Goals, Problems and Realization of a Colour Loop: ISO-Colour File – Print – Scan – back to ISO-Colour File

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Introduction in the colour information technology

The colour information technology uses in files *rgb*-colour values. In the *sRGB*-colour space according to IEC 61966-2-1 the *rgb*-colour values are in the colour-value range between 0 and 1. In the standard 8-bit range the *rgb*-colour-values are between 0 and 255.

According to IEC 61966-2-1 the visual lightness L^* should be equally spaced in the display output. For example for the 9 grey steps with the *rgb* values between (0, 0, 0) and (1, 1, 1) the visual lightness L^* is equally spaced in the range $0 <= L^* <= 100$. In this case the lightness L^* increases linearly as a function of the *rgb*-colour values. In ergonomics the *rgb*-colour values are specified by a star (*) according to ISO 9241-306. This decribes the visual metric of the *rgb**-values. For example for the 16 grey steps the *rgb**-colour values $r^*=g^*=b^*=i/15$ change between i=0 and 15.

Achromatic colours, intermediate colours	**Chromatic colours, elementary colours**	**chromatic colours, device colours**
five achromatic colours:	**"*neither-nor*"*-colours***	***TV, print (PR), photo (PH)***
N black (French noir)	*four elementary (e) colours:*	*six device (d) colours:*
D dark grey	$R = R_e$ red *neither yellowish nor bluish*	$C = C_d$ cyan blue (cyan)
Z central grey		$M = M_d$ magenta red (magenta)
H light grey	$G = G_e$ green *neither yellowish nor bluish*	$Y = Y_d$ yellow
W white	$B = B_e$ blue *neither greenish nor reddish*	$O = R_d$ orange red (red)
two intermediate colours:		$L = G_d$ leaf green (green)
C_e = G50B$_e$ *blue-green*	$J = Y_e$ yellow (French jaune) *neither greenish nor reddish*	$V = B_d$ violet blue (blue)
M_e = B50R$_e$ *blue-red*		

AEY20−3N

Figure 1: Visual criteria for elementary colours red R_e, yellow Y_e, green G_e, and blue B_e.

Figure 1 shows the visual criteria for the definition of the elementary colours. The ergonomic standard ISO 9241-306 requires a linear increase in relative lightness L^* and chroma C^*_{ab} for 9 red steps with *rgb** values between (0, 0, 0) and (1, 0, 0). The ergonomic standard 9241-306 further requires the output of the elementary Red R_e for the *rgb**-values (1, 0, 0). The elementary colours are visually defined in Figure 1.

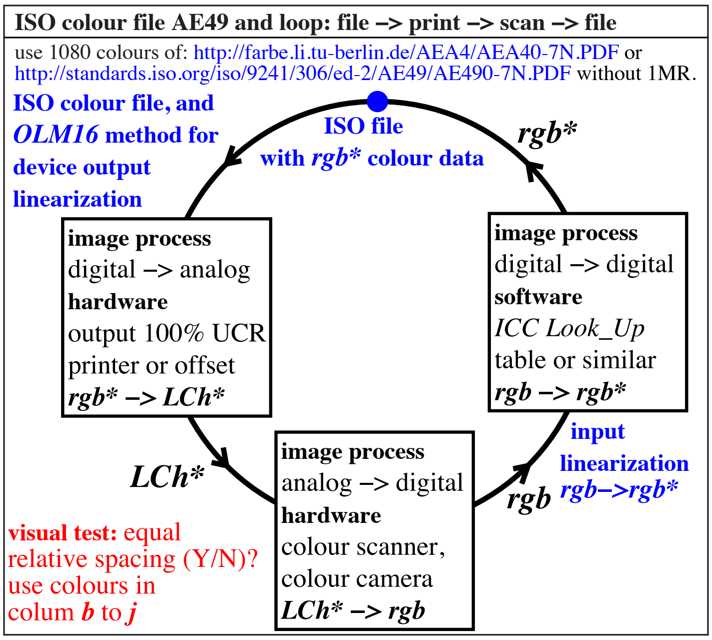

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Figure 2: Colour loop: ISO-colour file – print - scan and back to the ISO-colour file
Figure 2 shows a colour loop. The output of an ISO-colour file to a printer and the subsequent scan of the printer-output results in a file with approximately the same *rgb**-colour values as in the ISO-startup file. The ergonomic standard 9241-306 further requires the output of elementary Red R_e for the *rgb**-values (1, 0, 0), for example on any display or in offset printing or with any printer.

