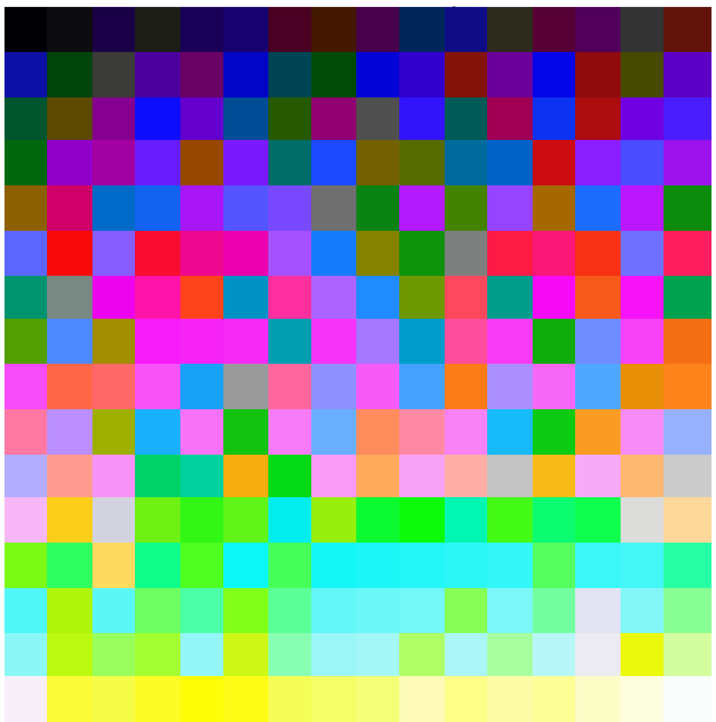
Gernot Hoffmann

Luminance Models for Grayscale Conversions



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Gray Gamma 2.2

1. Introduction

Several algorithms for the calculation of the luminance in images are discussed. Colorimetrically correct is the one which uses CIE XYZ luminance Y in the linear light space, based on Rec.709 primaries, D65 white point and Gamma=2.2, as used in sRGB.
Calibrated monitors are near to sRGB, therefore this conversion should deliver the best result.
It turns out that saturated colors do not follow this rule. Mainly saturated blue appears much lighter than expected by XYZ luminance.

TrueColor

1/3 Weight

NTSC

Photoshop 5

2. Luminance Models NTSC and 1/3 weight

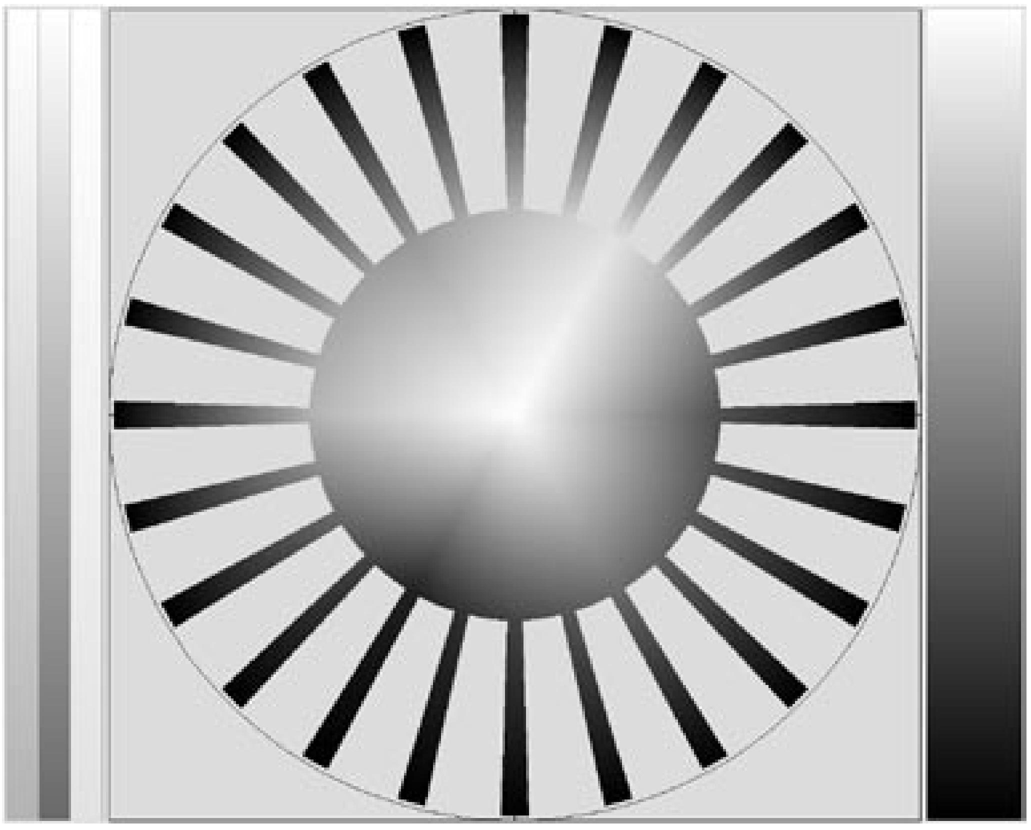
This is an RGB test image, a mathematical construction.
R,G,B are treated equally. The color wheel is a top view on the HLS cone (Hue, Lightness, Saturation).

This is the Grayscale Conversion, according to the Luminance Model which is used by NTSC and JPEG for nonlinear data in a gamma working space, marked by an apostroph:

Y' = 0.299 R' + 0.587 G' + 0.114 B'

R' = G' = B' = Y'

The same weight factors are used for convenience in nonlinear PAL/SECAM working spaces.

