

Colourimetric Reproduction of Luminance and Chromaticity of rgb^* images on SDR and HDR displays by a TUB colour-vision model

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1. Introduction

New displays of the High Dynamic Range (HDR) lead to new possibilities for the output of the scene luminance compared to the Standard Dynamic Range (SDR).

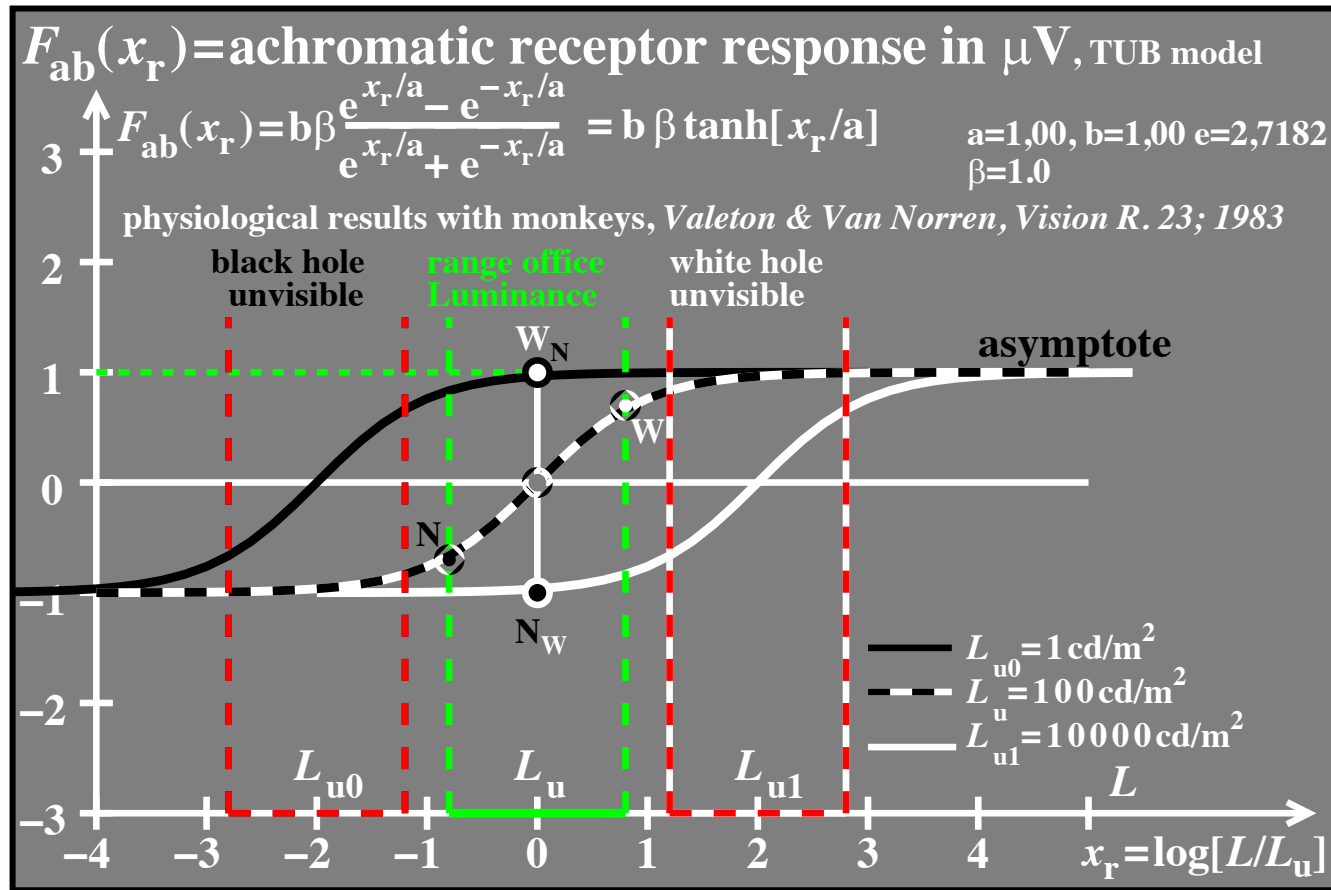
The analog photography could input at least about 4 log-luminance units. In negative film the luminance was coded in density which is proportional to the log luminance. The present digital photography can store at least 4 log-luminance units. In addition the information is directly available as a digital image file.

For any encoding of the scene luminance by a power, logarithmic or hyperbolic function the inverse decoding will produce the display luminance and chromaticity. However, there is always a mixture of the emissive display light with the ambient light. This contrast reduction is considered in ISO 9241-306 and not in ISO 22028-5.

For application the appropriate coding and inverse coding according to the properties of the human visual system is important. Proposals and solutions will be discussed in the following.

Fig. 1 shows a fit of the visual responses of monkeys by an exponential function. The literature is given in the figure. The visual responses are always in the range 0 to 1. They have been measured for four log units of adaptation and for about 6 log units of sample luminance.

2. TUB model of achromatic physiological responses and psycho-physical data



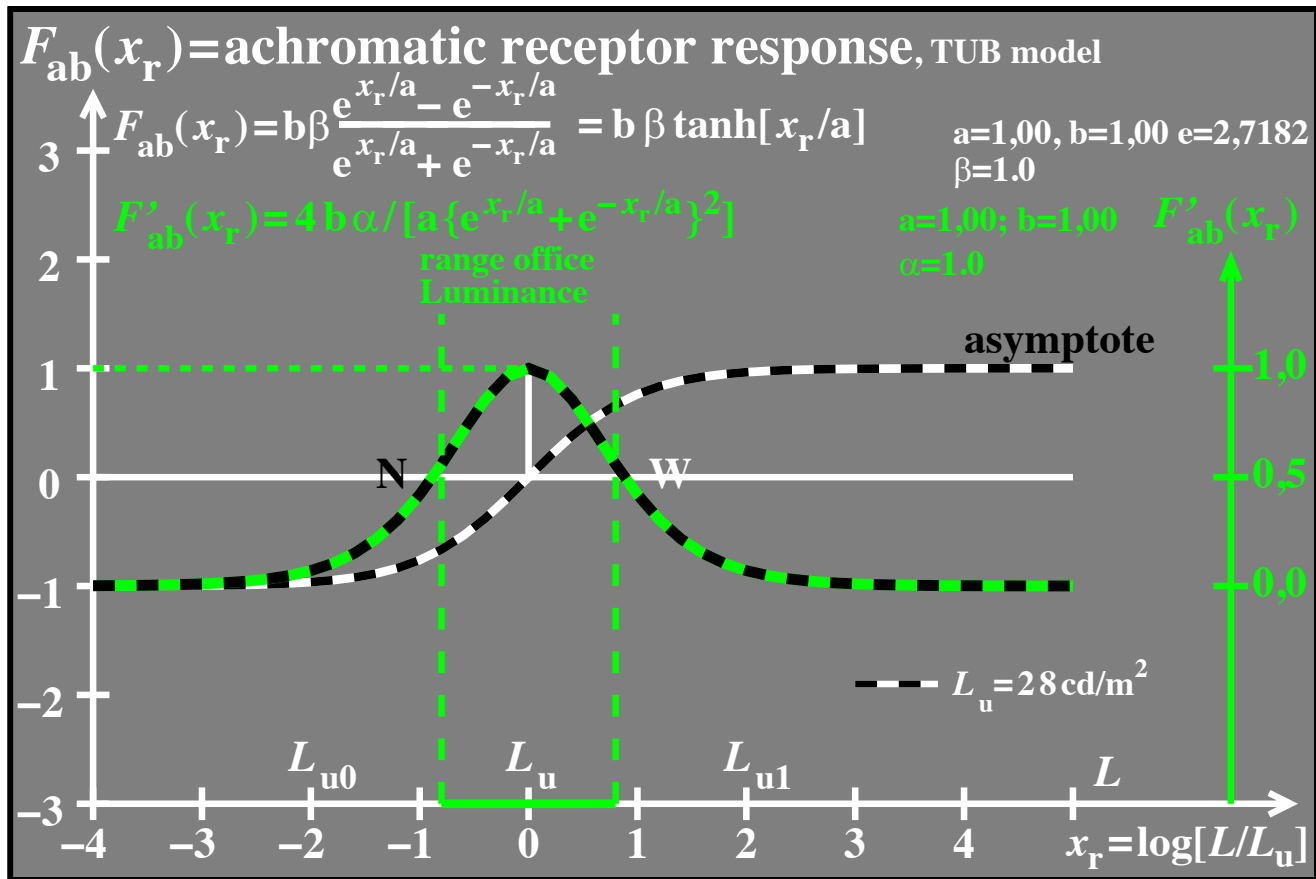
eeg00-5n

Fig. 1 Physiological response curves of monkeys for three adaptation levels.

The literature, the sample luminance range and the adaptation level is given in the figure.

The samples black N, Grey U and White W near the office-colour range are shown.

