A Comparison of Color Difference Data and Formulas

BY

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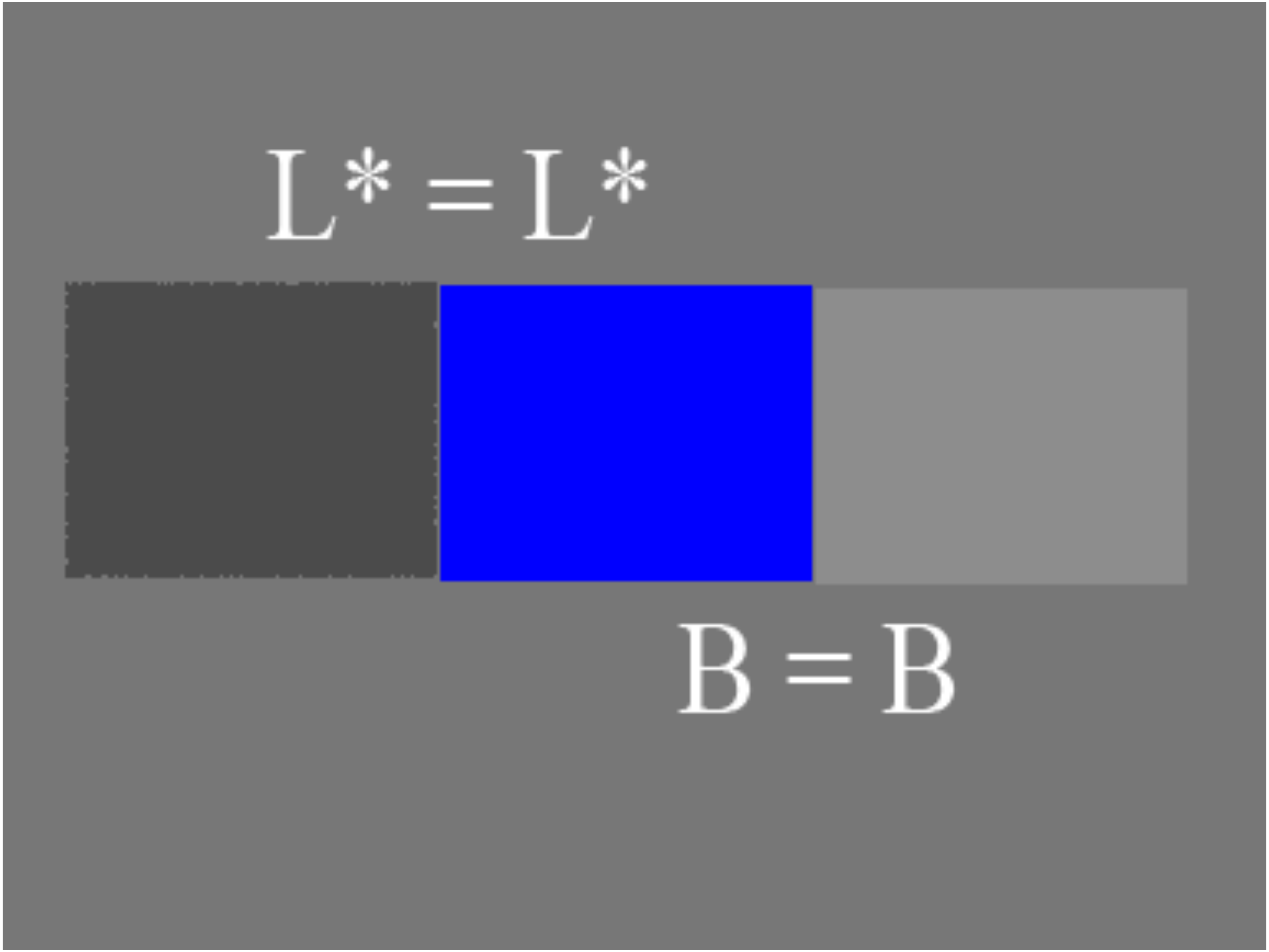
