color adjustment
- Gamut mapping: custom algorithm
- Color transfer: various methods
- Cool to warm shading: similar to Amy Gooch et al.
Color adjustment

Figure 15. Instead of applying mean shifting to the final image, as in Figure 14, we used the intuitive oRGB axes as a color "variations" selector for the diffuse term in a car rendering.
Cool to warm shading

Figure 16. (a) shading from Amy Gooch and her colleagues.²⁰ (b) the luma channel in oRGB is modified to partially resemble traditional Gouraud-style shading while maintaining a cool-to-warm transition.
Figure 18. The statistics of the target image are transferred to the original image in a variety of color spaces: (a) original image; (b) oRGB none; (c) oRGB scale; (d) HSV; (e) Photoshop; (f) lab; (g) target image; (h) Schwarz; (i) RBW; (j) RGBY; (k) CIE L*a*b*; (l) YCC. A magenta shifted toward pure red becomes pure red in oRGB instead of remaining magenta.
Table 1: Different color spaces producing different out-of-gamut results. The first column lists the color space tested. The second column shows the average percentage of out-of-gamut pixels. The remaining three columns demonstrate the out-of-gamut percentage range per RGB channel.

<table>
<thead>
<tr>
<th>Color space</th>
<th>% Pixels</th>
<th>% R</th>
<th>% G</th>
<th>% B</th>
</tr>
</thead>
<tbody>
<tr>
<td>oRGB</td>
<td>10.36</td>
<td>22.58</td>
<td>16.59</td>
<td>26.42</td>
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<tr>
<td>HSV</td>
<td>9.07</td>
<td>121.87</td>
<td>122.12</td>
<td>118.93</td>
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<tr>
<td>lαβ</td>
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<td>104.54</td>
<td>40.56</td>
<td>25.02</td>
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<tr>
<td>Schwarz</td>
<td>16.45</td>
<td>&gt;999.99</td>
<td>&gt;999.99</td>
<td>&gt;999.99</td>
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<tr>
<td>RBW</td>
<td>11.95</td>
<td>146.29</td>
<td>124.20</td>
<td>154.94</td>
</tr>
<tr>
<td>RGBY</td>
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<td>234.07</td>
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<tr>
<td>CIE L<em>a</em>b*</td>
<td>10.89</td>
<td>117.82</td>
<td>66.05</td>
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<tr>
<td>YCC</td>
<td>11.24</td>
<td>22.99</td>
<td>15.99</td>
<td>25.91</td>
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