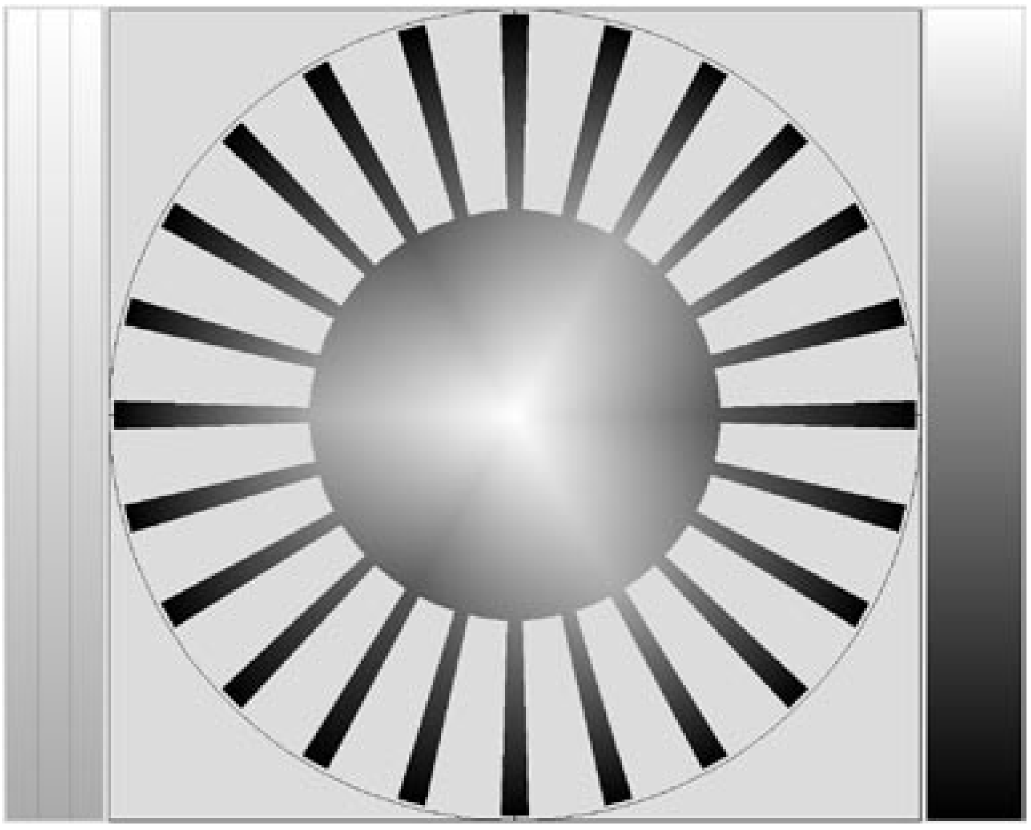


This is the Grayscale Conversion for the Mathematical Luminance Model:

Y' = 0.333 R' + 0.333 G' + 0.333 B'

R' = G' = B' = Y'

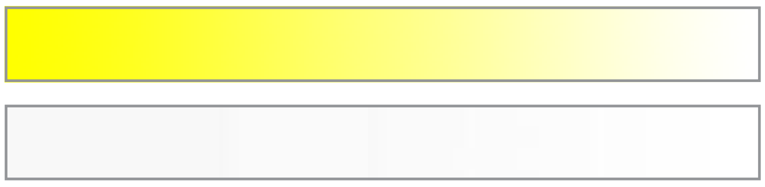
The area looks well balanced, nevertheless we do not see equal grays on a circle with given radius.
This is the result of the specific HLS to RGB conversion.



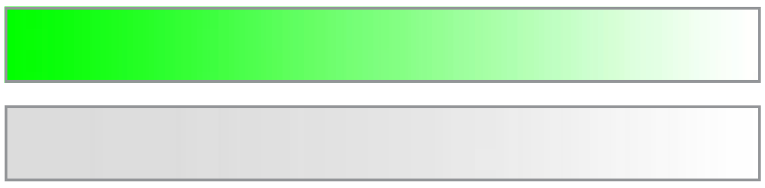
3. Luminance Model in Photoshop 5.0

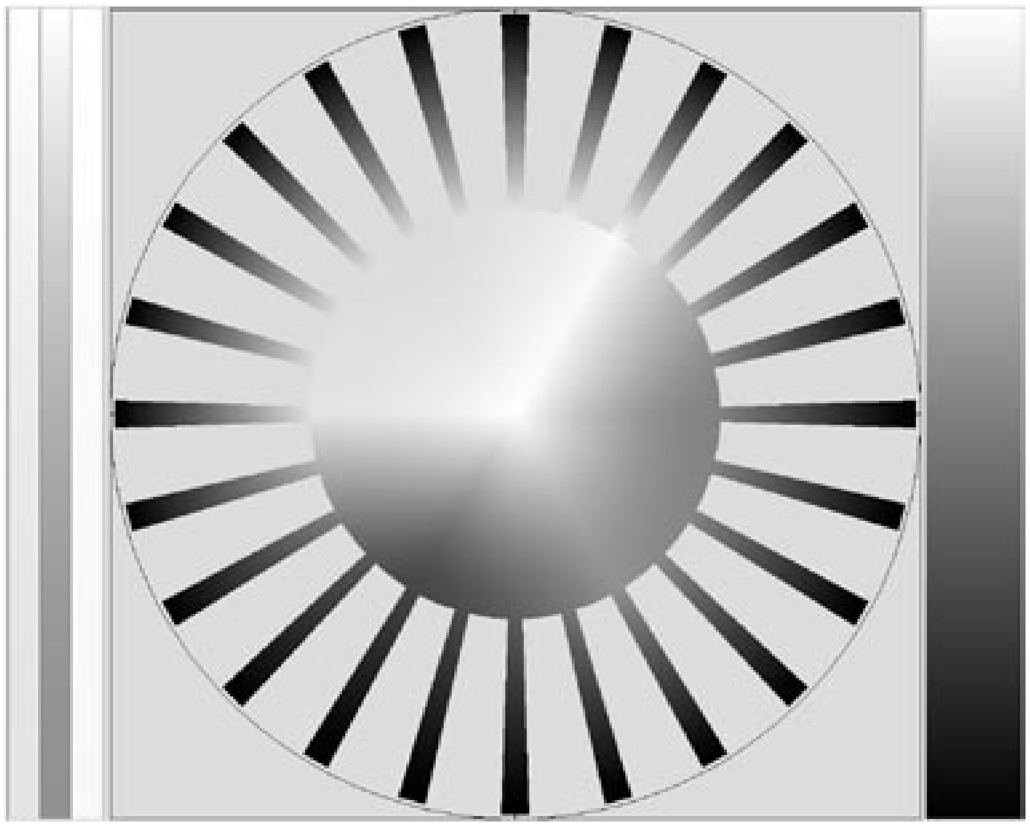
This is the Photoshop 5.0 Grayscale Conversion. Which model has been used ?

255,255,0 Yellow 255,255,255



0,255,0 Green 255,255,255





Photoshop applies first a transformation into the linear working space Gamma = 1, then the weighting by the factors below and finally the reverse transformation into the Gamma working space Gamma = 2.2.

$$Y = 0.2126\,R'^{2.2} + 0.7152\,G'^{2.2} + 0.0724\,B'^{2.2}$$

$$R' = G' = B' = Y^{1/2.2}$$

According to Poynton, FAQs about Color, this is the appropriate linear luminance calculation in a nonlinear working space for modern monitors (Rec.709, PAL/SECAM, EBU/ITU).
Green counts nearly ten times more than blue. This cannot be proved by tests.

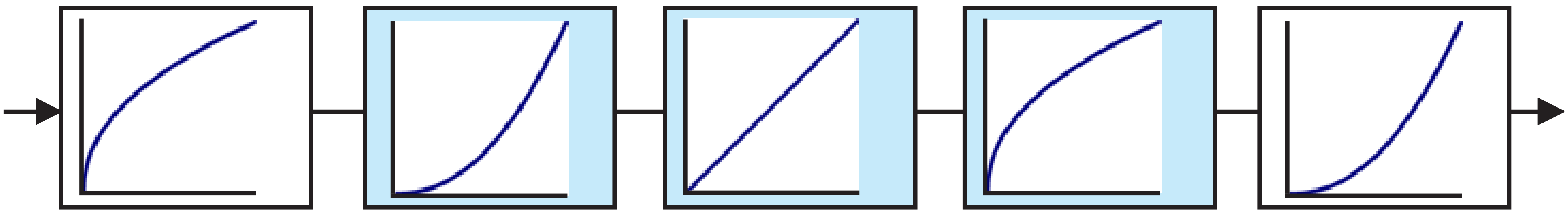
Most likely later versions of Photoshop apply weight factors according to an accurate conversion of linear RGB data to CIE XYZ, depending on the working space.