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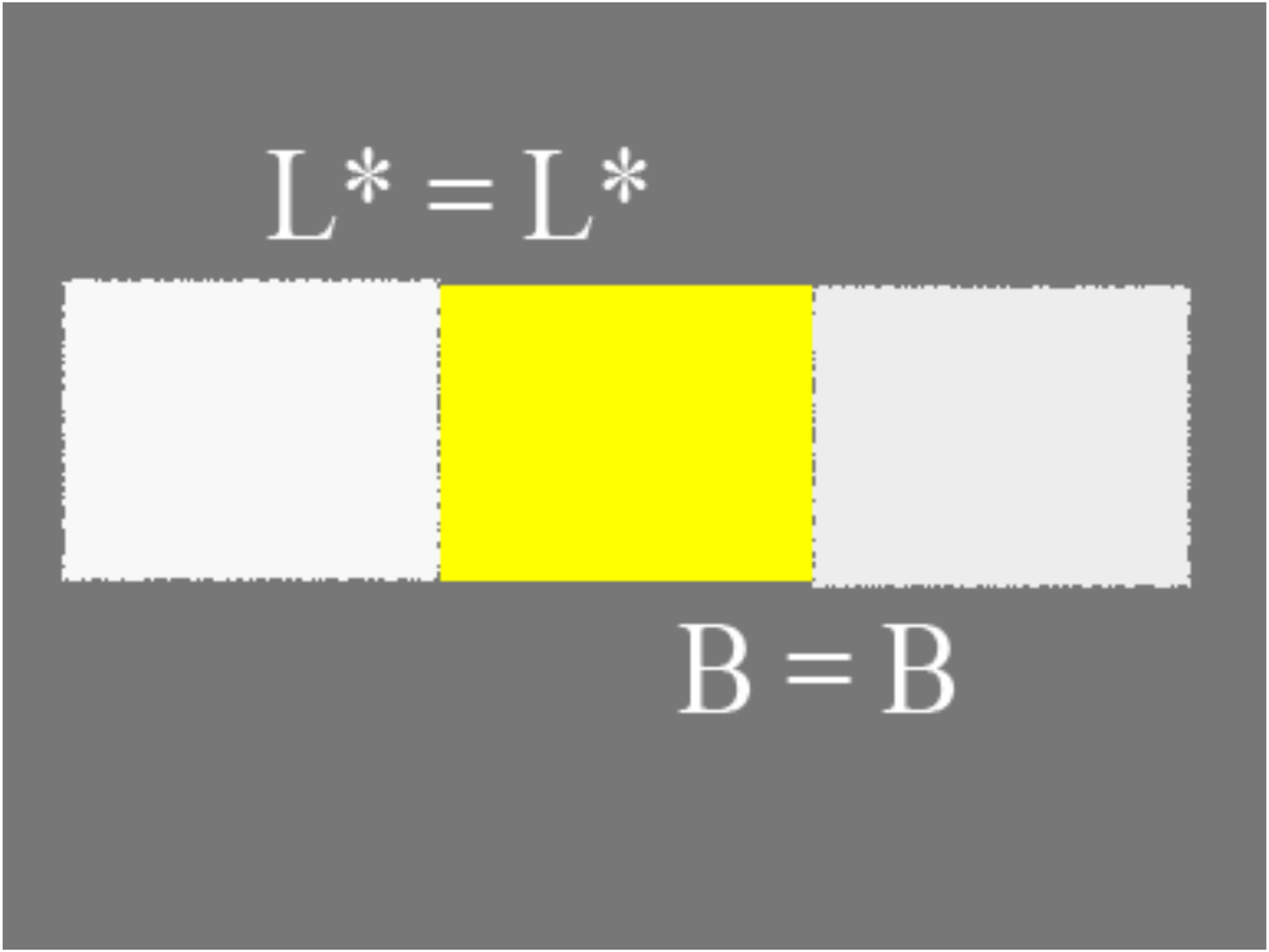
B = B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