For the download of this figure, see <http://color.li.tu-berlin.de/eeg0/eeg00-5n.pdf>



eeg00-3n

Fig. 2 Physiological response curve and derivation for one adaptation level

It is appropriate to use the *relative* luminance. All physiological response curves in Fig. 1 are similar for different adaptation levels. ISO 9241-306 defines $L_u=28 \text{ cd/m}^2$ for Grey U. For the download of this figure, see <http://color.li.tu-berlin.de/eeg0/eeg00-3n.pdf>

Mathematical equations of hyperbolic functions

See: *Handbook of mathematical functions, NBS, USA, Sec. 4.5*

$$F_{ab}(x_r/a) = b \tanh(x_r/a) = b \frac{e^{x_r/a} - e^{-x_r/a}}{e^{x_r/a} + e^{-x_r/a}} \quad [1]$$

$$\frac{dF_{ab}(x_r/a)}{dx_r} = \frac{4b}{a[e^{x_r/a} + e^{-x_r/a}]^2} \quad x_r = \log(L/L_u) \quad [5]$$

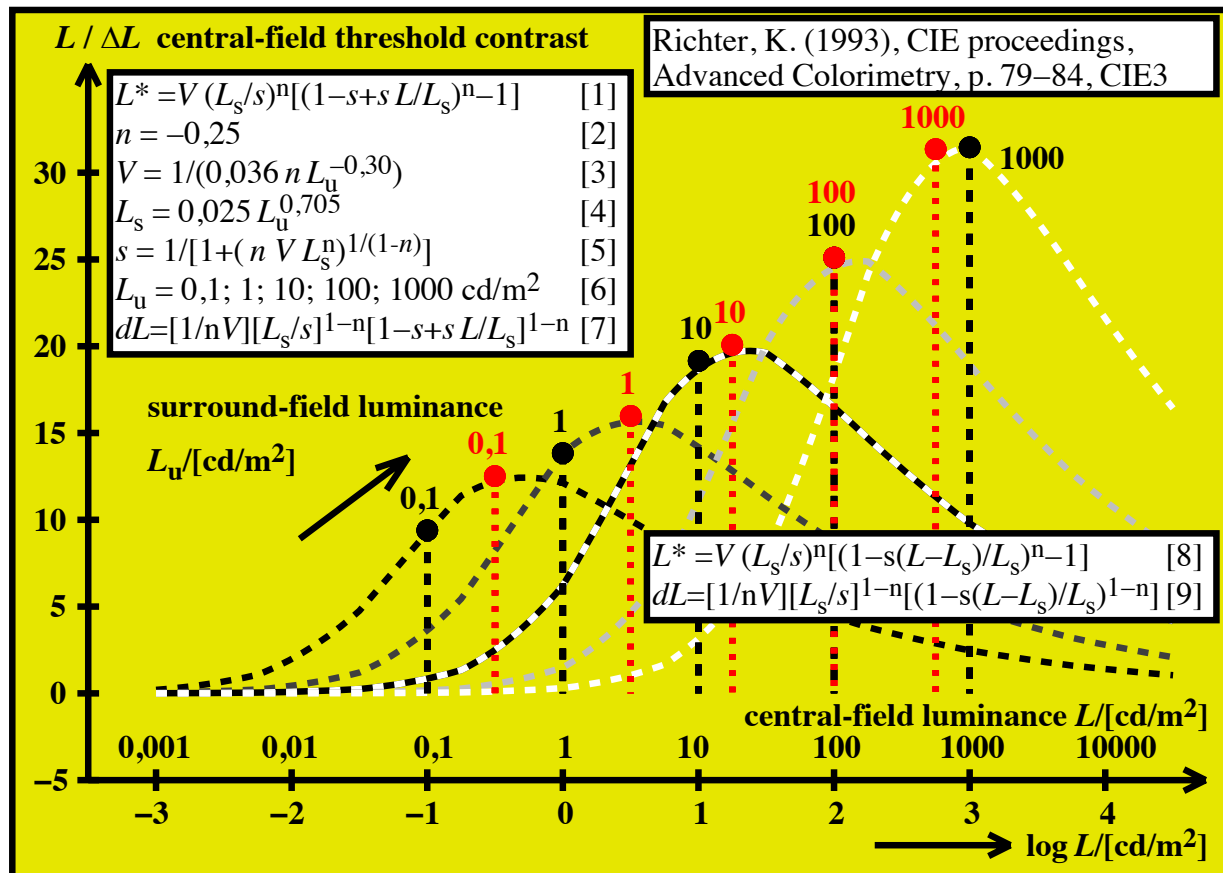
$$dx_r/dL = \ln(10)/L$$

$$\frac{dF_{ab}(x_r/a)}{dx_r} \frac{dx_r}{dL} = \frac{4b}{a[e^{x_r/a} + e^{-x_r/a}]^2} \frac{\ln(10)}{L} \quad [6]$$

$$\frac{L}{dL} = \frac{4b \ln(10)}{a[e^{x_r/a} + e^{-x_r/a}]^2} \quad dL = \frac{a[e^{x_r/a} + e^{-x_r/a}]^2 L}{4b \ln(10)} \quad [7]$$

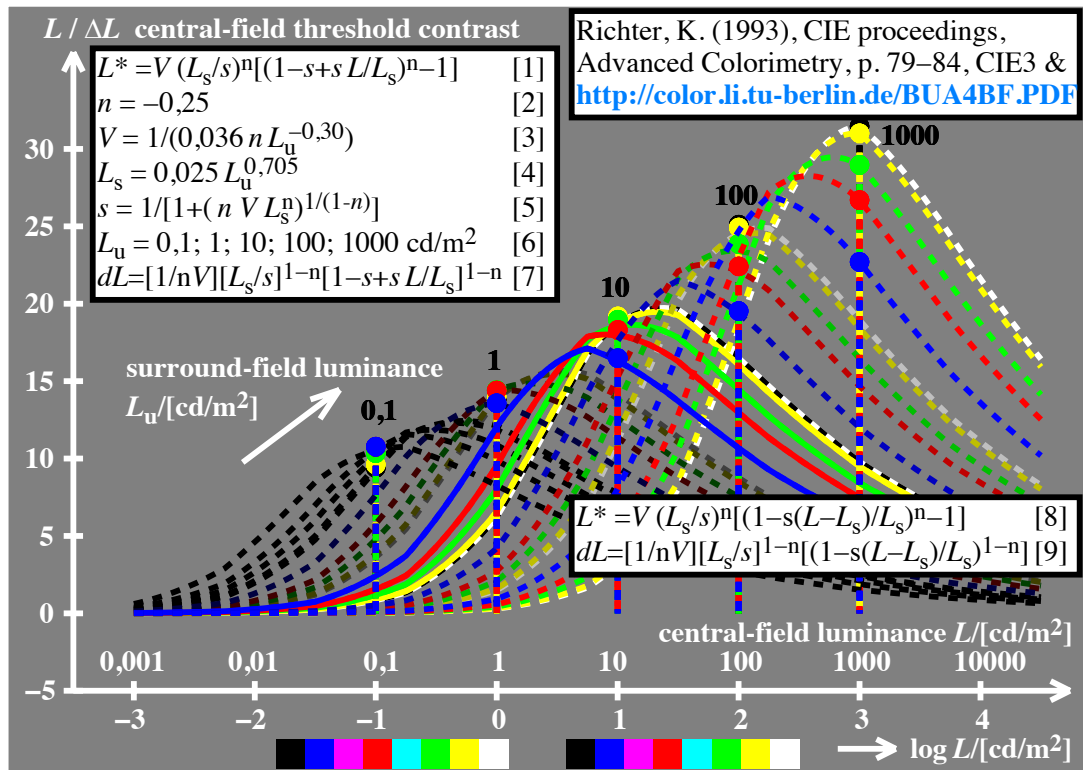
fek01-7n

Fig. 3 Receptor-response curves are described by hyperbolic functions.
 The derivation of $F_{ab}[\log(L/L_u)]$ is proportional to the luminance contrast ($L/\Delta L$). If this contrast is constant (*Weber-Fechner law*), then the response curve is a straight line.
 For the download of this figure, see <http://color.li.tu-berlin.de/fek0/fek01-7n.pdf>



ees01-2n, ees10-2a

Fig.4 Psychophysical luminance contrast for achromatic colours and 5 adaptations
 On the linear ordinate this contrast increases by about 20% for the luminance change 100 and 1000 cd/m². For the HDR luminance headroom 200 to 1000 cd/m² according to ISO 22028-5 the contrast may increase by 10% which may not be visible in most applications.
 For the download of this figure, see <http://color.li.tu-berlin.de/ees0/ees01-2n.pdf>



ees90-2a

Fig. 5 Psychophysical luminance contrast for achromatic and chromatic colours

A shift of the luminance contrast ($L/\Delta L$) is assumed for chromatic colours. For the display colours RGBY the luminance according to IEC 61966-2-1 is used. The appearance of the 8 colours is approximately constant over a wide range of luminance. By a luminance change between 100 and 1000 cd/m² (factor 10) the contrast sensitivity changes from 25 to 30 (factor 1,2). For RGBY the maximum contrast is shifted to lower luminance.

For the download of this figure, see <http://color.li.tu-berlin.de/ees9/ees90-2a.pdf>