This image shows the difference between the Photoshop result and an explicite application of the algorithm above, shifted to the medium gray level 128.

The difference is mostly in the range of ±1, but larger in very dark areas.
Photoshop uses a linear slope for low values in the inverse Gamma function $C' = C^{1/2.2}$.

4. Photoshop Workflow

Finally, we show the complete Photoshop workflow from scene luminance to monitor luminance.
The weight factors are valid for modern Rec.709 monitors and for the sRGB working space.



5. Luminance in Real Images

In real images we have nearly never fully saturated colors. We can split the colors into a common gray base $C = R_1 = G_1 = B_1$ and one or two (but not three) additional colors R_2, G_2, B_2 .

$$C = \mathrm{Min}(R,G,B)$$

$$R = C + R_2$$
$$G = C + G_2$$
$$B = C + B_2$$

Now we calculate the luminance by three weight factors $r + g + b = 1$:

$$Y = rR + gG + bB$$
$$Y = (r+g+b)C + rR_2 + gG_2 + bB_2$$
$$Y = C + rR_2 + gG_2 + bB_2$$

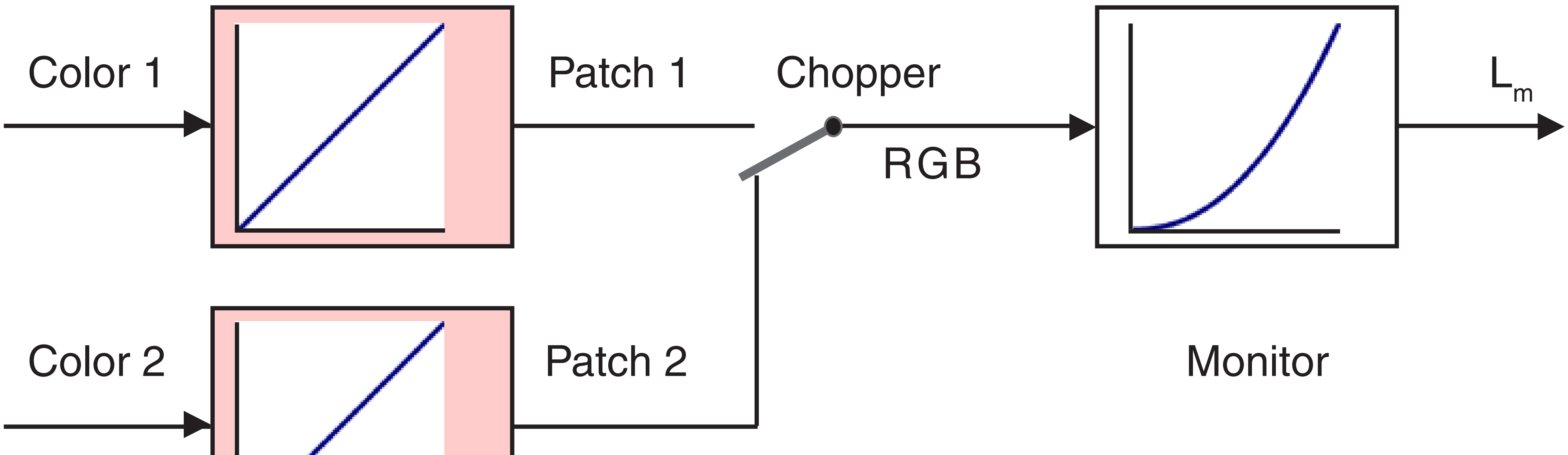
The weight factors concern only the one or two colors R_2, G_2 or B_2 .
A pure blue will be very dark in the gray image, but a blue sky looks normal in the gray image, because the base C dominates. If the sky blue has a cyan tint, then the large weight factor for green may cause an increase of gray lightness.

The gray conversion for real images does not depend very much on accurate weight factors (compare chapter 7).

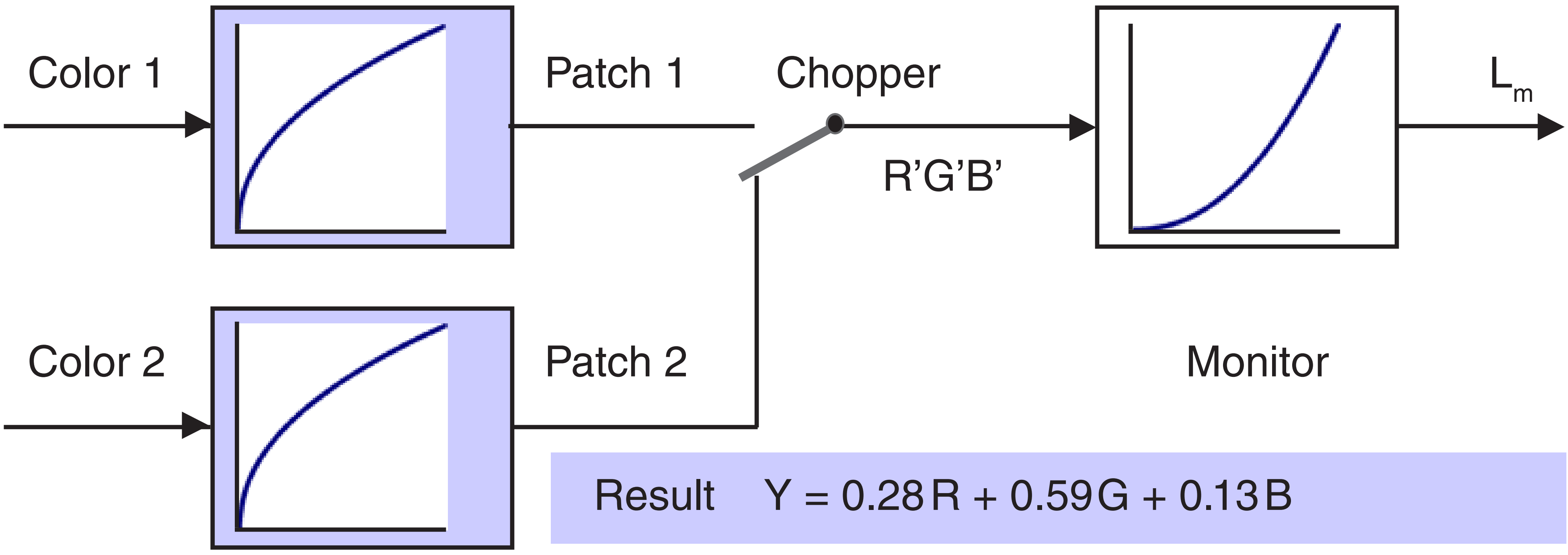
6.1 Luminance by Flicker Test

The author had tried to find the relative weights by a flicker test.

Two patches with edge lengths 1 inch are shown alternating on a black monitor.
The flicker frequency is adjustable.
The alternation is synchronized to the vertical refresh frequency.
Monitor Gamma=2.2, 9300K, calibrated.



Result $Y = 0.31\,R + 0.46\,G + 0.23\,B$



Result $Y = 0.28\,R + 0.59\,G + 0.13\,B$

Now find the best match of Green to Blue and Red to Blue for minimal flicker.