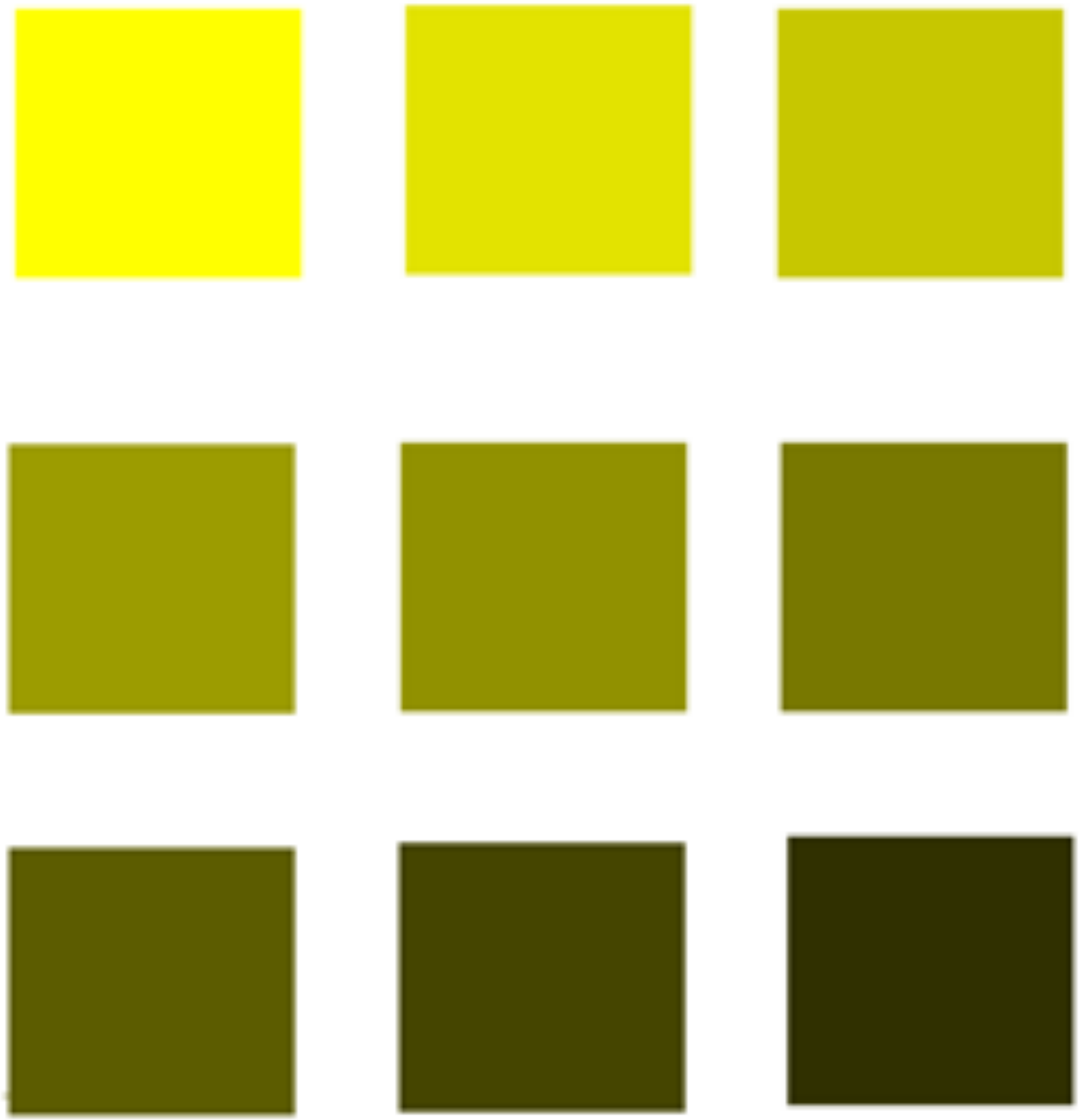
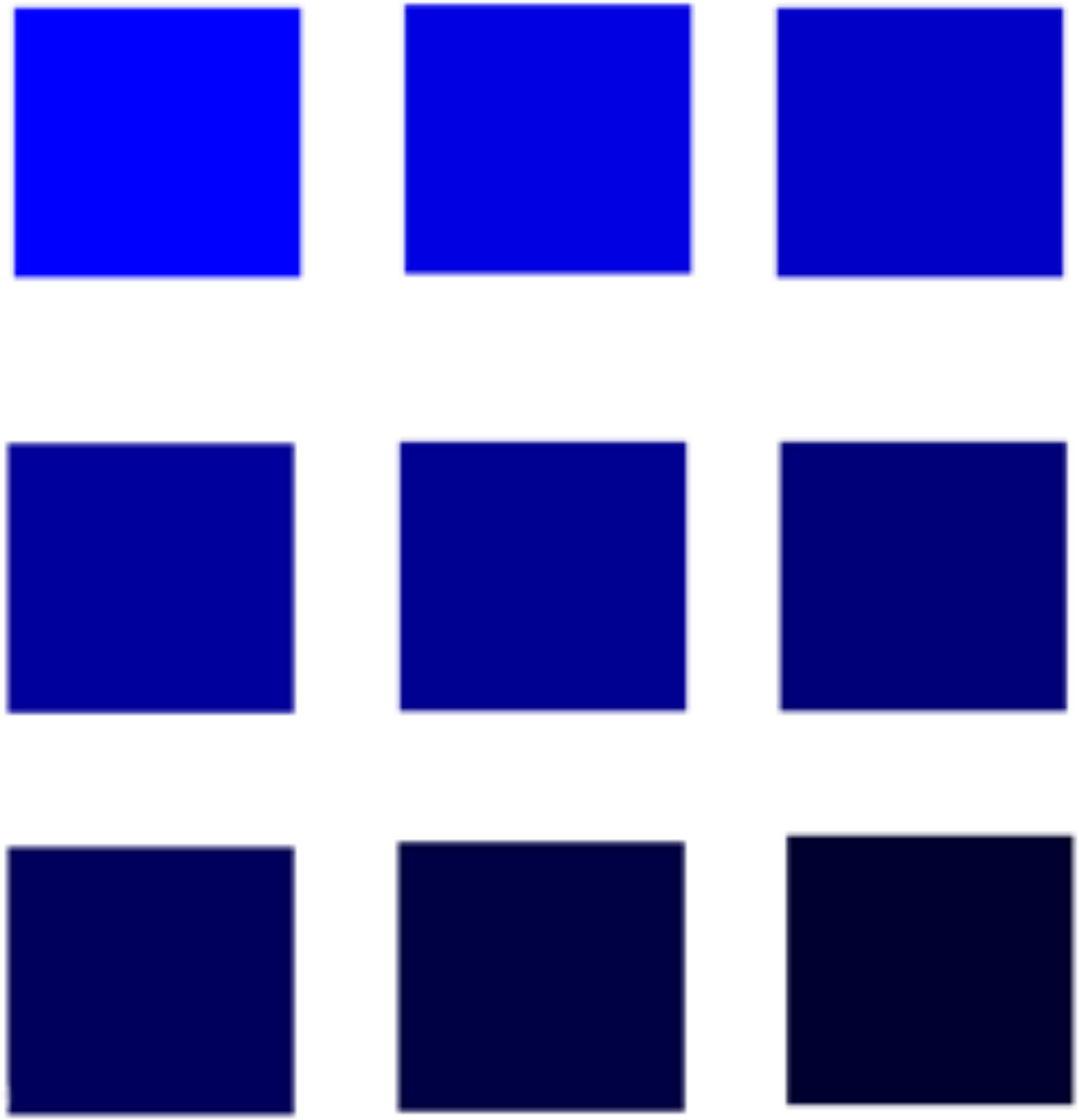
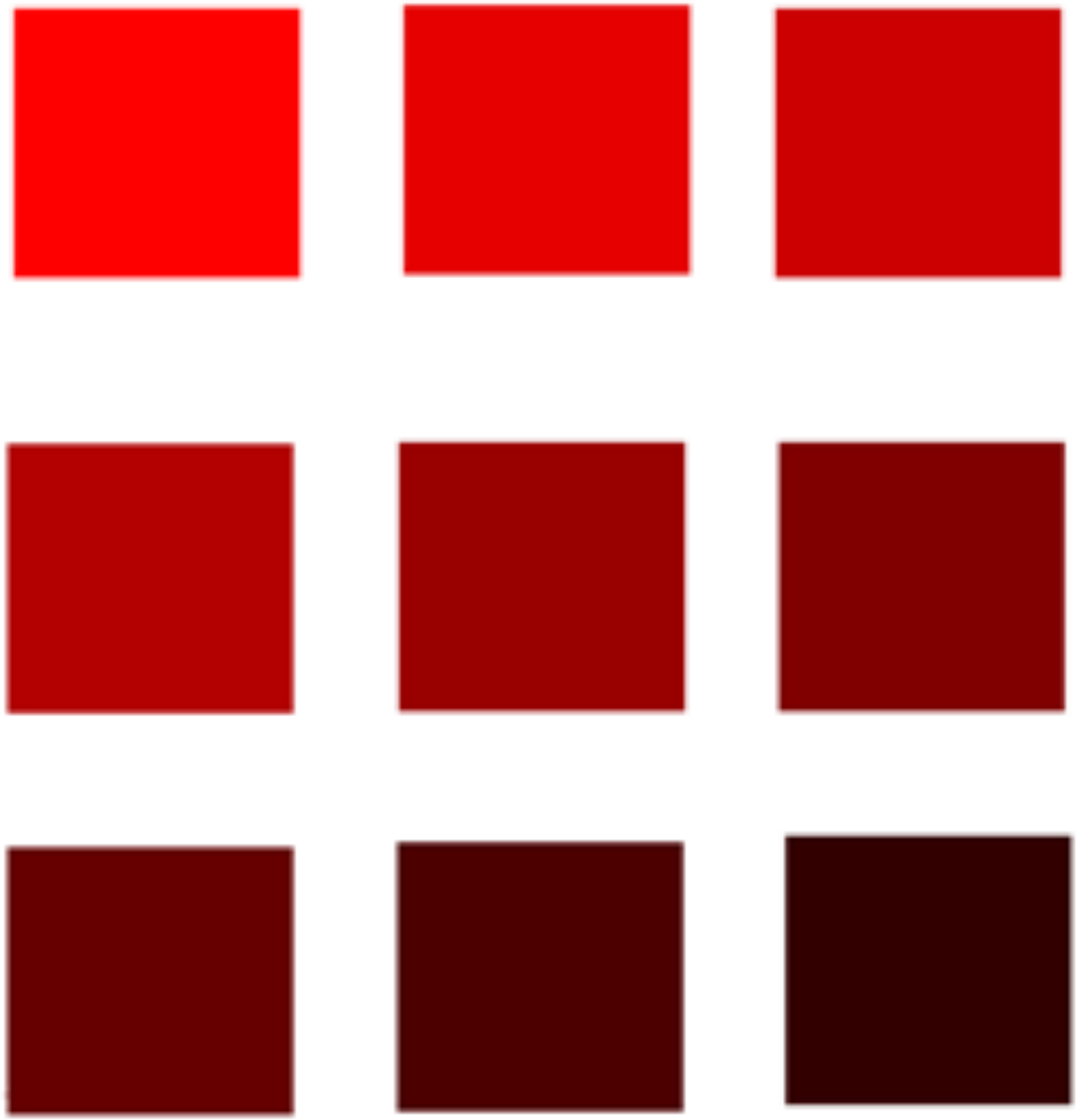