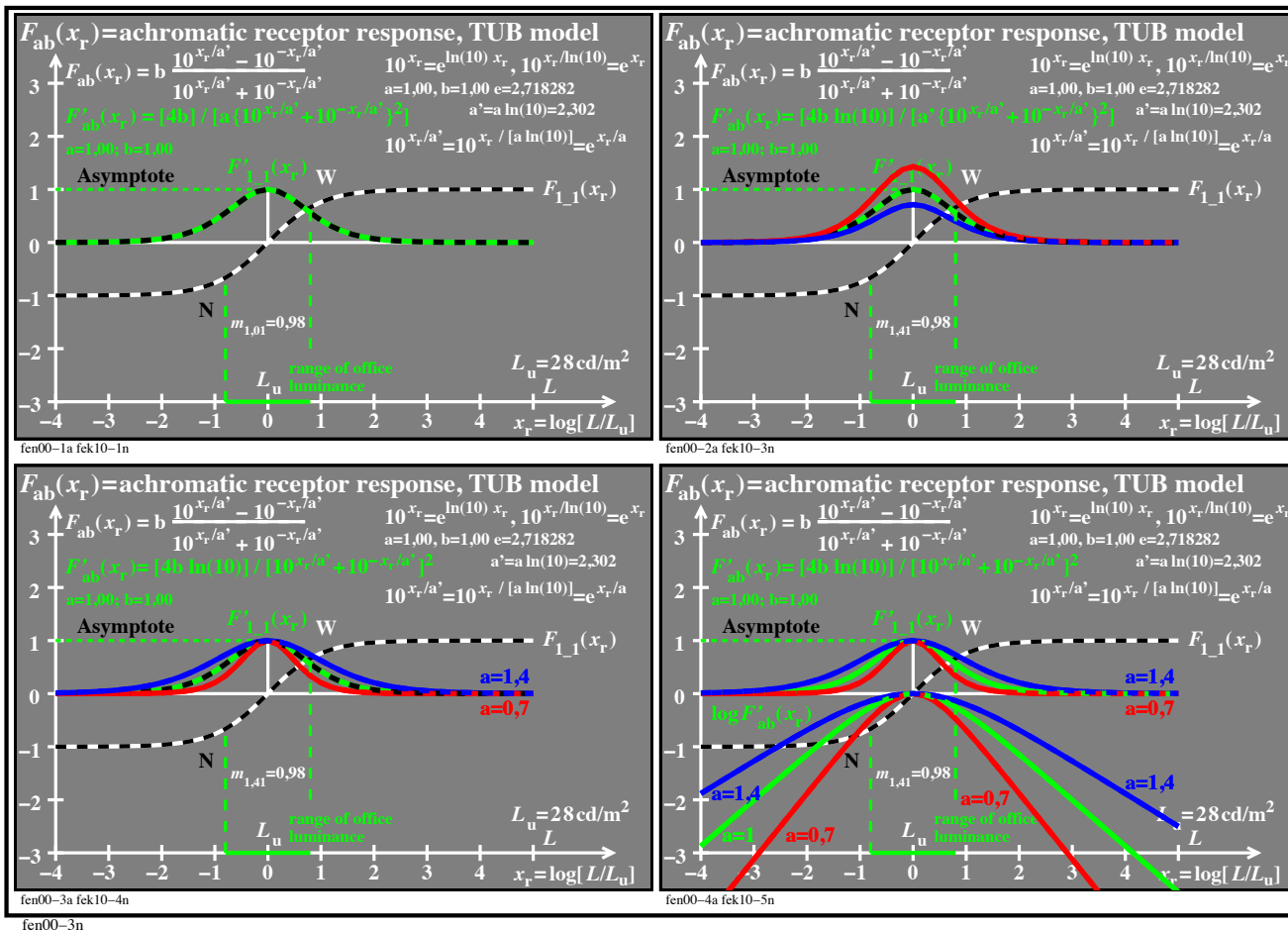


Fig. 6 Model of physiological response functions with two parameters a and b . The value of the *relative* response $\log(L/L_u) = 0$ is independent of the parameter b and shall be used. The parameter a changes the bandwidth on the x -axis. For example for lighter colours with $a=1,4$ the slope is less compared to $a=1,0$, compare Fig. 4 and 5. For the download of this figure, see <http://color.li.tu-berlin.de/fen0/fen00-3n.pdf>

Colour-line element of *Stiles*

(1946) with „colour values” L_P , M_D , S_T

three separate colour-response functions

$$F(L_P) = i \ln(1 + 9 L_P)$$

$$F(M_D) = j \ln(1 + 9 M_D)$$

$$F(S_T) = k \ln(1 + 9 S_T)$$

Taylor-derivations:

$$\begin{aligned} \Delta F(L_P, M_D, S_T) &= \frac{dF}{dL_P} \Delta L_P + \frac{dF}{dM_D} \Delta M_D + \frac{dF}{dS_T} \Delta S_T \\ &= \frac{9i}{1+9L_P} \Delta L_P + \frac{9j}{1+9M_D} \Delta M_D + \frac{9k}{1+9S_T} \Delta S_T \end{aligned}$$

een31-1n

Fig. 7 Logarithmic colour line element of *Stiles* (1946) with derivation and integration.

The Report CIE 15 *Colourimetry* assumes response functions of the three receptors (L , M , S) or (P =Protanop, D =Deuteranop, T =Tritanop). For example *Stiles* assumes that the lightness L^* is a logarithmic function of the luminance L . Further research is needed in this area. In Fig 7 a black threshold is assumed with the value “1”.

For the download of this figure, see <http://color.li.tu-berlin.de/een3/een31-1n.pdf>

3. Scaling of display colours between Black N, Grey U, White W, and Peak White P2

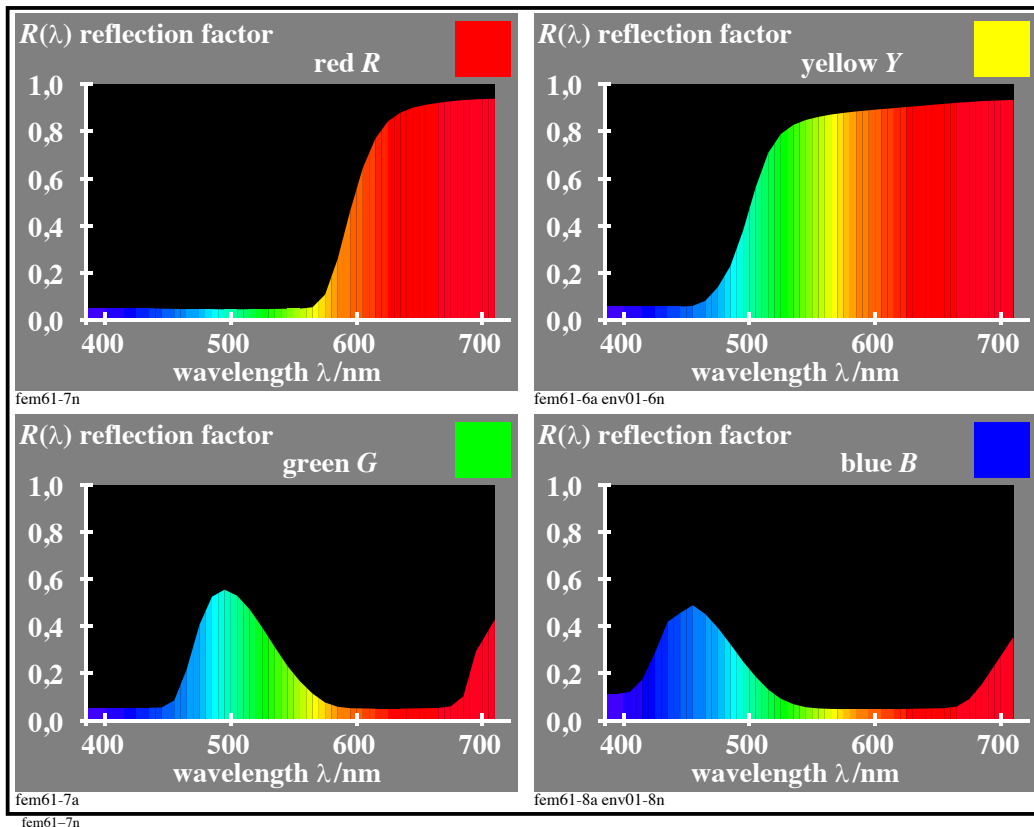


Fig. 8 Reflection curves of the CIE-test colours RYGB according to CIE 13.3

The spectral reflection of all matte surface colours is between near 3,6% for Black N, 18% for Grey U and 90% for White W. For displays the proportional values 4, 20, and 100% are used. The *factor 5* between 4 and 20, 20 and 100, and similar in ISO 22028-5 [3] between 200 and 1000 cd/m^2 lead to a *logarithmic* scaling function, see Fig. 9.

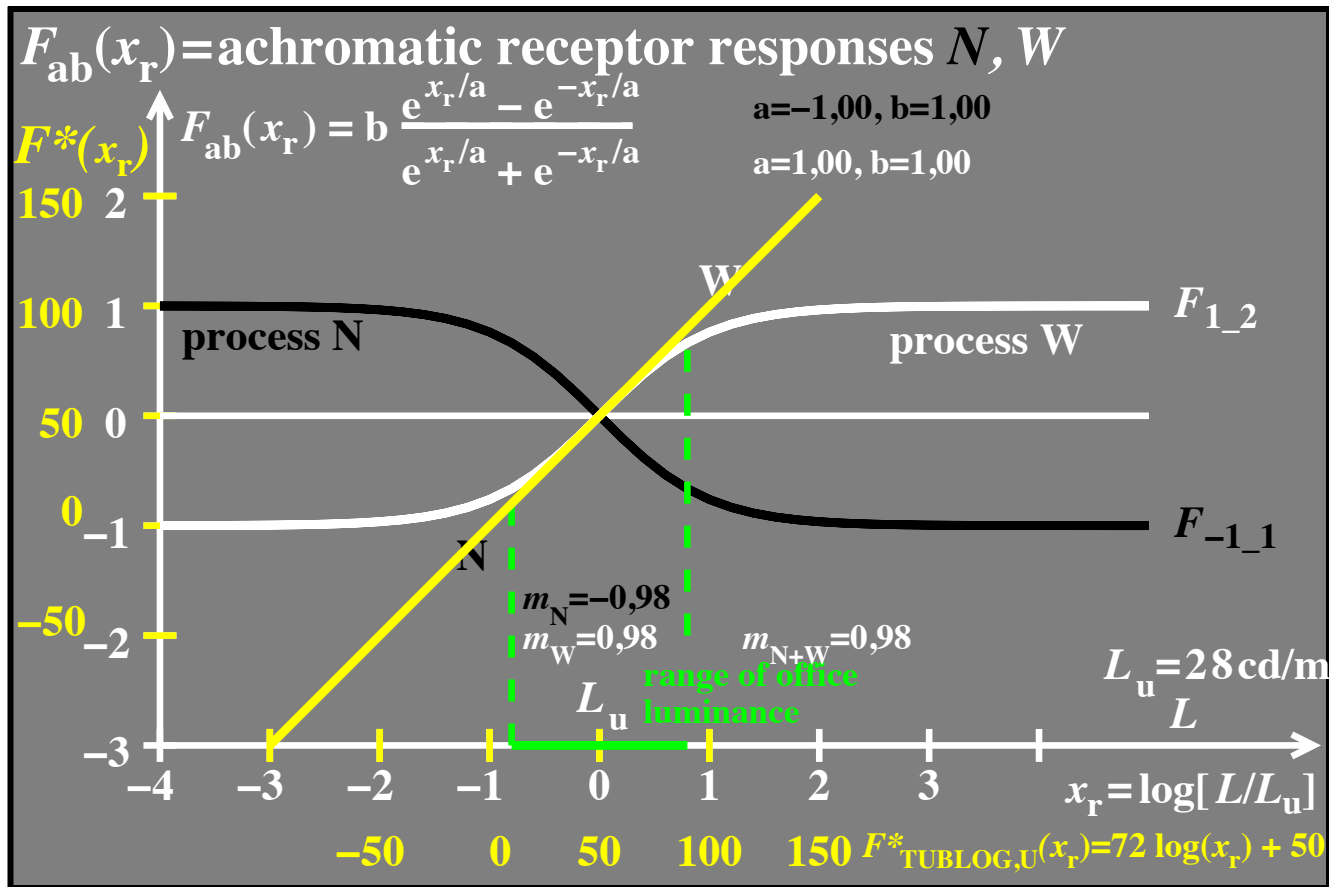
For the download of this figure, see <http://color.li.tu-berlin.de/fem6/fem61-7n.pdf>