The device measurement data $rgb_d = rgb$ are often specified by an index d (d=device). For example they are called rgb_d for a colour space of any device. If they are changed to produce an equally spaced output on the same or another device (d) they are called rgb_{dd}. If they are changed to produce the *device-independent* elementary (e) hue output on the same or another device they are called rgb_{de}. If a misunterpretation is excluded in the text, then the first index d can be deleted. This leads instead of the notations rgb_d, rgb_{dd}, and rgb_{de} to the notations *rgb*, rgb_d, and rgb_e.

The CIE-lightness L^* is an exponential function of the CIE tristumulus value Y. Similar the *rgb**-colour values are nonlinear functions of the rgb_d values of the device (d). The transfer is usually different for any device. For different display reflections the ergonomic r^*-colour value is approximately *only* an exponential function of the r_d-colour value of the device. It is valid

$$r^* = (r_d)^n \qquad [1]$$

with for example n=1, 0,75 or 0,50. For g_d and b_d similar equations apply.

Figure 2 uses the two notations *rgb* and *rgb**. The notation *rgb* is identical to rgb_d.
The data in the ISO-file are called *rgb**. The use of the notation *rgb** for the ISO-file data indicates the ergonomic intention to produce *equally spaced* output series according to ISO 9241-306. If a device manufacturer produces an *equally spaced output* by a change of the file data rgb_d in the range 0 to 1 to new data rgb_{dd} in the same range, then the requirement of ISO 9241-306 is fulfilled.

Usually the device manufacturers can produce the equally spaced output only for a special standard condition. For example for the display output in a dark room without a reflection of the ambient light on a display. However, for the *different* reflections of the ambient light *different* transfers rgb_d to rgb_{dd} or rgb_{de} are required to make the output *equally spaced*. Therefore ISO 9242-306 defines eight ISO-contrast steps for workplaces.

The users appreciate, if the manufacturers produce eight device drivers or profiles. Then the users can choose the most appropriate profile from a profile list by a click.

***rgb** input and *LCh** output of *Offset* colours**

Color	rgb*	LCh*
R_e elementary red	**1 0 0**	47, 74, **26**
Y_e elementary yellow	**1 1 0**	86, 88, **92**
G_e elementary green	**0 1 0**	53, 57, **162**
B_e elementary blue	**0 0 1**	42, 45, **272**
N black	**0 0 0**	18, 0, 0
W white	**1 1 1**	95, 0, 0

Data according to test chart DIN 33872-2, p.9-12
http://farbe.li.tu-berlin.de/A/33872E.html
Elementary-hue angles of CIE R1-47, see
http://web.archive.org/web/20160304130704/http://files.cie.co.at/526.pdf

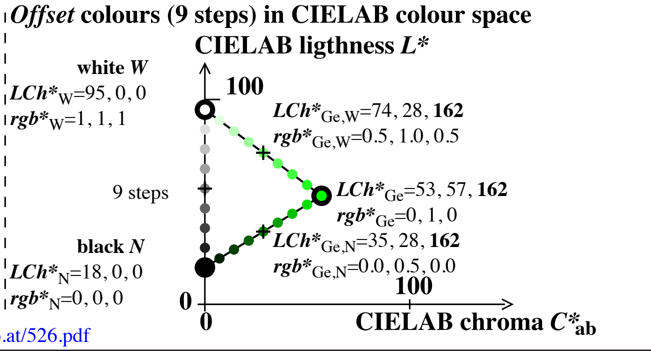

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Figure 3: Elementary colours with *rgb and CIELAB-*LCh** colour values**
The nine colour steps between Black *N* and White *W*, as well as Black *N* and Green G_e, as well as White *W* and Green G_e are marked by circles. The linear relationships between the *rgb** and *LCh**-colour values are shown in the triangles. In addition the *rgb**-colour values for the elementary hue and the corresponding CIELAB *LCh**-values are given for the standard offset-colour space.