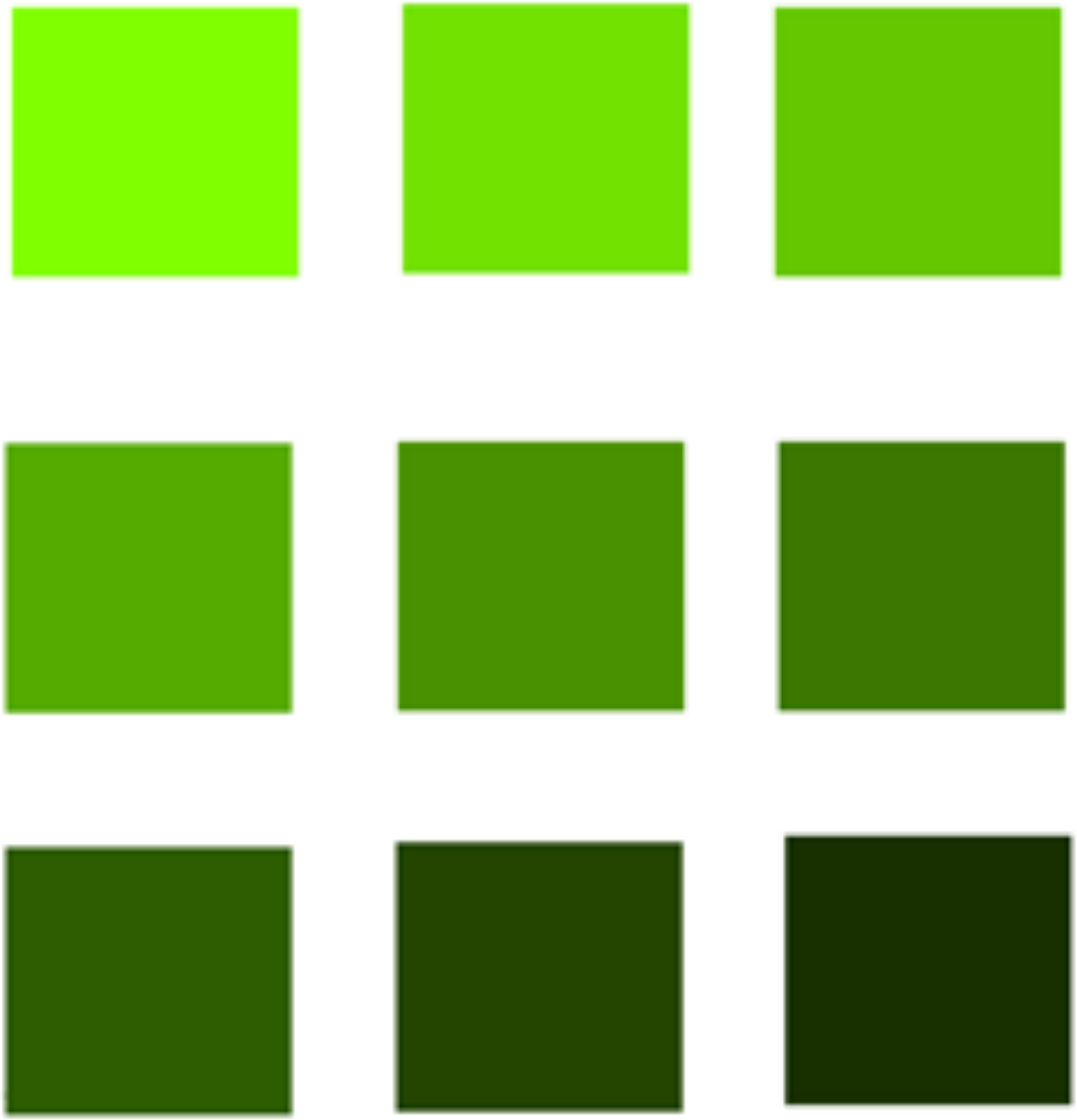
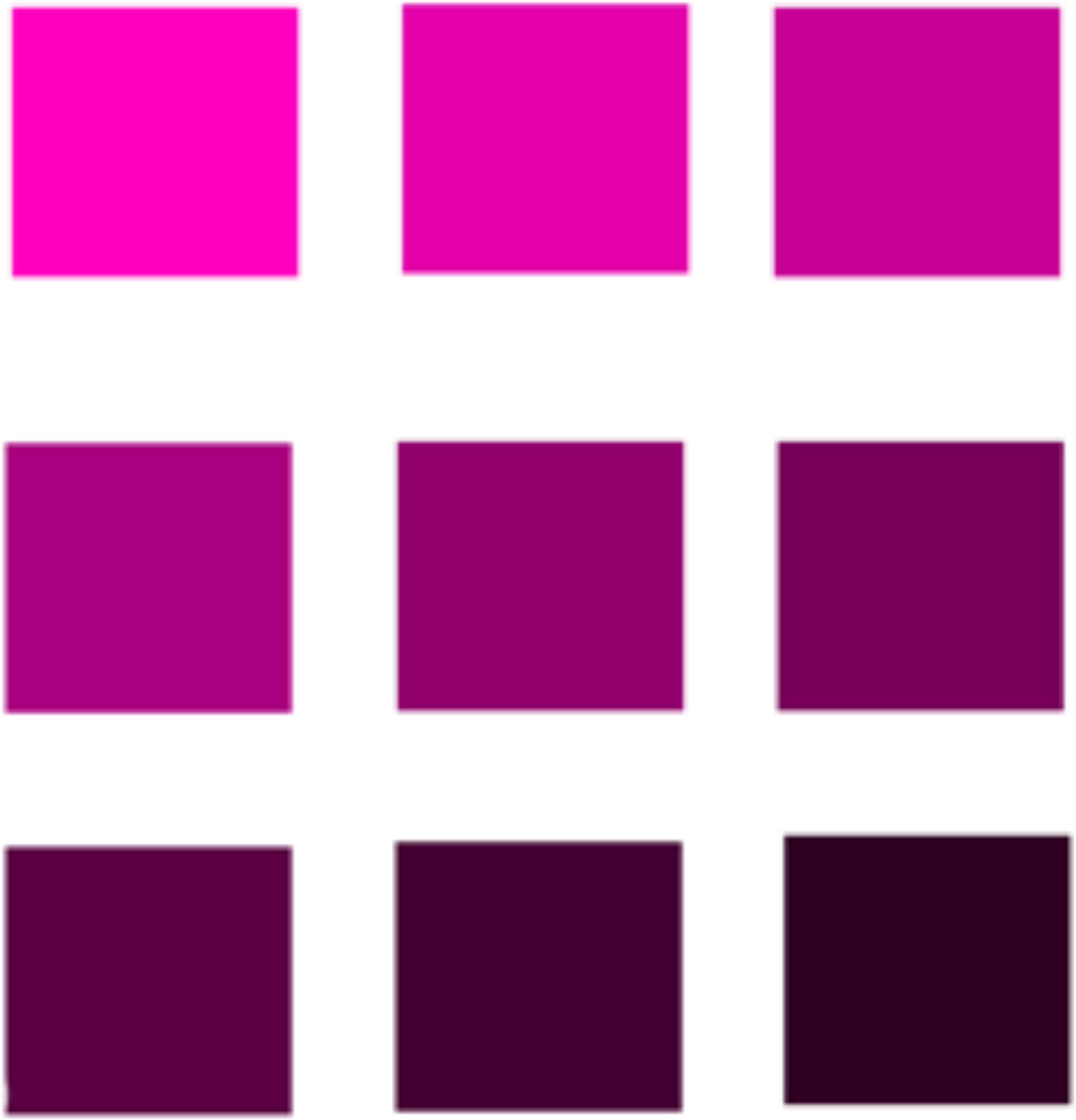
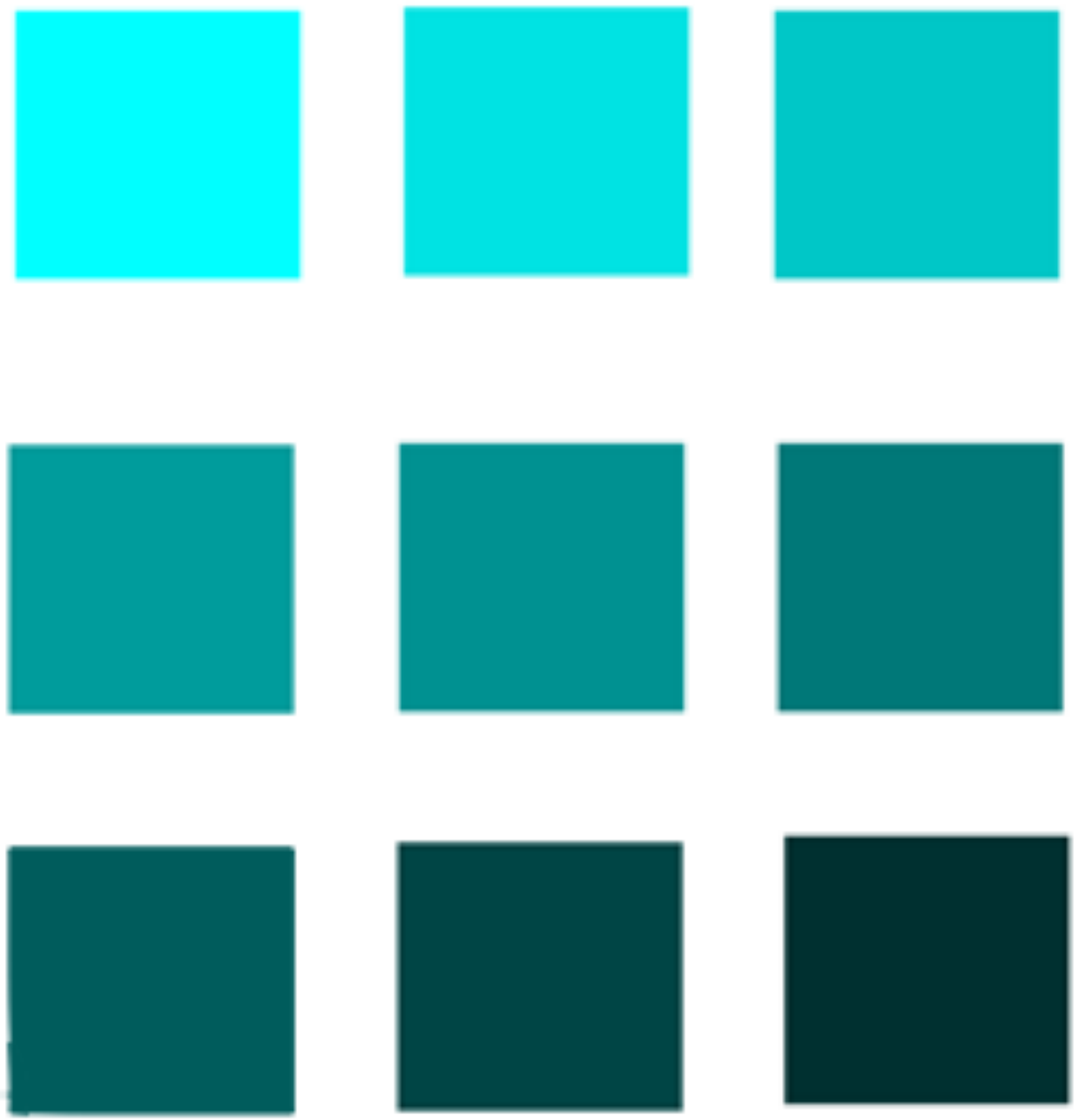