Colourimetric scaling of achromatic colours between peak white and black. Relations between tristimulus value Y , luminance L , and lightness L^* of ISO-standards						
Colour (light or paper)	tristimulus values	HDR display luminance	relative luminance		CIELAB _W lightness	TUBLOG _U lightness
Contrast W:N (25:1=100:4)	Y ($5^{0,5}=2,24$)	L [cd/m^2]	L_{rU} = L/L_U	L_{rW} = L/L_W	$L^*_{\text{CIELAB}W}$ = $c_W L_{rW}^{1/3} - 16$	$L^*_{\text{TUBLOG}U}$ = $t_U \log(L_{rU}) + 50$
White P2 (light)	500 = $20 \cdot 25$	1000 = $40 \cdot 25$	25	5,00	$182=50+132$ = $c(5,00)^{1/3}-16$	$150=50+102$ = $t \log(25,00)+50$
White W (fluorescent paper)	100 = $20 \cdot 5$	200 = $40 \cdot 5$	5	1,00	$100=50+50$ = $c(1,00)^{1/3}-16$	$100=50+52$ = $t \log(5,00)+50$
light Grey H (paper)	44,8 = $20 \cdot 2,24$	89,6 = $40 \cdot 2,24$	2,24	0,45	$72=50+22$ = $c(0,45)^{1/3}-16$	$75=50+27$ = $t \log(2,24)+50$
Grey U (paper)	20	40 $40 \cdot 1$	1	0,20	$51=50+1$ = $c(0,20)^{1/3}-16$	$50=50+2$ = $t \log(1,00)+50$
dark Grey D (paper)	8,9 = $20/2,24$	17,8 $40/2,24$	0,45	0,09	$35=50-14$ = $c(0,09)^{1/3}-16$	$24=50-23$ = $t \log(0,45)+50$
Black N (paper)	4 = $20/5$	8 $40/5$	0,20	0,04	$23=50-26$ = $c(0,04)^{1/3}-16$	$0=50-48$ = $t \log(0,20)+50$
Black P2 (glossy paper)	1,9 = $20/11,2$	3,6 $40/11,2$	0,09	0,022	$14=50-35$ = $c(0,02)^{1/3}-16$	$-24=50-72$ = $t \log(0,09)+50$

It is valid: CIELAB_W: $c_W=c=116$, TUBLOG_U: $t_U=t=50/\log(5)=72$

feo90-7n

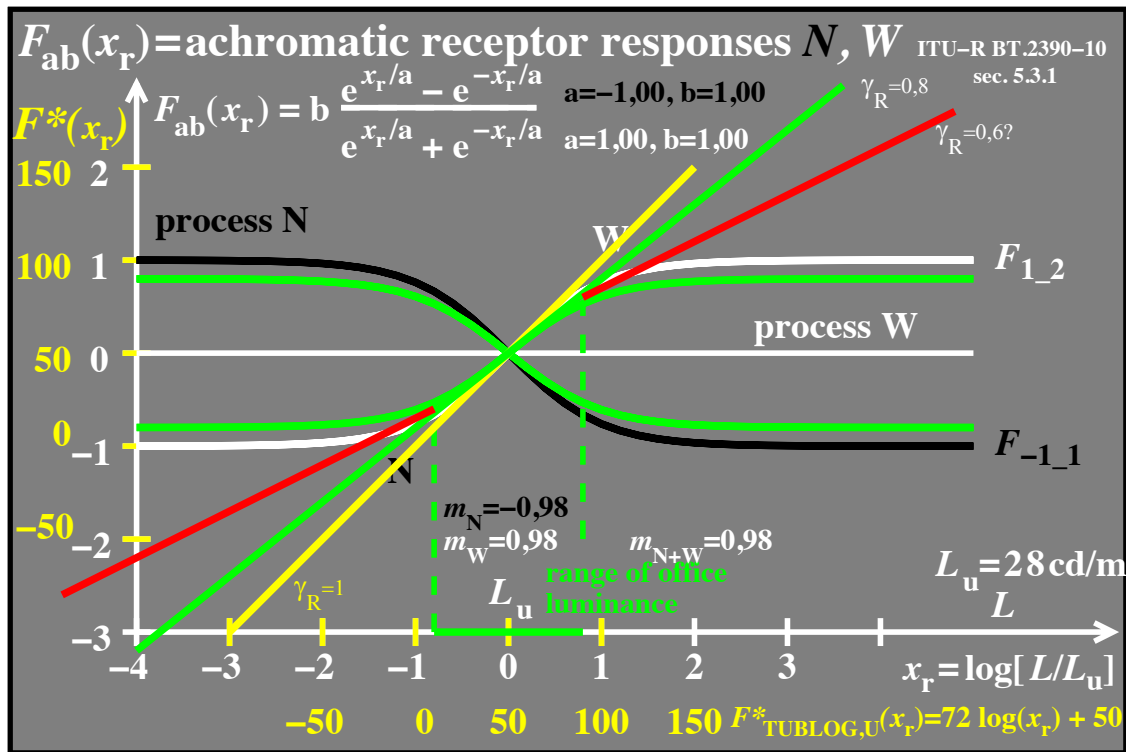
Fig. 9 Lightness-scaling functions $L^*_{\text{CIELAB},W}$ and $L^*_{\text{TUBLOG},U}$ as function of $\log(L_{ru})$
The *logarithmic* lightness-scaling function $L^*_{\text{TUBLOG},U}$ approximates the lightness $L^*_{\text{CIELAB},W}$ in the range between Black N and White W. The values between mean grey and white are very similar. There are several advantages of $L^*_{\text{TUBLOG},U}$. The value difference is 50 for the three series N-U, U-W, and W-P2. The colours W and P2 determine the HDR headroom. For the download of this figure, see <http://color.li.tu-berlin.de/feo9/feo90-7n.pdf>



few30-1a

Fig. 10 Physiological and inverse response $F_{ab}(x_r)$, and lightness $L^*_{TUBLOG,U} = F^*(x_r)$
 In the range of office luminance the lightness $L^*_{TUBLOG,U} = F^*(x_r)$ (yellow) is approximately equal to the *hyperbolic* function $F_{ab}(x_r)$ (white). The lightness on the y-axis produces the a straight line as function of the *logarithmic relative* luminance $x_r = \log(L/L_u)$.

For the download of this figure, see <http://color.li.tu-berlin.de/few3/few30-1a.pdf>



few40-1a

Fig. 11 Functions physiological response $F_{ab}(x_r)$ and lightness $L^*_{TUBLOG,U} = F^*(x_r)$.
 In applications the yellow line approximates the white response $F_{ab}(x_r)$, and the green one the lower contrast range of 80% similar to ISO 9241-306. For 80% contrast the ITU uses the slope of the L^* -function IECsRGB at W for extrapolation. At $x_r=2$ (P2) the 3 lightness values 150 (yellow), 130 (green), and 110 (red) of $F^*(x_r)$ deviate from the lightness value $F_{ab}(x_r)$ 90 (green). Therefore about 20% HDR-head room (P2-W) seems appropriate. For the download of this figure, see <http://color.li.tu-berlin.de/few4/few40-1a.pdf>

4. Test charts for scaling of colour and grey series with 3, 5, 9, 17, and 33 steps

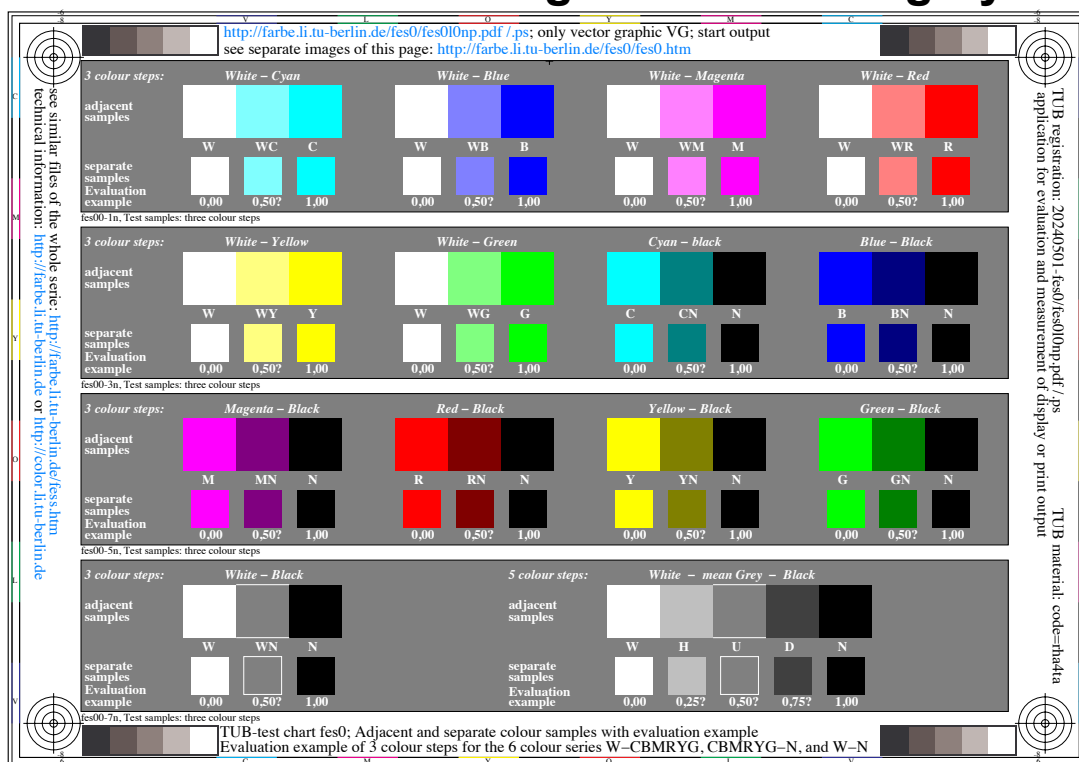


Fig.12 Chromatic 3 step samples with equally spaced file data $0 \leq rgb^* \leq 1$