For the display and print output various strategies are required to achieve the ergonomic requirements.

The print output works with the basic colours $cmyk_d$. Therefore a transfer of the rgb_d- into the $cmyk_d$-colour values is necessary.

The display output works with the basic colours rgb_d. For the equally spaced output the rgb_d-colour values must be changed according to the reflection of the ambient light on the display. Already 2,5% reflection according to ISO 9241-306 of the ambient light on the display relative to the white display reduces the colour space to approximately 50%.

In Figure 3 the CIELAB-lightness range *L** between 0 and 100 is reduced to the range between 18 and 95. This reduction to approximately 75% is also valid for the CIELAB chroma C*ab. Therefore the green colour area in Figure 3 shrinks to approximately 50%. Therefore also the colour space is reduced to approximately 50% according to ISO/IEC 15775.

For the colorimetric and at the same time the ergonomic steering of the display and print output, and the scan input ISO/IEC 15775, ISO/IEC TR 24705 and ISO 9241-306 define digital and analog test charts with equally spaced colour series.

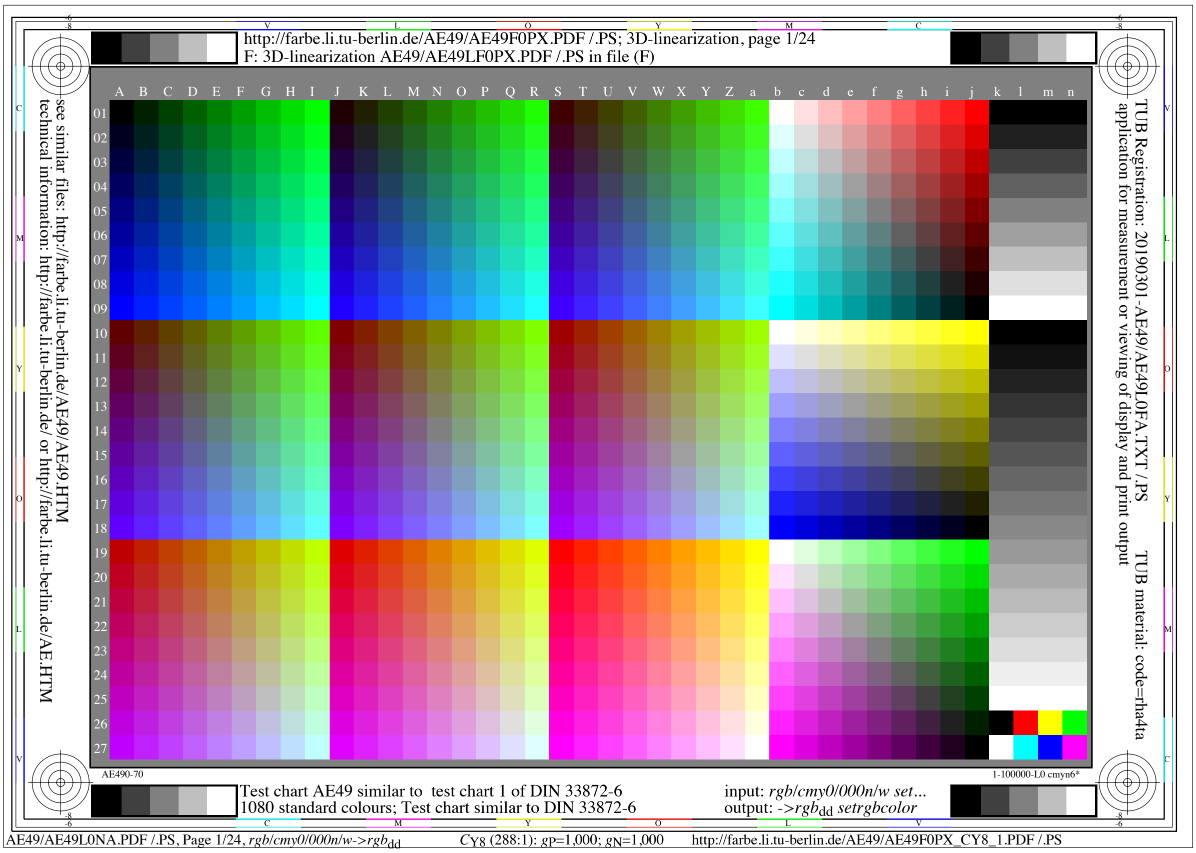