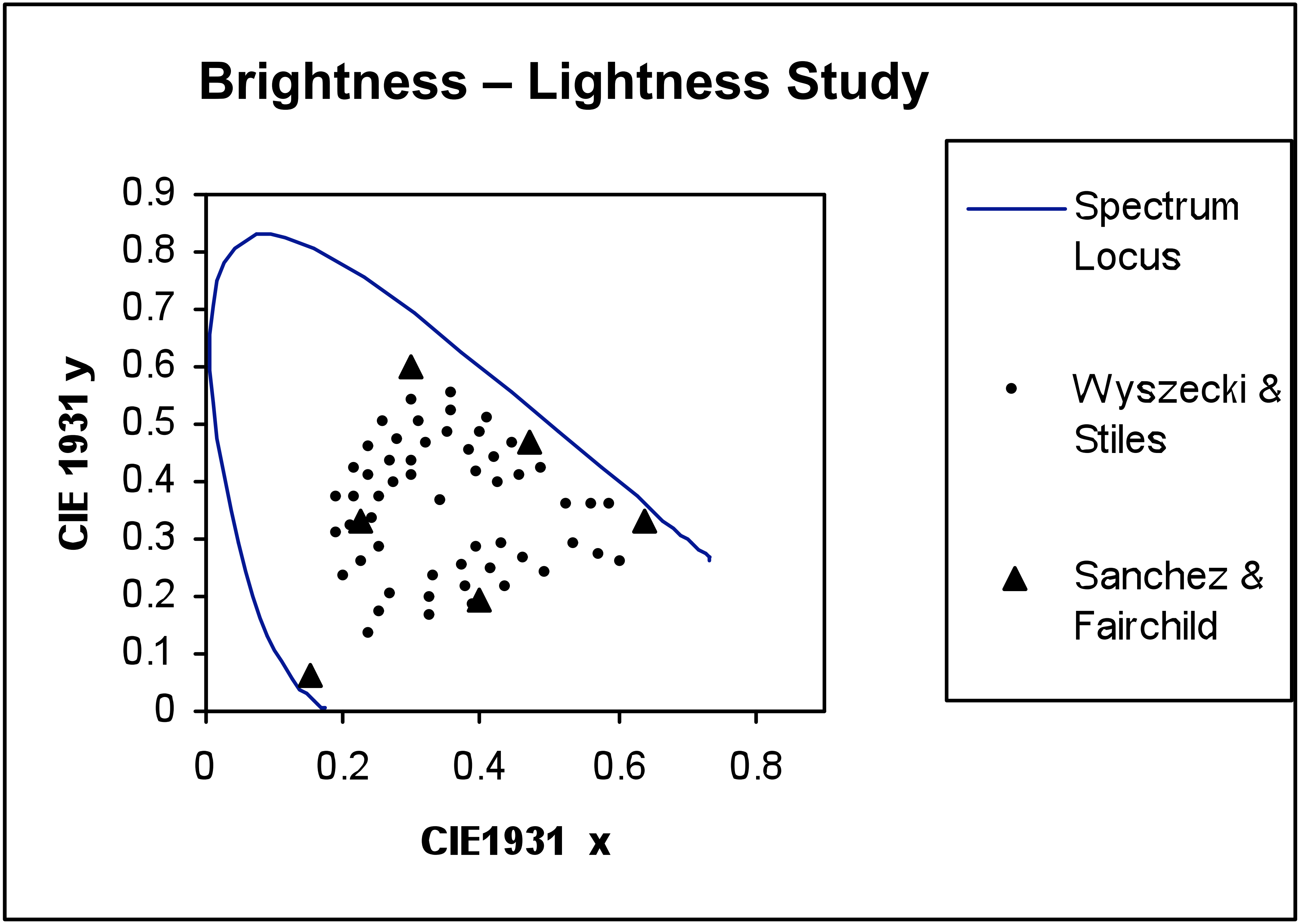
IQ Colour – Color Space XYZ to Qtd

$$\left[ATD\right] = \left[LMS\right] * \begin{bmatrix} .6352 & .8057 & .3021 \\ .3915 & -1.084 & -.0931 \\ 0 & .2056 & -.3618 \end{bmatrix}$$