Color 1:	Blue	255		Blue 255
Color 2:	Green	0...255 adjustable	Red	0...255 adjustable
Color 1:	Blue	128		Blue 128
Color 2:	Green	0...255 adjustable	Red	0...255 adjustable
Color 1:	Blue	64		Blue 64
Color 2:	Green	0...255 adjustable	Red	0...255 adjustable

6.2 Luminance by Flicker Test

Numbers are used uncompensated for a Gamma = 2.2 monitor:

$$Y = 0.31\,R + 0.46\,G + 0.23\,B$$

Here we commmand gun intensities, but the luminance results from the inherent monitor gamma function.

Numbers are used compensated for a Gamma = 2.2 monitor:

$$C = C^{1/2.2} \quad \text{for } C = R,G \text{ or } B$$
$$Y = 0.28\,R + 0.59\,G + 0.13\,B$$

Here we command luminances.
The compensated weight factors are near to the NTSC, JPEG weight factors for non-linear data, but in fact the test situation doesnot reflect the nonlinear working space for NTSC. Our RGB numbers are given *as inputs* of the nonlinear block. For NTSC we should use the numbers R'G'B' , the *outputs* of the nonlinear block.

This test should deliver the Y weight factors for CIE XYZ for a Rec.709 monitor, but it does not.

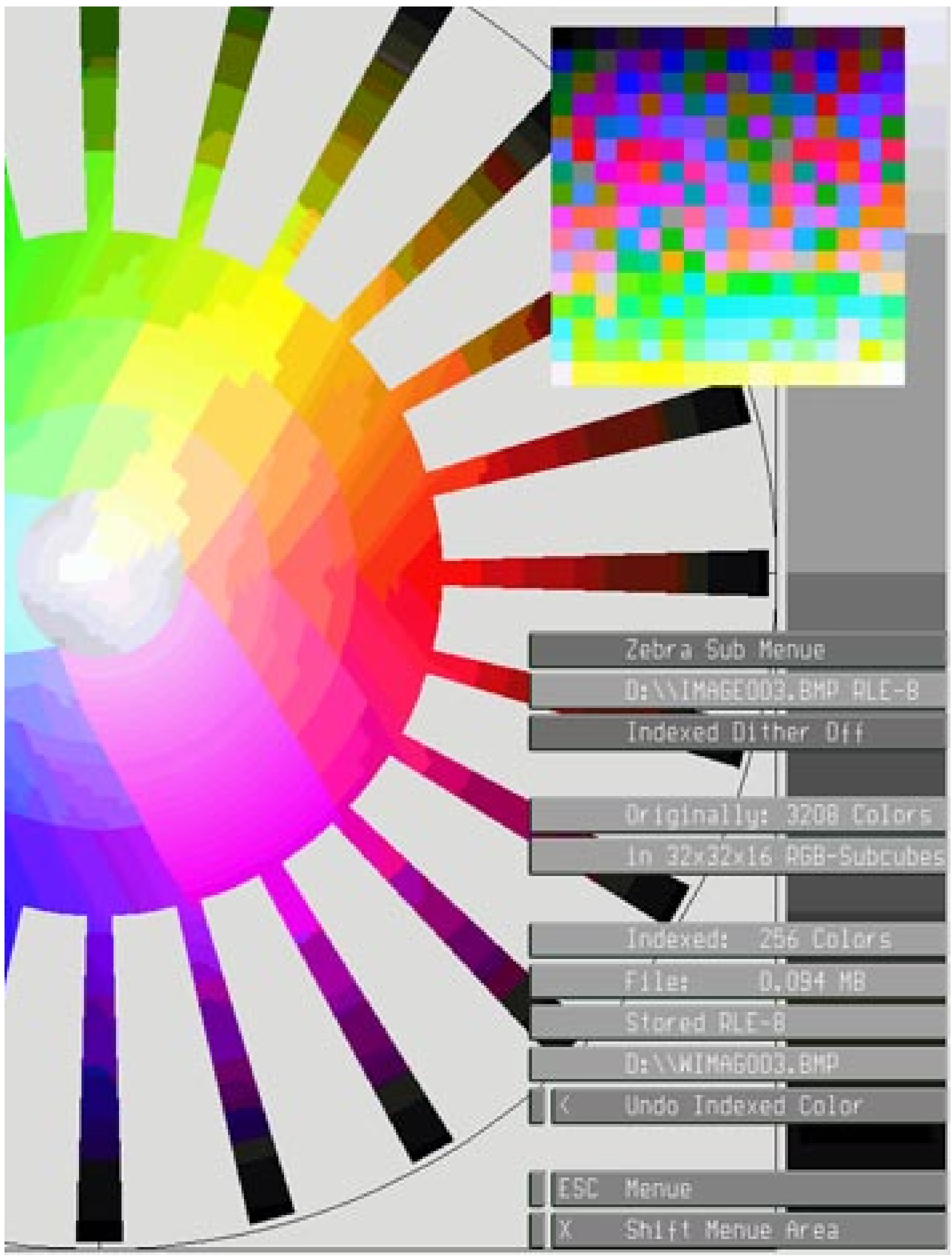
Some further confusion may result from the fact that we do not command absolute but relative luminances. 0...255 means 0...100% of the *maximal* luminance for the respective channel.