The main series between White W, Grey U, and Black N are shown. The file data $0 \leq rgb^* \leq 1$ vary for the different colours. One or two values may be 0,5 and the others 0,0 or 1,0. For D the values are 0,25 and for H 0,75. The visual result for the grey series is similar to the chromatic series. The threshold for the separate samples may be by a factor 3 less compared to the adjacent samples, but the *relative* spacing is usually similar. For the download of this figure, see <http://color.li.tu-berlin.de/fes0/fes0f0np.pdf>

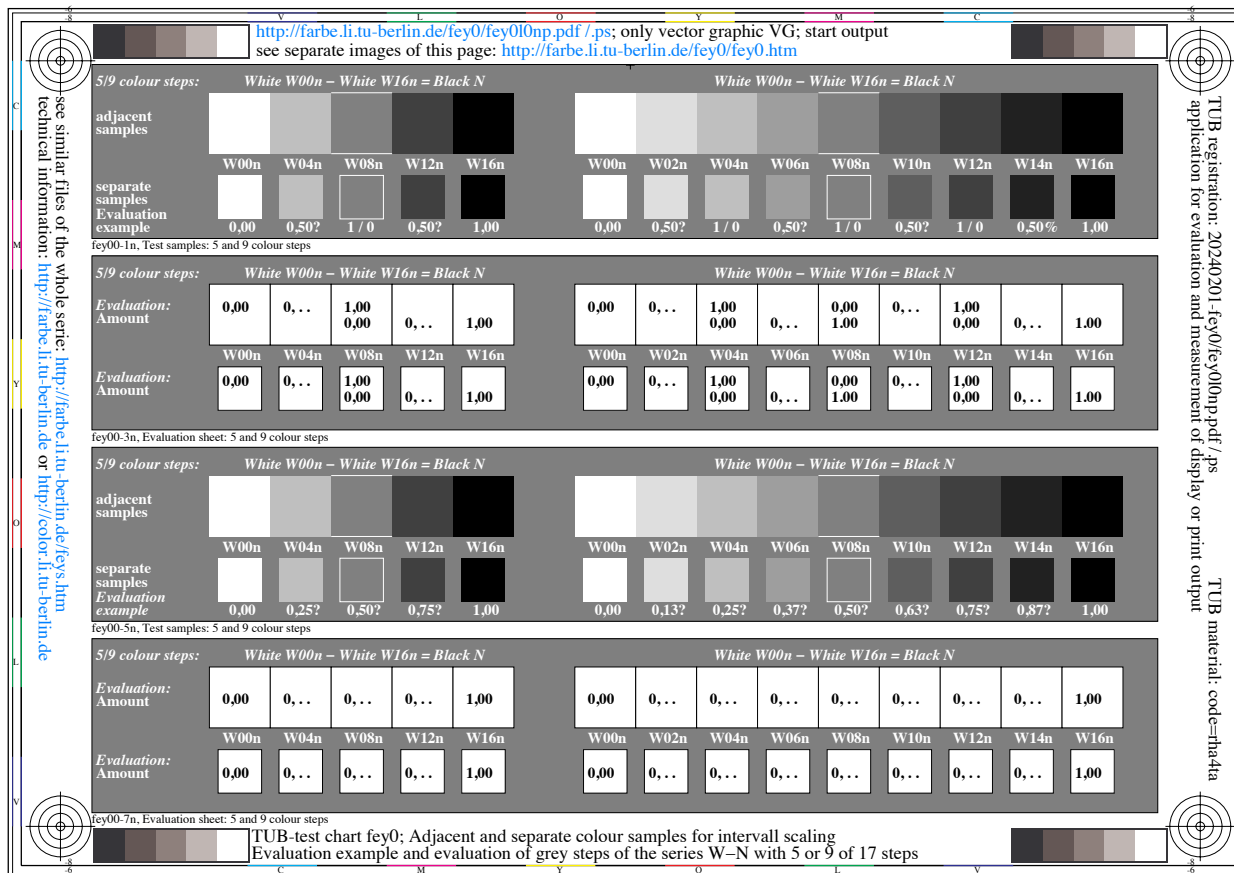


Fig.13 Five and 9 step grey scales with equally spaced file data $0 \leq rgb^* \leq 1$

It is expected according to IEC 61966-2-1 (sRGB-colour space) that the output is equally spaced. *Visual* interval scaling can produce the *visual gamma* values. Application of the inverse gamma produces the intended equal visual display scaling. A good result is also possible by a gamma change with the software *GraphicConverter*, see *Richter* [11].

For the download of this figure, see <http://color.li.tu-berlin.de/FeY0/Fey0l0np.pdf>

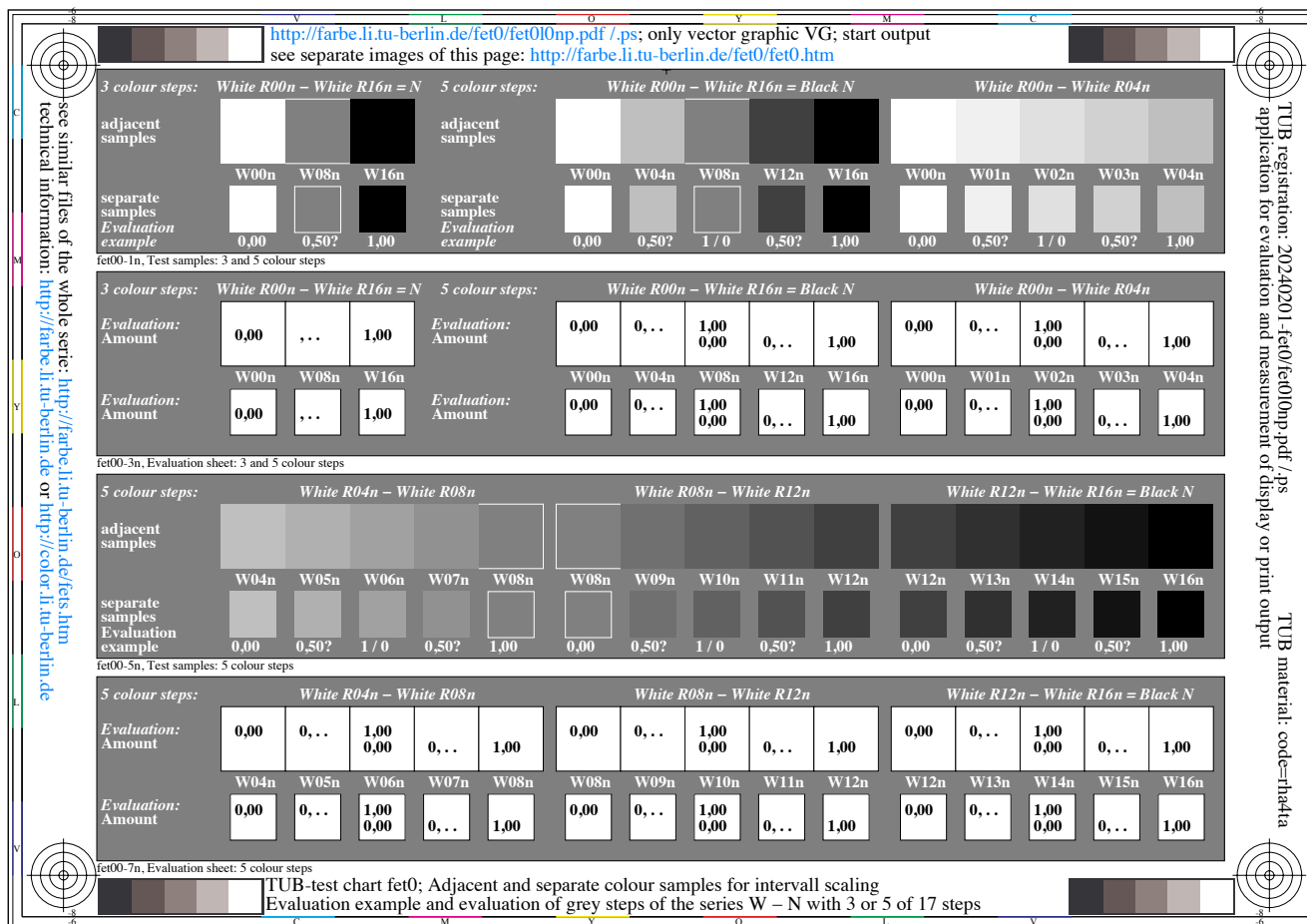


Fig. 14 Five and 17 step grey scale with equally spaced file data $0 \leq rgb^* \leq 1$
 The display output is usually not equally spaced. The visual interval scaling depends on *local properties*: ambient light reflection, increasing stray light with the observer age, actual display gamma, luminance range, for example with or without HDR headroom.
 For the download of this figure, see <http://color.li.tu-berlin.de/fet0/fet0lonp.pdf>