IQ Colour – Perception Space

Q = A + T / 2 – D

t = T/Q and d = D/ Q

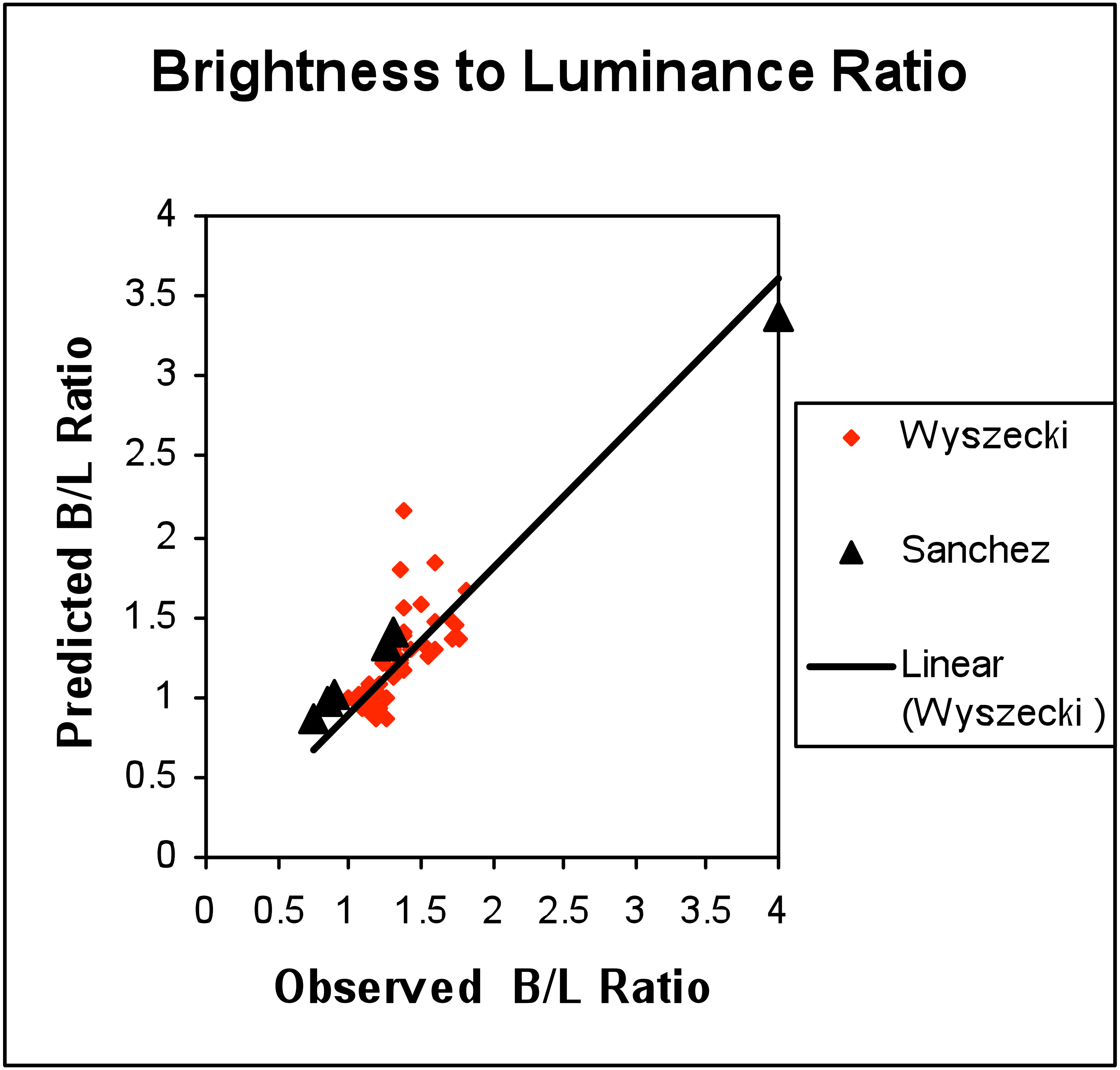

Brightness – Lightness Study
CIE 1931 y
CIE1931 x
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
0.2
0.4
0.6
0.8
Spectrum Locus
Wyszecki & Stiles
Sanchez & Fairchild

Brightness Lightness Ratio

- The old ATD – Qtd Model used
  - Q = A + T / 2 – D
  - Did not take account of Blue – Yellow Interaction
  - Proposed

    Q = A + C1 * T + C2 * D for the Yellow Region

    Q = A + C1 * T + C3 * D for the Blue Region



Brightness to Luminance Ratio
Predicted B/L Ratio
Observed B/L Ratio
0
0.5
1
1.5
2
2.5
3
3.5
4
Wyszecki
Sanchez
Linear (Wyszecki)

Brightness Formula

$Q = A + 0.5 * T$ → Yellow

$Q = A + 0.5 * T - 0.75 * D$ →Blue

Just Noticeable Difference Formula Development

- Test only JNDs less than 5
- Use Least Absolute Regression
- Visual Channels
  - Q, t and d
- Simple City Block Metric

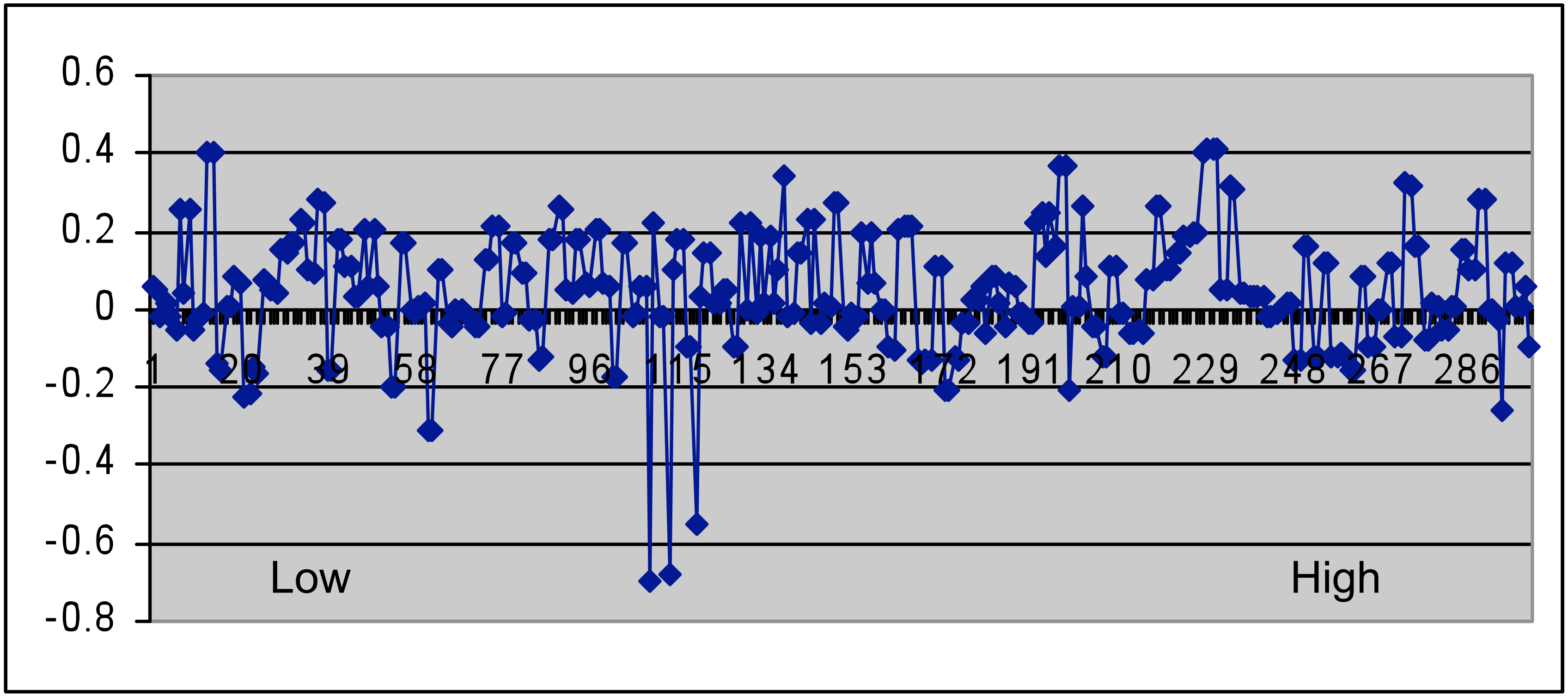
Delta Perception Model

- S = absolute value of the greater of t or d
- H= absolute value of the lesser of t or d
- $DP = a * \left|\Delta Q\right|^{\gamma} + b * \left|\Delta S\right|^{\gamma} + c * \left|\Delta H\right|^{\gamma}$

Delta P Color Difference

$$DP = 1.9 * \left|\Delta Q\right|^{1/3} + 1.9 * \left|\Delta S\right|^{1/3} + 2.5 * \left|\Delta H\right|^{1/3}$$