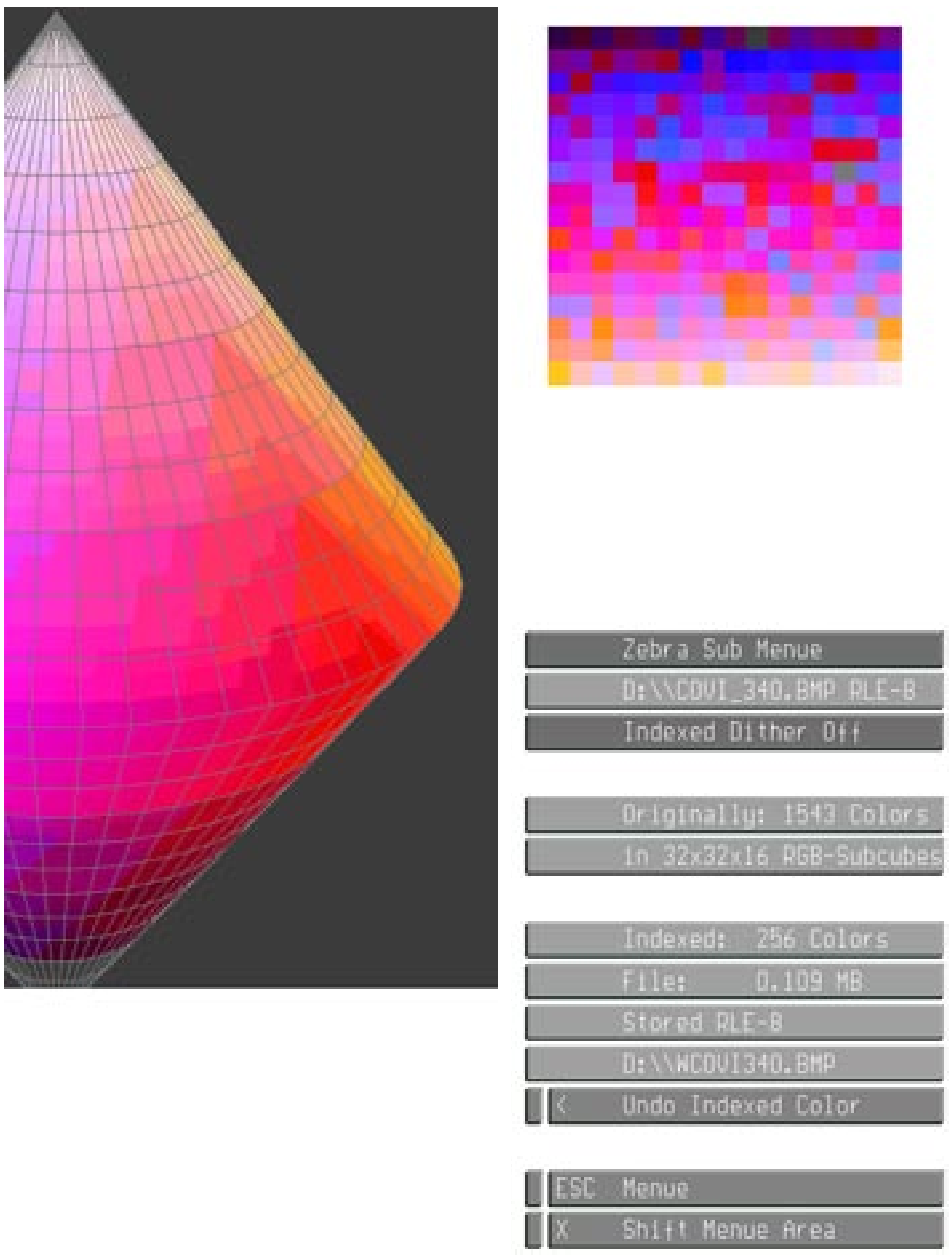
7.1 Luminance in Indexed Color Images

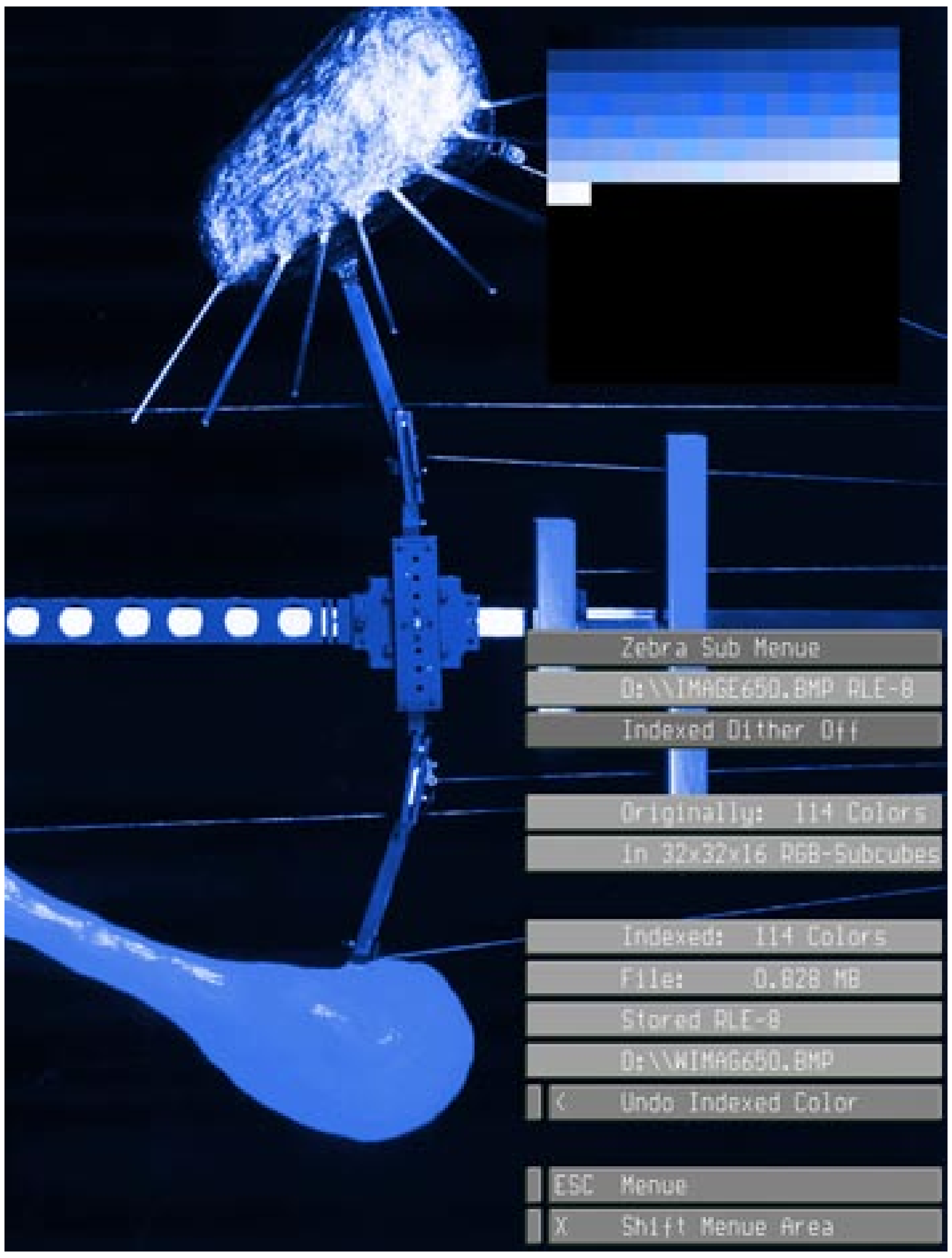
Twelve very different images were converted to Indexed Color.
The colors in the palette are shown sorted using Rec.709/sRGB, linear light space and CIE Y luminance.
Obviously the patches do not appear sorted by perceptual lightness.

The left halves of the source images are cropped. The palettes are valid for the entire images.

