Research on Google’s Monet

Tones

In pursuit of perceptual lightness, Google uses L^* (called T (tone) in Google’s HCT) in CIE Lab to replace J in CAM16.

The 100 tone is always pure white, the lightest tone in the range; the 0 tone is pure black, the darkest tone in the range.

Styles

STYLE	ATTRIBUTE	A1	A2	A3	N1	N2
DEFAULT	Chroma*	≥ 48**	16	24	4	8
	Hue shift			+60°		
SPRITZ	Chroma	12	8	16	4	8
	Hue shift			+30°		
VIBRANT	Chroma	≥48	24	≥32	8	16
	Hue shift					
EXPRESSIVE	Chroma	≥64	24	≥48	12	16
	Hue shift	−60°	−30°			
RAINBOW	Chroma	≥48	16	24	0	0
	Hue shift			−60°		
FRUIT SALAD	Chroma	≥48	36	36	10	16
	Hue shift	−50°	−50°			

* Due to the chroma scale change in the proposed CAM16 model, the chroma color attributes should be multiplied by a roughly estimated factor $\frac{2}{3}$.

** The “≥” means there is a lower bound of the chroma but no upper bound; if without “≥” marked, the chroma must be the specified constant.

Appendices

Appendix A: The Simplified CAM16 Model

Define

$$F = 3.8848145378003529E-3$$
$$R = 29.482183021342301$$
$$d = 1.3173270022537199$$

$$M_{16} \equiv \begin{pmatrix} 0.401288 & 0.650173 & -0.051461 \\ -0.250268 & 1.204414 & 0.045854 \\ -0.002079 & 0.048952 & 0.953127 \end{pmatrix}$$

$$\boldsymbol{D} \equiv \begin{pmatrix} 1.0211774459482703 \\ 0.98630789117685210 \\ 0.93396137406301061 \end{pmatrix}$$

$$\Re \equiv \begin{pmatrix} 2 & 1 & \frac{1}{20} \\ 1 & -\frac{12}{11} & \frac{1}{11} \\ \frac{1}{9} & \frac{1}{9} & -\frac{2}{9} \end{pmatrix}$$

$$\mathcal{F}(\boldsymbol{v}) \equiv \left\{400 \operatorname{sign}(s) \frac{(F\boldsymbol{v}_i)^{0.42}}{(F\boldsymbol{v}_i)^{0.42} + 27.13}\right\}$$

$$\mathcal{F}^{-1}(\boldsymbol{v}) \equiv \left\{\frac{\operatorname{sign}(\boldsymbol{v}_i)}{F}\left(\frac{27.13|\boldsymbol{v}_i|}{400 - |\boldsymbol{v}_i|}\right)^{\frac{1}{0.42}}\right\}$$

$$\begin{aligned} \varepsilon(h) \equiv 1 &- 0.0582 \cos h - 0.0258 \cos 2h \\ &- 0.1347 \cos 3h + 0.0289 \cos 4h \\ &- 0.1475 \sin h - 0.0308 \sin 2h \\ &+ 0.0385 \sin 3h + 0.0096 \sin 4h \end{aligned}$$

From CIE XYZ to CAM16

Input: CIE XYZ vector $\boldsymbol{X}$
Output: CAM16 (JCh) vector $\boldsymbol{M}$

$$\begin{pmatrix} A \\ a \\ b \end{pmatrix} = \Re\mathcal{F}(\mathrm{Diag}(\boldsymbol{D}) M_{16} \boldsymbol{X})$$

$$h' = \arctan\left(\frac{b}{a}\right)$$

$$\boldsymbol{M} = \begin{pmatrix} 100\left(\frac{A}{R}\right)^{d} \\ \frac{1505}{R}\varepsilon(h')\sqrt{a^2 + b^2} \\ \frac{180^\circ}{\pi} h' \end{pmatrix}$$

From CAM16 to CIE XYZ

Input: CAM16 (JCh) vector $(J, C, h)^T$
Output: CIE XYZ vector $\boldsymbol{X}$

$$h' = \frac{\pi}{180^\circ} h$$

$$\gamma = \frac{C}{1505\,\varepsilon(h')}$$

$$\boldsymbol{X} = M_{16}^{-1} \mathrm{Diag}(\boldsymbol{D}^{\circ -1}) \mathcal{F}^{-1}\left(\Re^{-1} R \begin{pmatrix} \left(\frac{J}{100}\right)^{\frac{1}{d}} \\ \gamma \cos h' \\ \gamma \sin h' \end{pmatrix}\right)$$

Notes on Appendix A

1. All the numbers were rounded to 17 significant digits (which was done in the last steps, but the intermediate values were arithmetically exact) except those defined in specifications.

2. The inverse of M_{16}

$$M_{16}^{-1} \equiv \begin{pmatrix} 1.8620678550872327 & -1.0112546305316844 & 0.14918677544445172 \\ 0.38752654323613716 & 0.62144744193147536 & -0.0089739851676125183 \\ -0.015841498849333855 & -0.034122938028515564 & 1.0499644368778494 \end{pmatrix}$$

3. The reference white $\boldsymbol{W}_{\mathrm{D65}}$ used throughout the calculation

$$\boldsymbol{W}_{\mathrm{D65}} \equiv \begin{pmatrix} 95.047055865428191 \\ 100 \\ 108.88287363958874 \end{pmatrix}$$

4. The Hadamard inverse (of a vector)

$$(\boldsymbol{v}^{\circ -1})_i = \frac{1}{\boldsymbol{v}_i}$$

Appendix B: Conversions between CIE XYZ and sRGB

$$M \equiv 100 \begin{pmatrix} 0.41245744558236514 & 0.35757586524551642 & 0.18043724782640035 \\ 0.21267337037840703 & 0.71515173049103283 & 0.072174899130560142 \\ 0.019333942761673366 & 0.11919195508183881 & 0.95030283855237520 \end{pmatrix}$$

$$M^{-1} \equiv \frac{1}{100} \begin{pmatrix} 3.2404462546477561 & -1.5371347618200895 & -0.49853019302273171 \\ -0.96926660624467829 & 1.8760119597883673 & 0.041556042214430008 \\ 0.055643503564352598 & -0.20402617973595953 & 1.0572265677226994 \end{pmatrix}$$

$$\mathcal{F}(\boldsymbol{v}) \equiv \left\{ \begin{cases} \left(\dfrac{\boldsymbol{v}_i + 0.055}{1.055}\right)^{2.4}, & \boldsymbol{v}_i \geq 3.530633592050228\mathrm{E}-5 \\ \dfrac{\boldsymbol{v}_i}{0.010775438668478016}, & otherwise \end{cases} \right\}$$

$$\mathcal{F}^{-1}(\boldsymbol{v}) \equiv \left\{ \begin{cases} 1.055\, \boldsymbol{v}_i^{\frac{1}{2.4}} - 0.055, & \boldsymbol{v}_i \geq 0.003039934639778422 \\ 0.010775438668478016\, \boldsymbol{v}_i, & otherwise \end{cases} \right\}$$

From sRGB to CIE XYZ

Input: sRGB vector $\boldsymbol{R}$
Output: CIE XYZ vector $\boldsymbol{X}$

$$\boldsymbol{X} = M\mathcal{F}(\boldsymbol{R})$$

From CIE XYZ to sRGB

Input: CIE XYZ vector $\boldsymbol{X}$
Output: sRGB vector $\boldsymbol{R}$

$$\boldsymbol{R} = \mathcal{F}^{-1}(M^{-1}\boldsymbol{X})$$