JND Error vs Luminance
RIT-DuPont Data



XYZ to Lab

$$x_r = \frac{X}{X_r}$$

$$y_r = \frac{Y}{Y_r}$$

$$z_r = \frac{Z}{Z_r}$$

$$f_x = \begin{cases} \sqrt[3]{x_r} & x_r > \varepsilon \\ \frac{\kappa x_r + 16}{116} & x_r \le \varepsilon \end{cases}$$

$$f_y = \begin{cases} \sqrt[3]{y_r} & y_r > \varepsilon \\ \frac{\kappa y_r + 16}{116} & y_r \le \varepsilon \end{cases}$$

$$f_z = \begin{cases} \sqrt[3]{z_r} & z_r > \varepsilon \\ \frac{\kappa z_r + 16}{116} & z_r \le \varepsilon \end{cases}$$

$$L = 116\, f_y - 16$$

$$a = 500\left(f_x - f_y\right)$$

$$b = 200\left(f_y - f_z\right)$$

Delta E CIE-76

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

DE CIE(CMC)

$$\Delta C = C_1 - C_2$$
$$C_1 = \sqrt{a_1^{\,2} + b_1^{\,2}}$$
$$C_2 = \sqrt{a_2^{\,2} + b_2^{\,2}}$$
$$\Delta H = \sqrt{\Delta a^2 + \Delta b^2 - \Delta C^2}$$
$$\Delta L = L_1 - L_2$$
$$\Delta a = a_1 - a_2$$
$$\Delta b = b_1 - b_2$$
$$S_L = \begin{cases} 0.511 & L_1 < 16 \\ \dfrac{0.040975\ L_1}{1 + 0.01765\ L_1} & L_1 \geq 16 \end{cases}$$
$$S_C = \frac{0.0638\ C_1}{1 + 0.0131\ C_1} + 0.638$$
$$S_H = S_C\left(FT + 1 - F\right)$$
$$T = \begin{cases} 0.56 + \left|0.2\cos(H_1 + 168)\right| & 164 \leq H_1 \leq 345 \\ 0.36 + \left|0.4\cos(H_1 + \ 35)\right| & otherwise \end{cases}$$
$$F = \sqrt{C_1^{\,4} / \left(C_1^{\,4} + 1900\right)}$$
$$H_1 = \tan^{-1}\left(b_1 / a_1\right)$$

$$\Delta E = \sqrt{\left(\Delta L / l\, S_L\right)^2 + \left(\Delta C / c\, S_C\right)^2 + \left(\Delta H / S_H\right)^2}$$

Delta E CIE 94

$$\Delta L = L_1 - L_2$$

$$\Delta C = C_1 - C_2$$

$$\Delta H = \sqrt{\Delta a^2 + \Delta b^2 - \Delta C^2}$$

$$C_1 = \sqrt{a_1^{\ 2} + b_1^{\ 2}}$$

$$\Delta E = \sqrt{\left(\frac{\Delta L}{K_L S_L}\right)^2 + \left(\frac{\Delta C}{K_C S_C}\right)^2 + \left(\frac{\Delta H}{K_H S_H}\right)^2}$$

$$C_2 = \sqrt{a_2^{\ 2} + b_2^{\ 2}}$$

$$\Delta a = a_1 - a_2$$

$$\Delta b = b_1 - b_2$$

$$S_L = 1$$

$$S_C = 1 + K_1 C_1$$

Delta E CIE2000

$$\bar{L}' = (L_1 + L_2)/2$$

$$C_1 = \sqrt{a_1^{\,2} + b_1^{\,2}}$$

$$C_2 = \sqrt{a_2^{\,2} + b_2^{\,2}}$$

$$\bar{C} = (C_1 + C_2)/2$$

$$G = \left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right) \Big/ 2$$

$$a_1' = a_1(1 + G)$$

$$a_2' = a_2(1 + G)$$

$$C_1' = \sqrt{a_1'^2 + b_1^{\,2}}$$

$$C_2' = \sqrt{a_2'^2 + b_2^{\,2}}$$

$$\bar{C}' = (C_1' + C_2')/2$$

$$h_1' = \begin{cases} \tan^{-1}(b_1/a_1') & \tan^{-1}(b_1/a_1') \geq 0 \\ \tan^{-1}(b_1/a_1') + 360^\circ & \tan^{-1}(b_1/a_1') < 0 \end{cases}$$

$$h_2' = \begin{cases} \tan^{-1}(b_2/a_2') & \tan^{-1}(b_2/a_2') \geq 0 \\ \tan^{-1}(b_2/a_2') + 360^\circ & \tan^{-1}(b_2/a_2') < 0 \end{cases}$$

$$\bar{H}' = \begin{cases} (h_1' + h_2' + 360^\circ)/2 & |h_1' - h_2'| > 180^\circ \\ (h_1' + h_2')/2 & |h_1' - h_2'| \leq 180^\circ \end{cases}$$

$$T = 1 - 0.17\cos(\bar{H}' - 30^\circ) + 0.24\cos(2\bar{H}') + 0.32\cos(3\bar{H}' + 6^\circ) - 0.20\,\mathrm{c}$$

$$\Delta h' = \begin{cases} h_2' - h_1' & |h_2' - h_1'| \leq 180^\circ \\ h_2' - h_1' + 360^\circ & |h_2' - h_1'| > 180^\circ;\ h_2' \leq h_1' \\ h_2' - h_1' - 360^\circ & |h_2' - h_1'| > 180^\circ;\ h_2' > h_1' \end{cases}$$

$$\Delta E = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

IQ Colour – Color Space XYZ to Qtd

$$\left[ATD\right] = \left[LMS\right] * \begin{bmatrix} .6352 & .8057 & .3021 \\ .3915 & -1.084 & -.0931 \\ 0 & .2056 & -.3618 \end{bmatrix}$$

IQ Colour – Perception Space

Q = A + T / 2 – D

t = T/Q and d = D/ Q

Delta Perception

S = absolute value of the greater of t or d

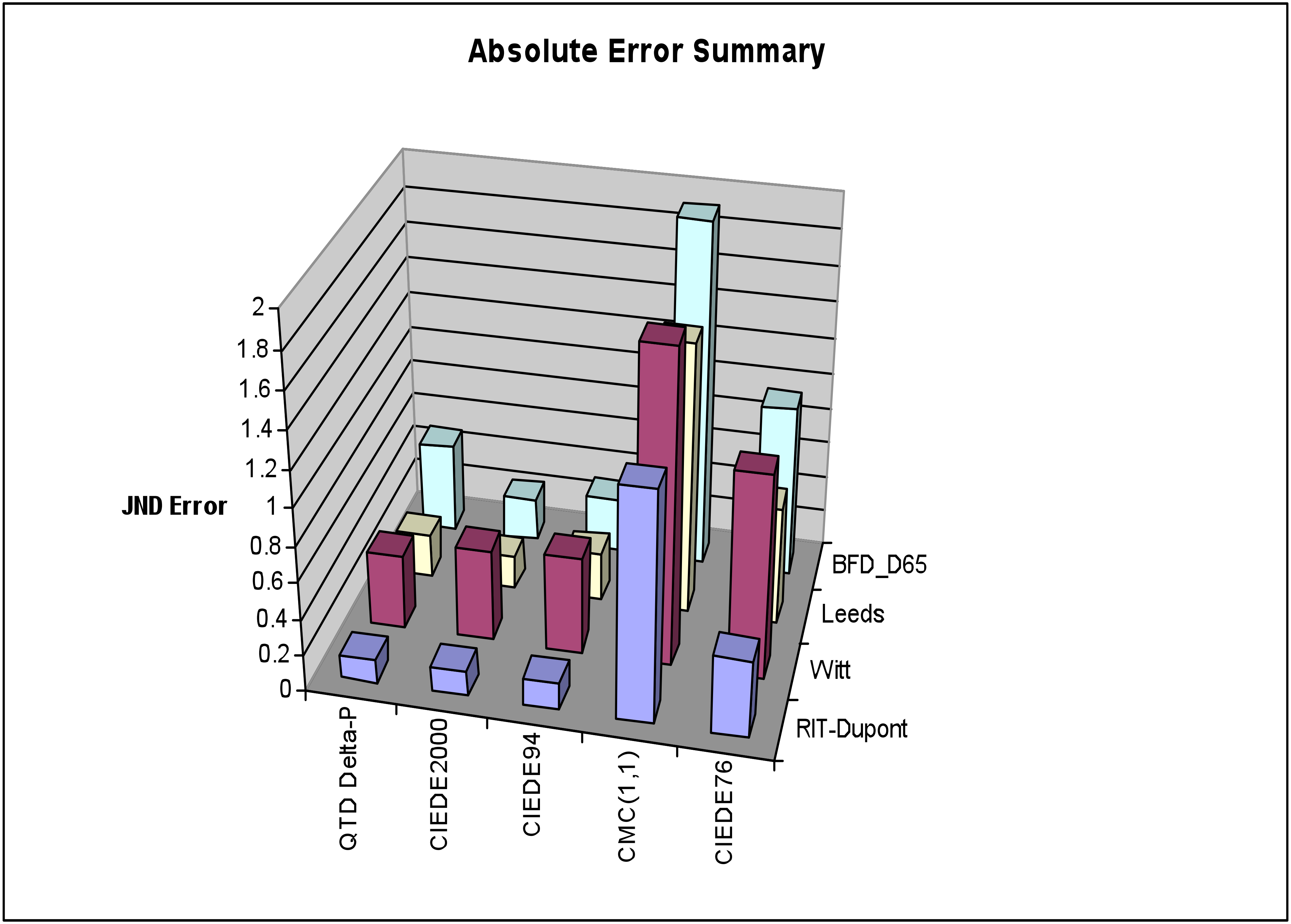
H= absolute value of the lesser of t or d