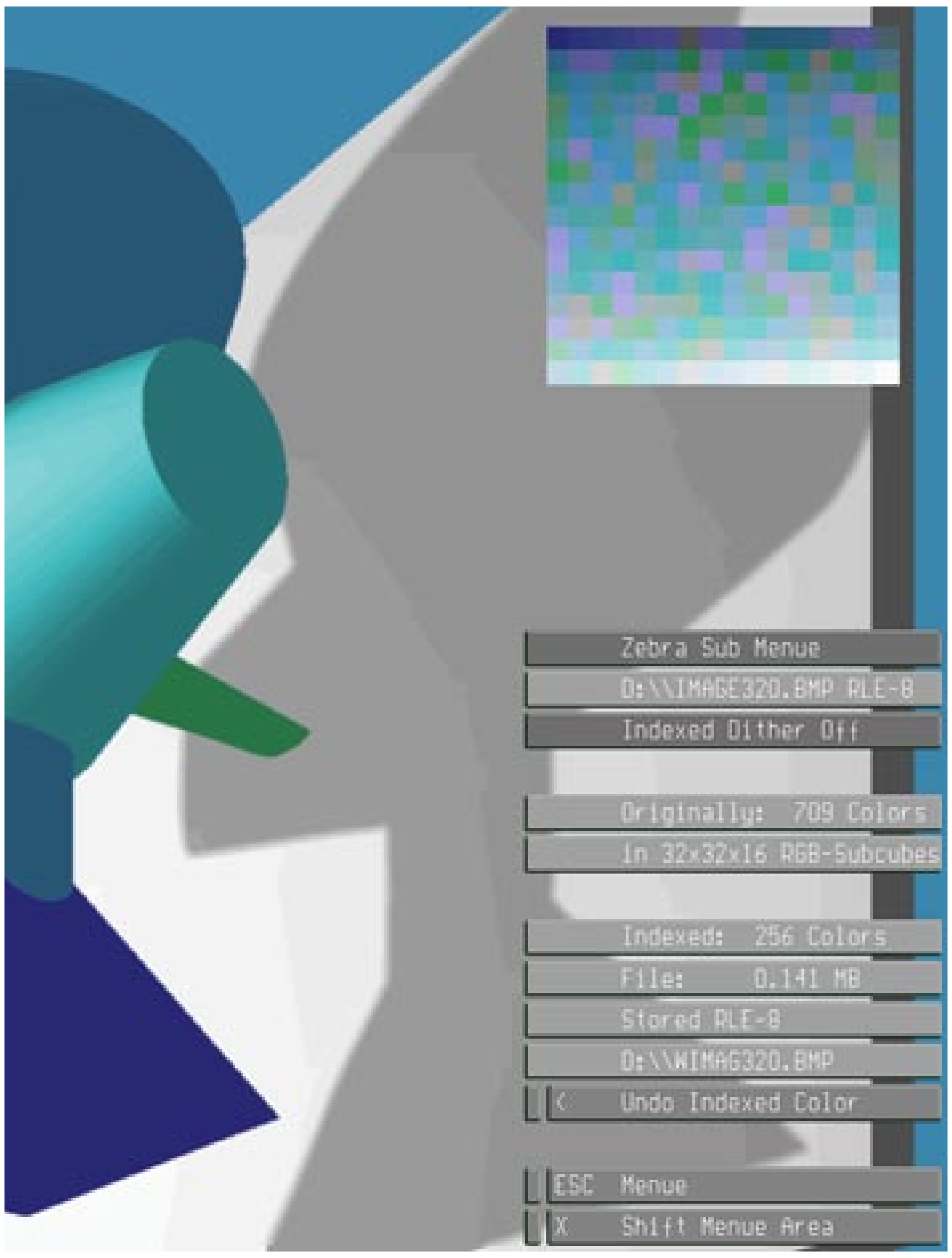
The conversion to Indexed Color was executed without dithering.
The images in the PDF are either JPEG or ZIP compressed (only ZIP is lossless).
Downsampling for 72 ppi.