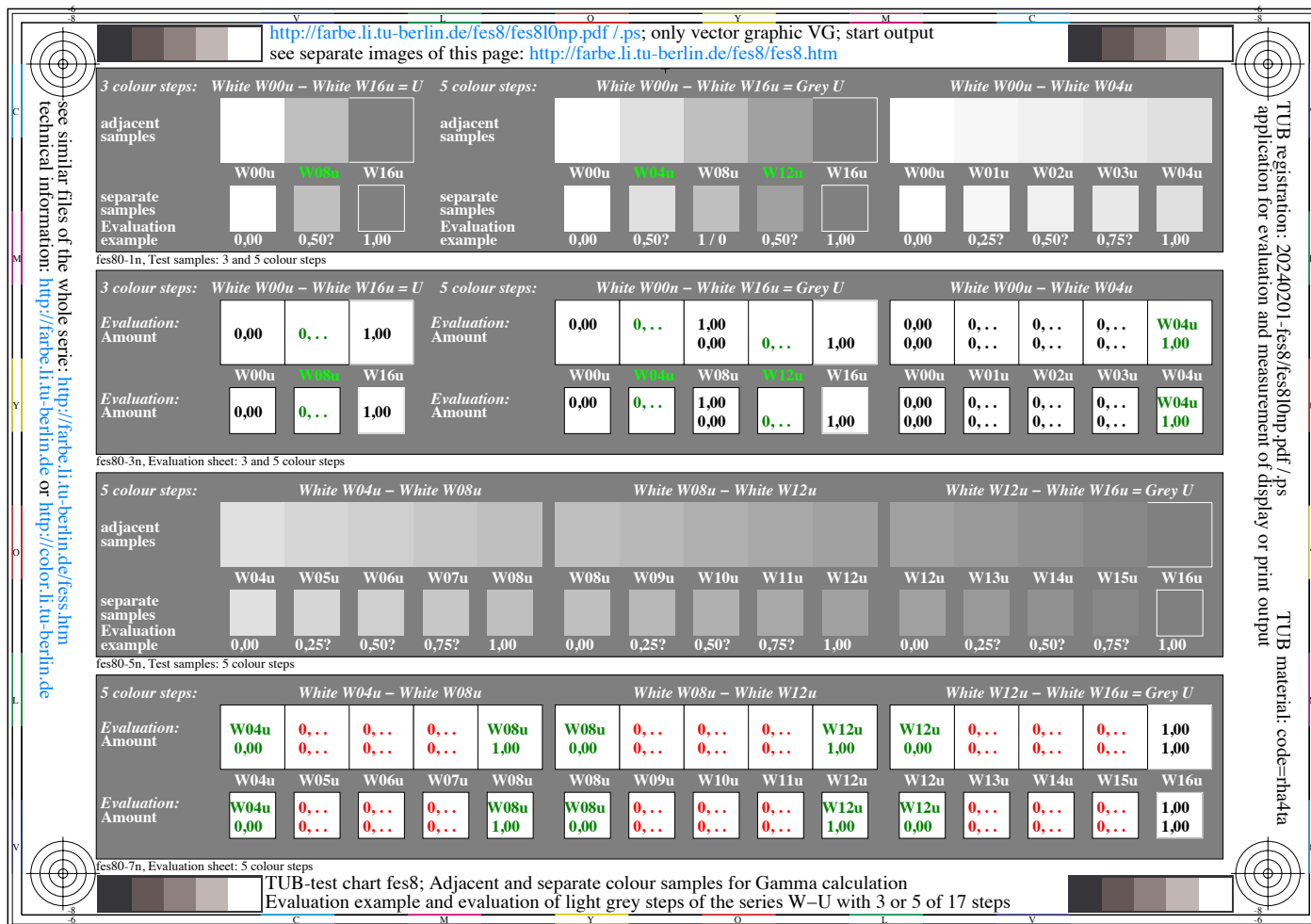


Fig. 15 Three, 5 and 17 step *light* grey scale with equally spaced data $0 \leq rgb^* \leq 1$
 Only lighter grey colours between White W and mean Grey U are included. The following
 Fig. 16 shows the *darker* grey series between mean Grey U and Black N.
 For the download of this figure, see <http://color.li.tu-berlin.de/fes8/fes810np.pdf>

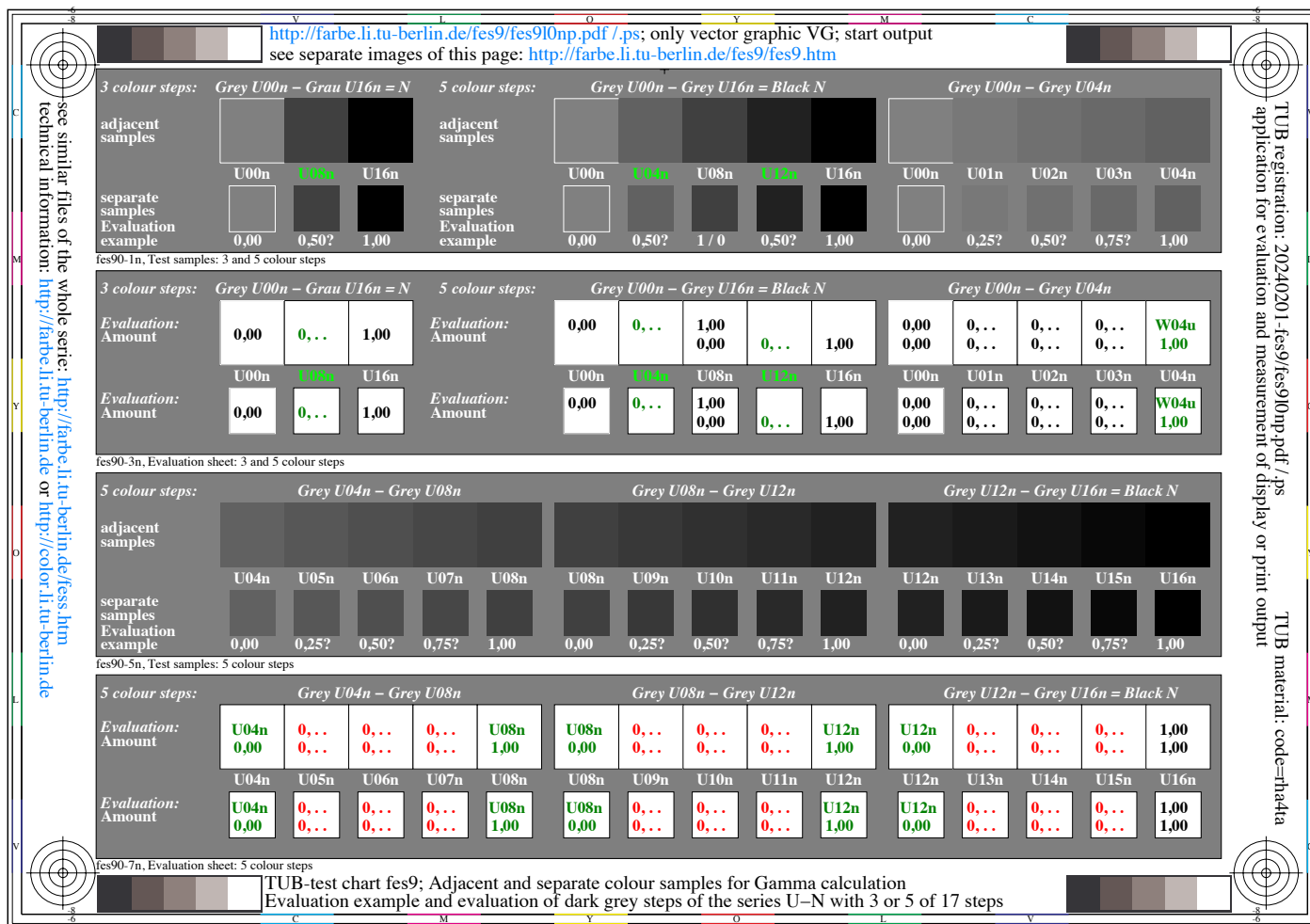


Fig. 16 Three, 5 and 17 step dark grey scale with equally spaced data $0 \leq rgb^* \leq 1$
 Only darker grey colours between mean Grey U and Black N are included. The preceding Fig. 15 shows the lighter grey series between White W and mean Grey U.
 For the download of this figure, see <http://color.li.tu-berlin.de/fes9/fes910np.pdf>

Colourimetric scaling of achromatic colours between peak white and black. Relations between tristimulus value Y , luminance L , and lightness L^* of ISO-standards						
Colour (light or paper)	tristimulus values	HDR display luminance	relative luminance		CIELAB _W lightness	TUBLOG _U lightness
Contrast W:N (25:1=100:4)	Y ($5^{0,5}=2,24$)	L [cd/m ²]	L_{rU} = L/L_U	L_{rW} = L/L_W	$L^*_{CIELABW}$ = $c_W L_{rW}^{1/3} - 16$	$L^*_{TUBLOGU}$ = $t_U \log(L_{rU}) + 50$
White P2=p00w (light)	500 =100*5	1000 =200*5	25 =5*5	5,00	182=50+132 = $c(5,00)^{1/3} - 16$	150=50+102 = $t \log(25,00) + 50$
White p02w (light)	334 =100*3,34	668 =200*3,34	16,7 =5*3,3	1,00	157=50+107 = $c(3,34)^{1/3} - 16$	137=50+89 = $t \log(16,70) + 50$
White p04w (light)	224 =100*2,24	448 =200*2,24	11,2 =5*2,2	0,45	135=50+85 = $c(2,24)^{1/3} - 16$	125=50+77 = $t \log(11,20) + 50$
White p06w (light)	150 100*1,50	300 =200*1,5	7,5 =5*1,5	0,20	120=50+70 = $c(1,62)^{1/3} - 16$	114=50+66 = $t \log(8,10) + 50$
White W=p08w (glossy paper)	100 =100/1	200 =200*1	5 =5*1	0,09	100=50+50 = $c(1,00)^{1/3} - 16$	100=50+52 = $t \log(5,00) + 50$
Grey U=w08n (paper)	20 =100/5	40 =200/5	1 =5/5	0,04	51=50+1 = $c(0,20)^{1/3} - 16$	50=50+2 = $t \log(1,00) + 50$
Black N=w16n (glossy paper)	4 =100/25	8 =200/25	0,2 =5/25	0,022	23=50-26 = $c(0,04)^{1/3} - 16$	0=50-48 = $t \log(0,20) + 50$
It is valid: CIELAB _W : $c_W=c=116$, TUBLOG _U : $t_U=t=50/\log(5)=72$						

few00-3n

Fig. 17 CIE tristimulus value, luminance and lightness for the HDR-headroom P2-W. For three parts N-U, U-W, W-P2 the minimum and maximum luminance values 8-40, 40-200, and 200-1000 differ by a factor 5. A logarithmic lightness function $L^*_{TUBLOG,U}$ produces for all three parts the equal lightness range $\Delta L^*=50$. The HDR room is 50% instead of 82% percent for CIELAB or similar for IECsRGB. *Scaling experiments* with the TUB-test charts in Fig. 12 to 16 can determine the *visual* headroom in real applications. For the download of this figure, see <http://color.li.tu-berlin.de/few0/few0-3n.pdf>