R= H / S

$$DP = 1.9 * |\Delta Q|^{1/3} + 1.9 * |\Delta S|^{1/3} + 2.5 * |\Delta H|^{1/3}$$

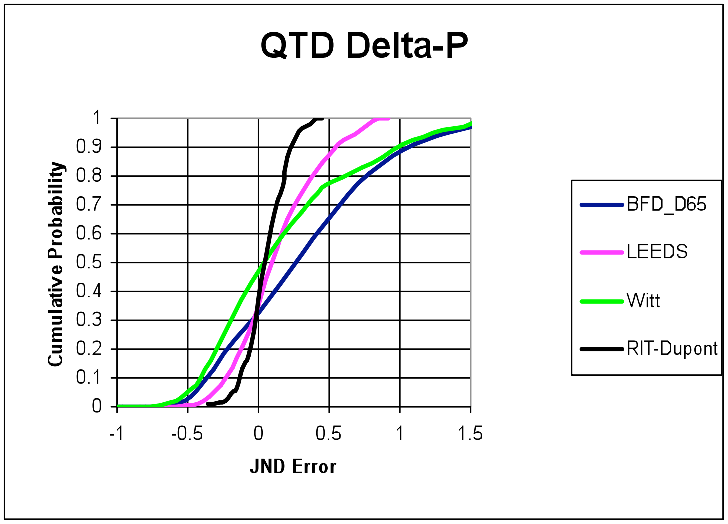
Least Absolute Error

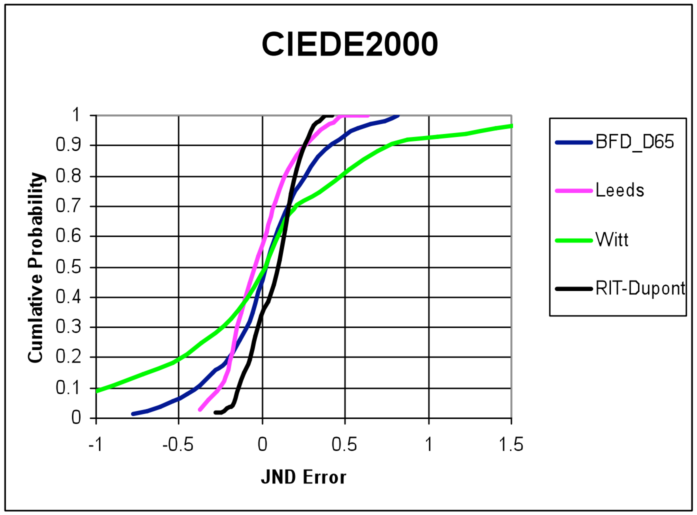
	QTD Delta-P	CIEDE2000	CIEDE94	CMC(1,1)	CIEDE76
RIT-Dupont	0.12	0.14	0.15	1.25	0.42
Witt	0.41	0.50	0.53	1.72	1.11
Leeds	0.24	0.18	0.27	1.50	0.66
BFD_D65	0.49	0.24	0.30	1.92	0.95

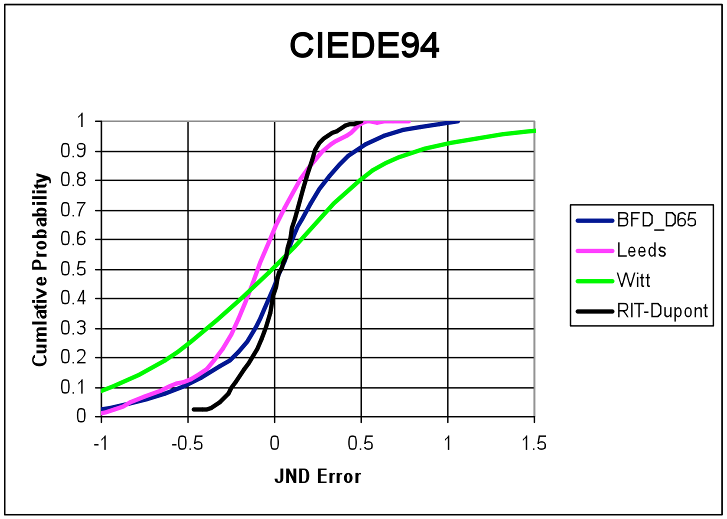


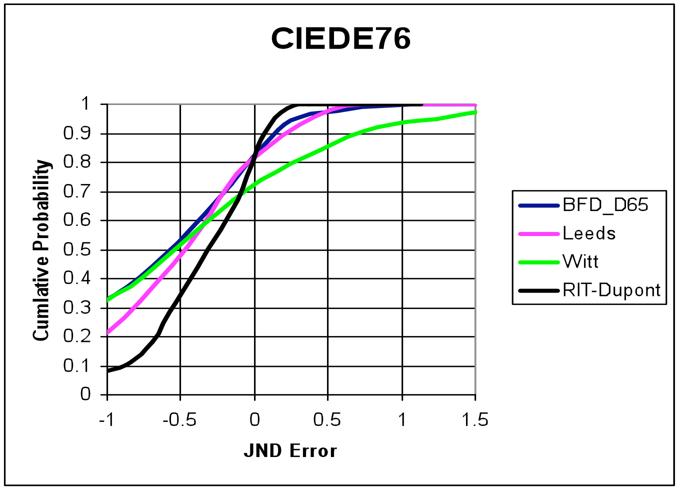
Absolute Error Summary
JND Error
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
QTD Delta-P
CIEDE2000
CIEDE94
CMC(1,1)
CIEDE76
BFD_D65
Leeds
Witt
RIT-Dupont

Statistical DE Comparison









Conclusions

- A simple vision based
  non-Euclidean Model
  - Performs as well as the more complex CIE color difference formulas.
- The noise in the measured data was equal to the prediction error of DP.
- The data set used to develop CIE DE2000 is in question as to its validity.
- CIE DE2000 is equivalent to CIE DE94

QUESTIONS ?