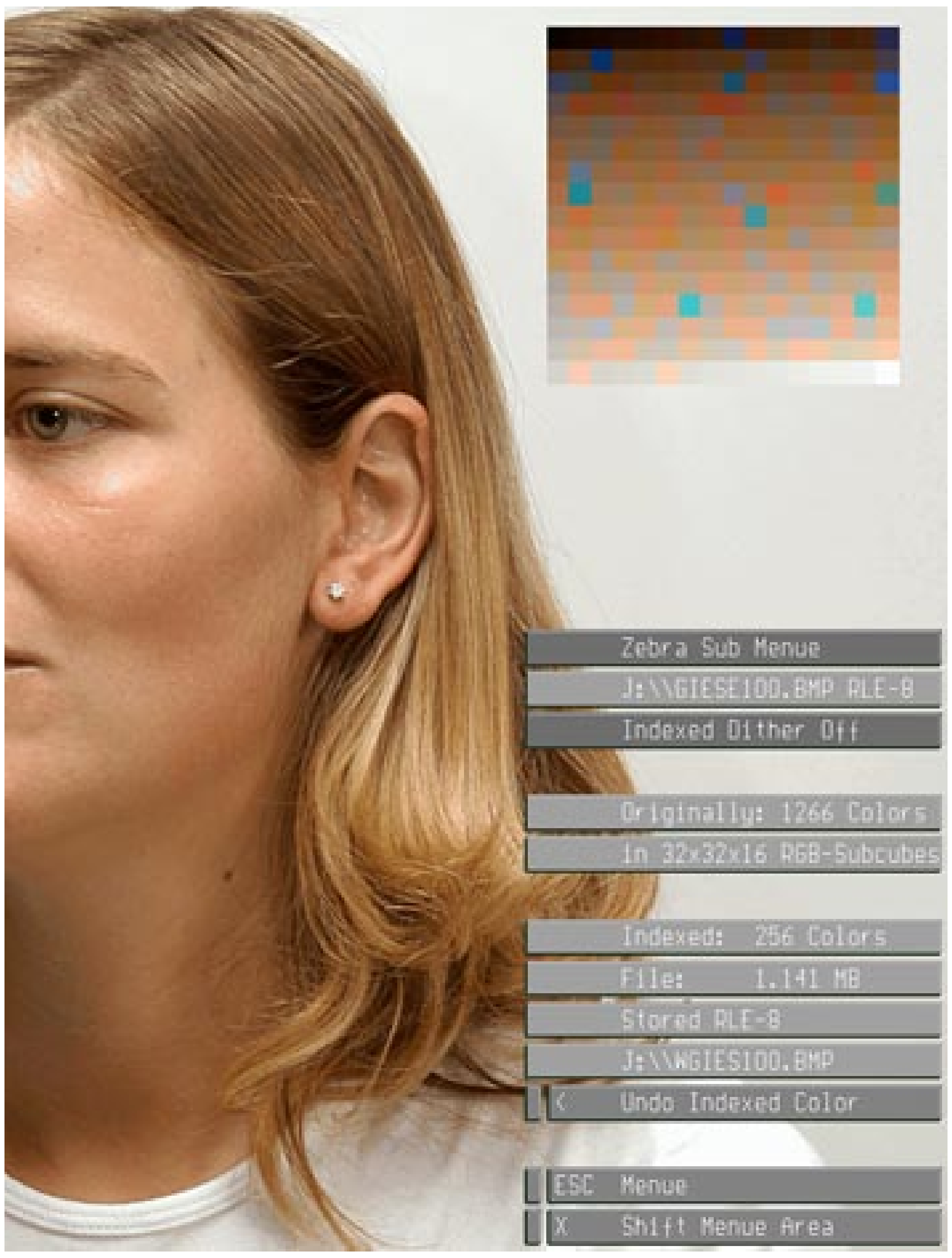


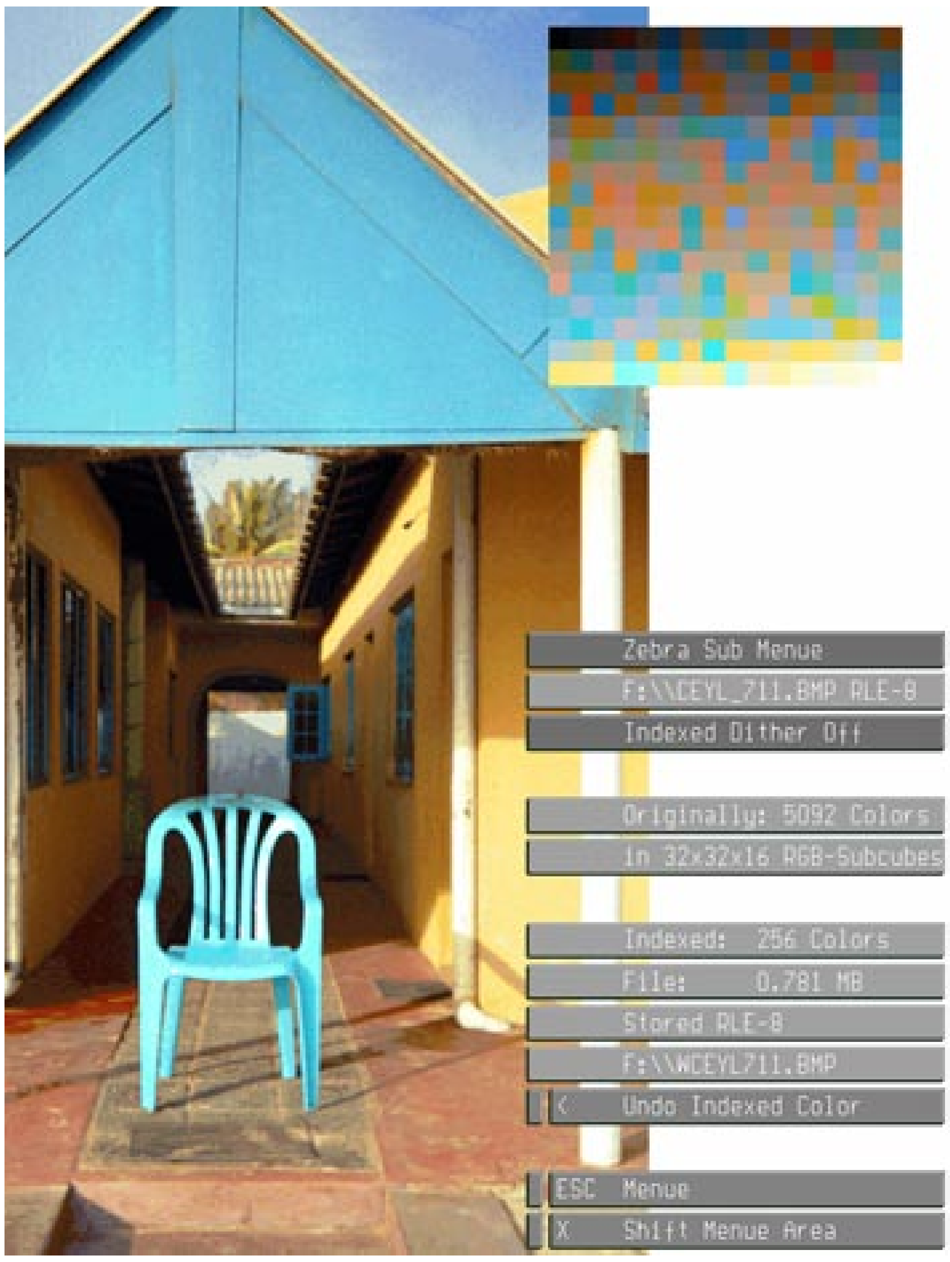




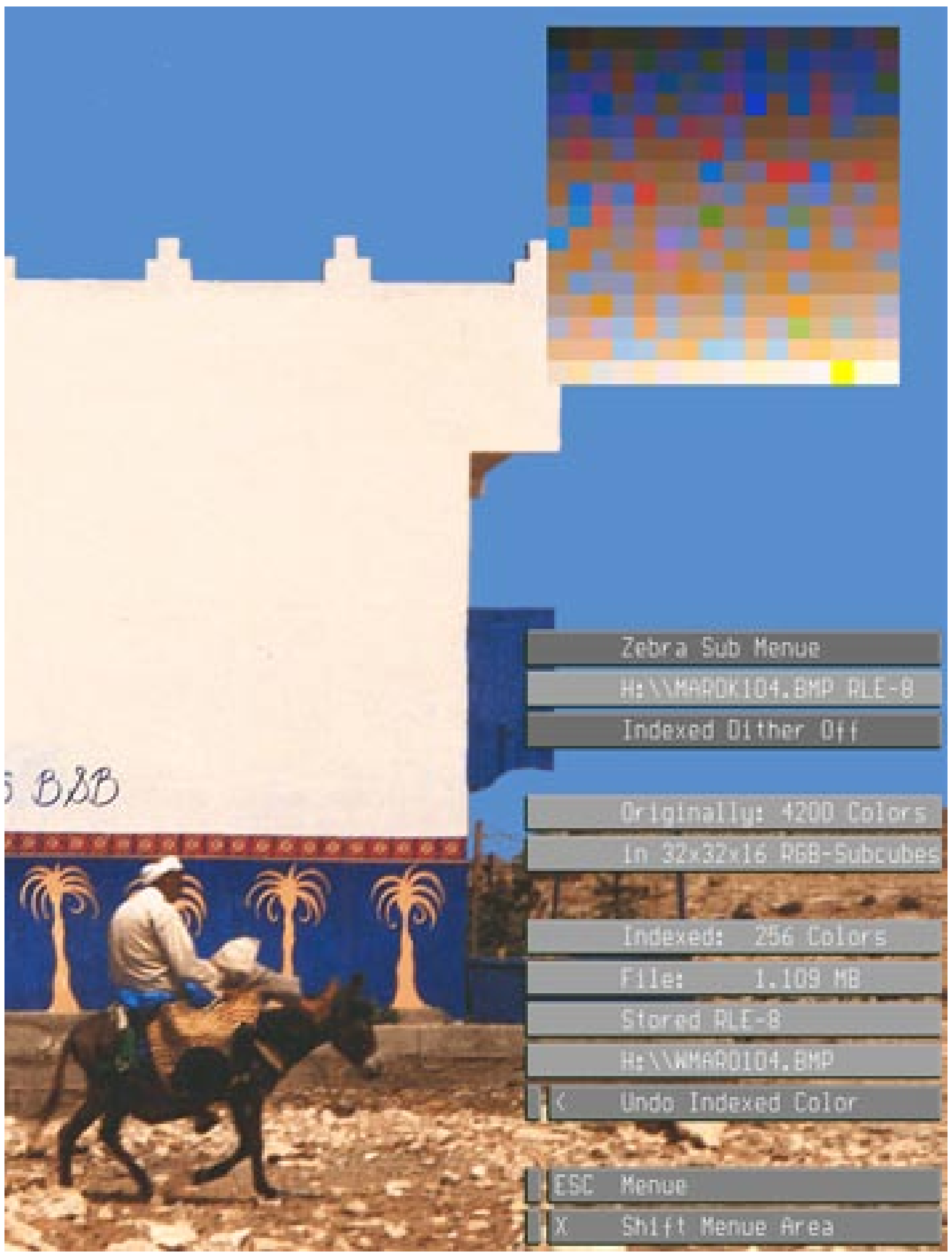
7.2 Luminance in Indexed Color Images

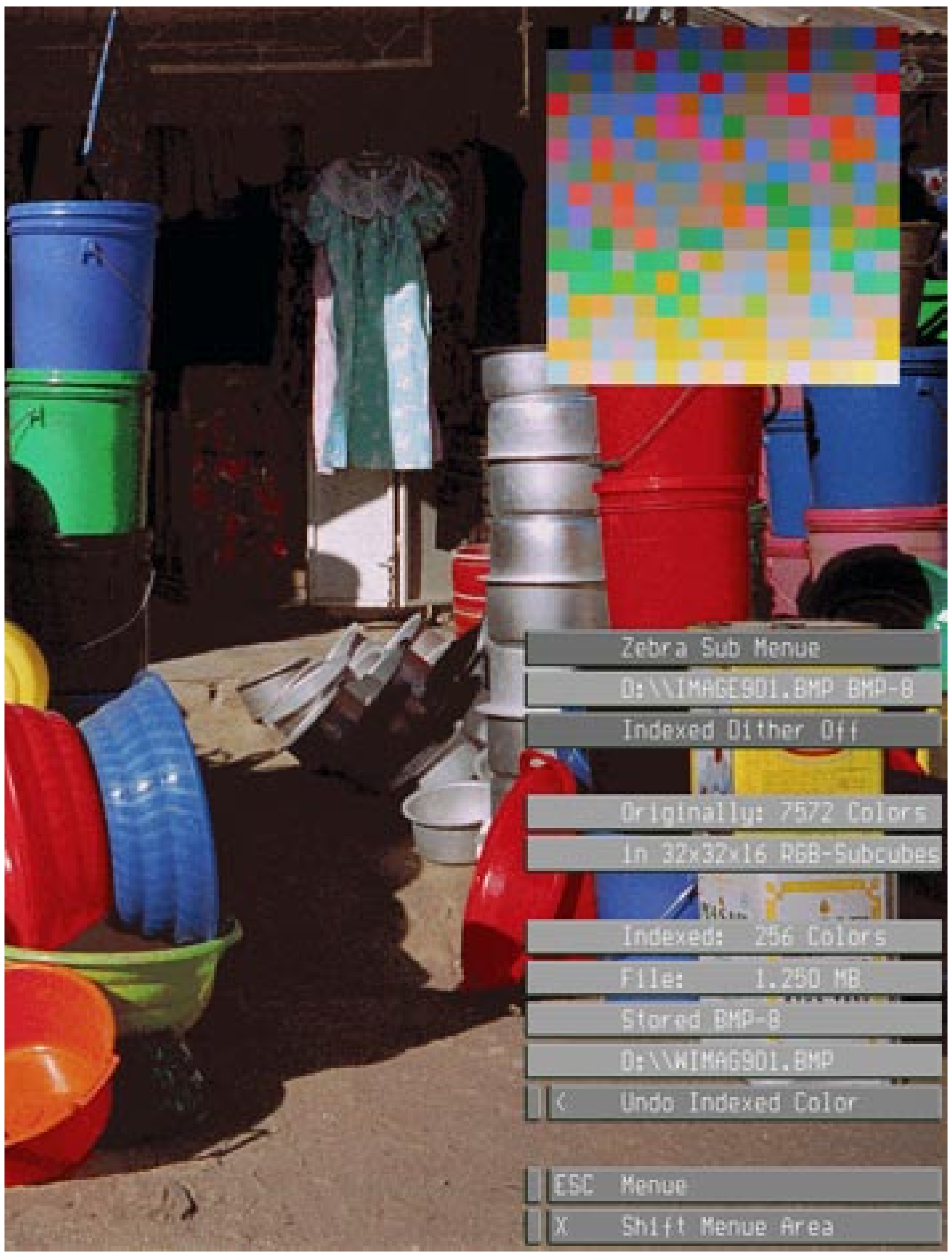




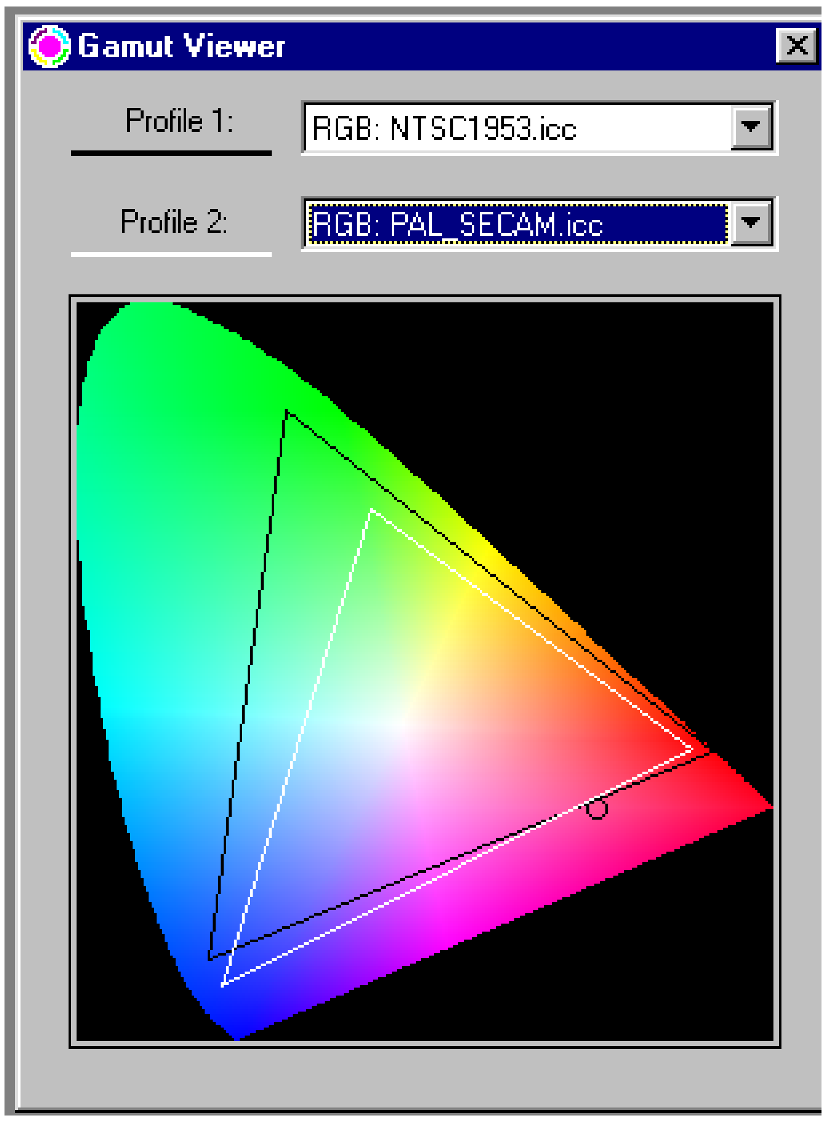


7.3 Luminance in Indexed Color Images





8. Primaries and Gamut



NTSC and PAL/Secam

Primaries and White Point

NTSC (1953)

xr	yr	xg	yg	xb	yb	xw	yw
0.6700	0.3300	0.2100	0.7100	0.1400	0.0800	0.3100	0.3160

Rec.709, EBU/ITU, PAL/SECAM

xr	yr	xg	yg	xb	yb	xw	yw
0.6400	0.3300	0.3000	0.6000	0.1500	0.0600	0.3127	0.3290
		0.2900					

Gernot Hoffmann
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