5. Definition and output of *pdf-test* charts with HDR-*rgb** values in two use cases

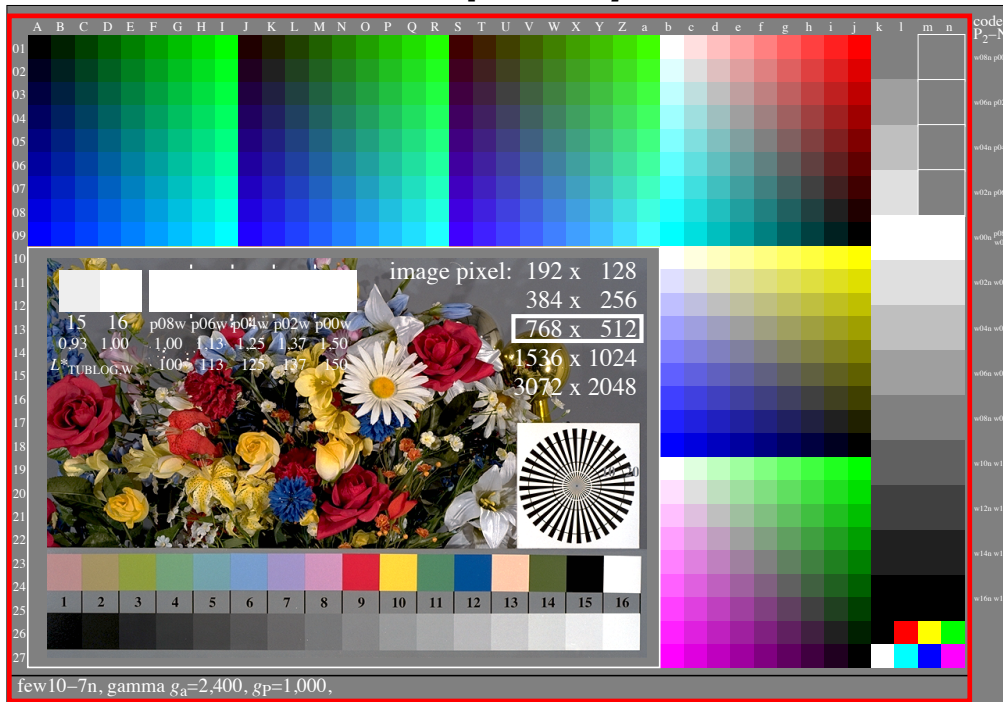


Fig. 18: Output of test chart with flower image of [1] on SDR display with white W . The output of the *pdf* file of Fig. 15 produces 5 white equal samples in the range W - $P2$. In the *pdf* file the values $0 \leq \text{rgb}^* \leq 1,5$ are proportional to the lightness values $0 \leq L^*_{\text{TUBLOG},W} \leq 150$. However, all values $\text{rgb}^* \geq 1$ are clipped to the value 1 by default. However, for the whole luminance range $P2$ - N all rgb^* values of the lightness $L^*_{\text{TUBLOG},W}$ up to 150 can be included in the *pdf*-file, if they are divided by the factor 1,5, see Fig. 19. For the download of this figure, see <http://color.li.tu-berlin.de/few1/few10-7n.pdf>

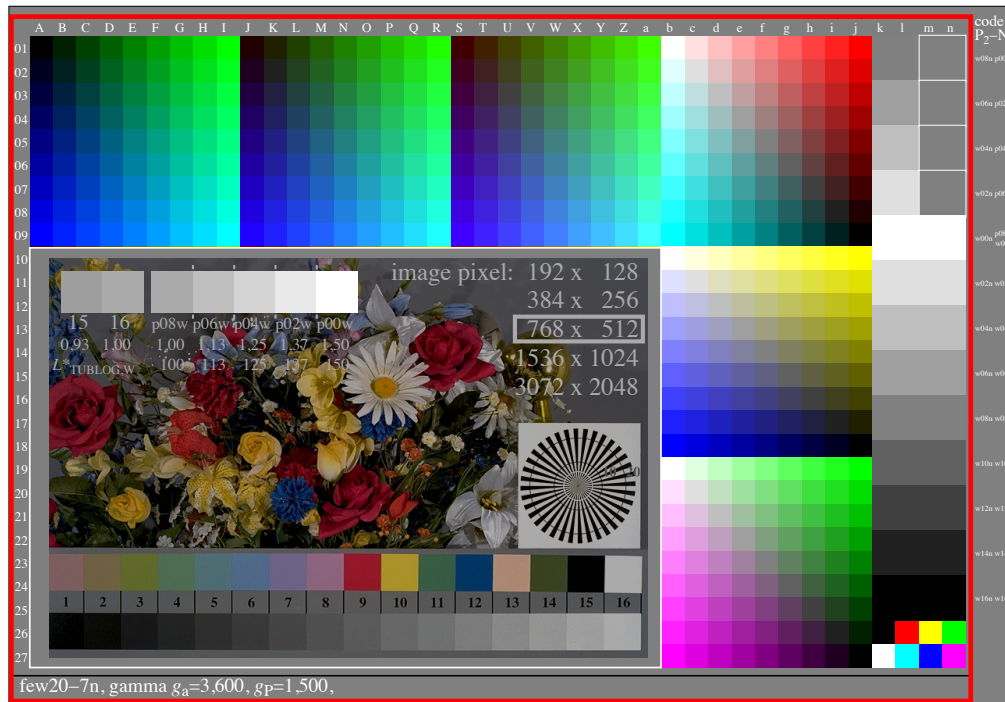


Fig. 19: Output of test chart and flower image of [1] on SDR display with white W . The standard flower motif according to ISO 9241-306 looks darker. The White $W=w00n=p08w$ is equal to the surface colour white in luminance and lightness of the 16 steps. One can study two cases. First case: the luminance of the display may be increased by a factor 5 from 200 to 1000 cd/m^2 . Then the luminance of the flower motif is equal to Fig. 18. However, the lightness $L^*_{\text{TULOG},W}$ of the 5 steps in the range $W-P2$ is equally spaced. Second case: One can input the image of Fig. 18 by *Photoshop* and edit the 5 white steps. The luminance can be made identical, or the lightness equally spaced. For the download of this figure, see <http://color.li.tu-berlin.de/few2/few20-7n.pdf>

6. Discussion

6.1 Relative colourimetric display output of luminance and chromaticity

The colourimetric display reproduction of the luminance and chromaticity of the original is a main goal of photography. Based on the similar properties of vision for 100 and 1000 cd/m^2 , see Fig. 4 and 5, a *relative* colourimetric reproduction of the luminance is sufficient. The chromaticity does not change with the luminance.

Therefore an original with the mean luminance 100 cd/m^2 may be reproduced by a display output with the mean luminance 1000 cd/m^2 or vice versa. The change of the contrast ($L/\Delta L$) by a factor 1,2 is small compared to the change of the luminance by the factor 10 and may be obvious in usual applications.

In the ergonomic office the white display luminance shall be 142 cd/m^2 . For the reasons see ISO 9241-306. For example the Peak White luminance P2 1000 cd/m^2 is not allowed at display work stations in offices.

This paper has not discussed the diffuse Black N and any Peak Black p2 (mall letter p) with lower luminance compared to N. Fig. 4 and 5 indicates that for *full luminance adaptation* to the Peak White P2 the following visual changes may occur: W->U, U->N, N->p2. The peak black p2 may not appear more black compared to N.

Depending on the display luminance distribution, no *full luminance adaptation* occurs. This reduces usually the W-P2 headroom and the above contrast increase by a factor 1,2.

6.2 Physiological S-shaped receptor response $F_{ab}(x_r)$ and approximation $F^*(x_r)$

In this paper the S-shaped receptor-response function $F_{ab}(x_r)$ is used as basis for the TUB-colour vision model.

The derivation $F_{ab}(x_r)/dx$ of the physiological S-shaped response function $F_{ab}(x_r)$ produces the luminance contrast $(L/\Delta L)$. By the CIE this ratio is also called contrast sensitivity. The maximum is reached at the adaptation luminance, see shifts in Fig. 4 and 5. The integration of $(L/\Delta L) dx$ produces again the response function $F_{ab}(x_r)$ see Fig. 1 to 3.

Remark: If $L/\Delta L$ is constant according to the *Weber-Fechner law* this integration produces a function $G(x_r)$, which is straight line as function of x_r .

For example for office displays and *only in the application area* the S-shaped receptor-response function $F_{ab}(x_r)$ is approximated by the lightness function $L^*_{TUBLOG,U}=F^*(x_r)$. This function is a straight line $F(x_r)$ as function of $\log(x_r)$. Values and similar values of $L^*_{CIELAB,W}$ are given as function of x_r , see Fig. 9.

Outside this application area the continuous increase of the lightness L^* by all lightness formulae seems wrong. The exponential S-shaped limitation was already described by a function very similar to $\log(x_r)$, see Richter (1996) [12].

Remark: The lightness L^* cannot be calculated as integration of the luminance differences ΔL . This was assumed for example by the line element of *Stiles*, see Fig. 7.

6.3 Luminance and lightness for the SDR range, and the HDR headroom

Compared to the lightness L^*_{CIELAB} which is very similar to L^*_{IECsRGB} , the lightness $L^*_{\text{TUBLOG,U}}$ includes other basic properties of vision. For example the same lightness range $\Delta L^*=50$ is used between N-U, U-W, and W-P2 or between:

1. the visual diffuse Black N (8 cd/m²), and the visual mean Grey U (40 cd/m²),
2. the visual mean Grey U (40 cd/m²), and the visual diffuse White W (200 cd/m²),
3. the visual diffuse White W (200 cd/m²), and the visual Peak White $P2$ (1000 cd/m²).

Within the range N-W of office luminance according to ISO 9241-306, see Fig. 2, the lightness $L^*_{\text{TUBLOG,U}}$ roughly similar to the receptor response function $F_{\text{ab}}(x_r)$. Within the range U-W the lightness $L^*_{\text{TUBLOG,U}}$ is very similar compared to the lightness L^*_{CIELAB} .

In the HDR headroom between diffuse White W and Peak White $P2$ and above there is an hyperbolic limitation of the receptor response $F_{\text{ab}}(x_r)$. However $L^*_{\text{TUBLOG,U}}$ and L^*_{CIELAB} or L^*_{IECsRGB} increase continuously. The report ITU-R BT.2390-10, section 5.3.1 extends the lightness L^*_{IECsRGB} by a lightness function which also increases continuously.

Fig. 11 includes 3 straight lines: The yellow straight line approximates IECsRGB or ITU BT.709. The green straight line approximates a lower contrast range. The slope of the relative gamma $1/1,2=0,8$ is more appropriate in many use cases, and for example used in the above ITU document, and according to the ergonomic standard ISO 9241-306, and for the display output of *Apple* until 2007 (Gamma = $1/1,8$ instead of $1/2,4$). However the 3 straight lines fail to describe the S-shaped response for the range W-P2 and above.

6.4 Achromatic and chromatic test charts for scaling and visual gamma

Fig. 11 to 15 include test charts which allow to make further research with 3, 5, 9, 17 and 33 step colour scales. This may lead to an improved metric for usual display applications.

For example the evaluation of the 9 steps in Fig. 13 produce visual data in the range 0,00 to 1,00. This data series is called the visual Gamma. Application of the inverse Gamma produces 9 equally spaced grey steps. The data series can be produced for the range N-W and the full range N-P2 including the HDR headroom. Both experiments may define the amount of the HDR headroom for applications. The *relative* differences may be small for the adjacent and separated greys.

For example the contrast ($L/\Delta L$) changes with the reflection of the ambient light on the display surface. The contrast is reduced by the 3% standard display reflection according to ISO 9241-306. In this case the lightness range is reduced from 100 to 80 similar as in Fig. 11 by the white and green response functions $F_{ab}(x_r)$. Further the contrast is reduced by the stray light of the optical system of the display user which increases with age.

Reflection changes are excluded in ISO 22028-5 by a *cinema viewing condition* in a black room. Compared to ISO 9241-306:2009 and 2018 with 16 different reflections in real application this cinema condition may be called a *stone age condition* of image technology. The intended user benefit in real use cases of still images is not clear and need more explanations.

6.5 User wish for equal relative spacing as basis for the evaluation of image quality

It seems that a solution of user wishes for different applications and use cases is not possible by a *global* software. *Local* solutions are needed at the display work place with the user and for the user. Solutions are for example possible by gamma corrections with the software *GammaAdjuster* and *GraphicConverter*, As alternate the experimental gamma is determined *visually* and the inverse gamma can be applied. Applications are described by the TUB- test charts of Fig. 11 to 16, and in a paper of *Richter* (2024) [11].

ISO 22028-5 and most ITU documents exclude the two changes of contrast and colour spacing. Both change may be large and are based on more or less display reflections of the ambient light, and on the stray light changes of the display observer with age.

ISO/IEC 15775 defines a *regularity index* g^* which is 100, if an original equally spaced relative colour scale remains equally spaced in the reproduction, for example by a copier. The image quality is 100 if the 16 grey samples of the flower motif in Fig. 18 and 19 with the 16 values lightness $L^*_{\text{CIELAB}} = 20, 25, \dots, 90, 95$ remain *relatively* equally spaced in the reproduction.

Different ranges of lightness L^* are possible. However, if two steps of the series are not distinguishable, then the value of the regularity index g^* is zero. The image quality is reduced because usually important information is missing. Without ambient reflection the measured values may be $L^*_{\text{CIELAB}} = 0, 7, 13, \dots, 93, 100$. However the standard reflection

4% reduces the CIELAB range to 80% and may change g^* from 100 to 70. However a gamma correction may produce again a value $g^*=95$.

ISO 22028-5 intends as default output a *pleasant* image output. However a definition is missing in ISO 22028-5.

The user benefit of the ISO 22028-5 may increase, if the colourimetric output of relative luminance and chromaticity is defined as default output.

The image quality shall be specified by the regularity index g^* of ISO/IEC 15775, Annex G. It must be considered that the image quality reduces for example with the ambient reflection. However, the application of a colourimetric or visual gamma will increase again the regularity index g^* which specifies the *image quality*.

These changes show that the relative luminance of the scene has to be modified by some amount for the display output to reach a high *image quality*.

Different output modifications, for example lighter or darker, and more or less chromatic may be specified for a *pleasant image output*. Software tools may allow these modifications.

7. Conclusions

The colourimetric display reproduction of the luminance and chromaticity of the original is a main goal of photography. Usually a *relative* colourimetric reproduction of the luminance is sufficient. The chromaticity does not change with the luminance.

A further main goal is *equal relative spacing* compared to the original. Otherwise important information is missing. The *regularity index* g^* according to ISO/IEC 15775, Annex G, is proposed to describe the image quality.

In this paper the S-shaped receptor-response function $F_{ab}(x_r)$ is used as basis for the TUB-colour vision model. The derivation $F_{ab}(x_r)/dx$ of the physiological S-shaped response function $F_{ab}(x_r)$ produces the luminance contrast $(L/\Delta L)$. The integration of $(L/\Delta L) dx$ produces again the response function $F_{ab}(x_r)$ see Fig. 1 to 3.

Between the display White W and the Peak White P2 and above, the lightness functions $L^*_{TUBLOG,U}$ and L^*_{CIELAB} or $L^*_{IECsRGB}$ increase continuously. However the S-shaped receptor-response function $F_{ab}(x_r)$ is limited by a hyperbolic function. The HDR headroom may be visually 20% by a visually defined hyperbolic function. Therefore this increase may be very limited compared to 82% as calculated by CIELAB, see Fig. 9.

Fig. 17 uses as example the TUB- test charts of Fig. 11 to 16 for scaling. For encoding of the lightness $L^*_{TUBLOG,U}$ in the range $0 \leq L^* \leq 150$ may be considered.

These values of L^* can be included in *pdf* files and images of this paper. One can import the pdf files with *Photoshop* and edit the files for equal visual scaling. This scaling depends for example on the ambient reflection and the observer.

Remark: ISO 22028-5 seems does not consider *pdf* files and the transfer of the SDR range to the HDR range and vice versa by *pdf* files.

For a wide application the file formats of ISO 22028-5 need to have a clear connection to the pdf files and images of the SDR range

8. Literature

[1] ISO 9241-306:2019, Ergonomics of human-system interaction - Part 306: Field assessment methods for electronic visual displays, see for download of the test charts with user question for an ergonomic output on displays, <https://standards.iso.org/iso/9241/306/ed-2/index.html>

[2] ISO/IEC 15775/ed-2:2022, Information Technology – Office Equipment –Method of Specifying image reproduction on colour copying machines and multifunctional devices with copying modes by printed test charts, see for download of test charts with user questions *for sustainable copiers*. The test charts of [1] and [2] are similar, see <https://standards.iso.org/iso-iec/15775/ed-2/en>

- [3] ISO/TS 22028-5:2023 Photography and graphic technology - Extended colour encodings for digital image storage, manipulation and interchange - Part 5: High dynamic range and wide colour gamut encoding for still images (HDR/WCG)
- [4] Richter, Klaus (2013), Output Linearization Methods for Displays, Printers, and Offset Print (63 pages, 1,4 MB, Format A4), see http://farbe.li.tu-berlin.de/OUTLIN13_02.PDF
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- [6] IEC 61966-2-1, Multimedia systems and equipment - Colour measurement and management - Part 2-1: Colour management – Default RGB colour space - sRGB.
- [7] ISO 8995-1:2002 Lighting at work place – Part 1: Indoor
- [8] *Richter, Klaus (2019)*, Colorimetric scan, display, and print for archiving based on the ergonomic International Standard ISO 9241-306:2018 at work places , *Proc. IS&T Archiving 2019*, pp 111-112, see for free pdf download <https://doi.org/10.2352/issn.2168-3204.2019.1.0.25>
- [9] *Richter, Klaus (2020)*, see different papers especially since 2020 at the link <http://farbe.li.tu-berlin.de/XY91FEN.html>
- [10] DIN 33872-1 to 6:2010, Information technology - Office machines - Method of specifying colour reproduction with YES/NO criteria - Part 1: Classification, terms and principles, only on CD-ROM and following Parts 2 to 6, see

<http://farbe.li.tu-berlin.de/A/33872E.html>

[11] *Richter, Klaus* (2024) Frame File Colour Management (FF_CM) for the ergonomic display output of SDR and HDR-*rgb**-images on SDR and HDR displays, see for free pdf download <http://farbe.li.tu-berlin.de/disgam24e.pdf>

[12] *Richter, Klaus* (1996), Computer graphic and colourimetry – Colour systems, *PostScript* and device independent CIE colours (in German), 228 pages, see at least figures of scaling and response functions on pages 104 to 127, see (8,7 MB)

<http://farbe.li.tu-berlin.de/BUCHAF.PDF>

Annex – Copyright

For free copyright see:

<http://farbe.li.tu-berlin.de/CEV1/CEV10-3N.PDF>

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