Figure 4: TUB-test chart AE49 with relative ISO gamma g_P=1,000 (ISO-contrast step C_{YP8}), use the ISO file http://standards.iso.org/iso/9241/306/ed-2/AE49/AE49F0PX.PDF.

Figure 4 contains 729 (=9x9x9) colours in the rows 01 to 27 and the columns A to a. These 729 rgb_d-colour values are used to steer the colour output and input. Within the Columns *b* to *n* colours that are particularly suitable for visual assessments.

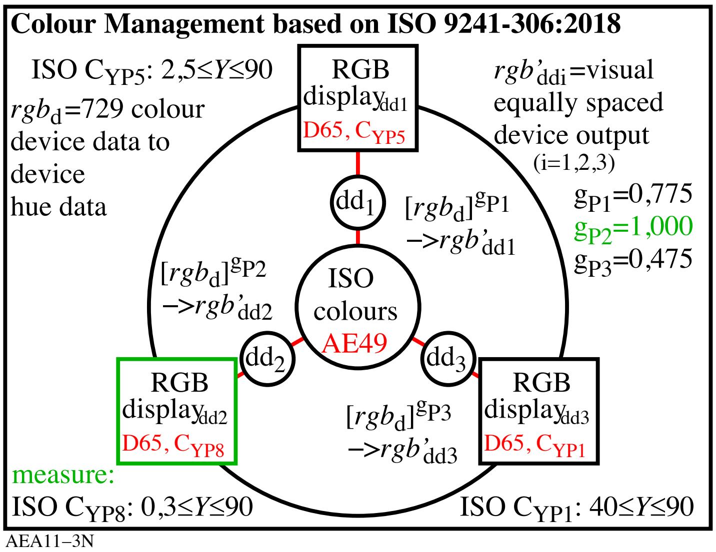


Figure 5: Colour output of the ISO-test chart AE49 for three ISO-contrast steps

In Figure 5 the ambient light at the screen workstation usually changes the ISO-contrast step between C_{YP8} (0,3 <= Y <=90) and C_{YP5} (2,5 <= Y <=90) to C_{YP1} (40 <= Y <=90). For example, the 9 grey steps in columns *k* to *n* and in the rows 01 to 09 in Figure 4 are visually only equal, if the rgb_d-standard colour values of the exponent g_{P1}=1,000 for C_{YP8} are replaced by the exponents g_{P2}=0,775 for C_{YP5} and g_{P3}=0,475 for C_{YP1}, compare Fig. 5. Three simple transfers apply

$$r_{dd}' = (r_d)^{g_P}, \qquad g_{dd}' = (g_d)^{g_P}, \qquad b_{dd}' = (b_d)^{g_P} \qquad [2]$$

These three transfers are performed in the *PostScript* (PS) programming language by only one PS operator *{g_P* exp *settransfer}* in a PS file. The same applies to PDF files.

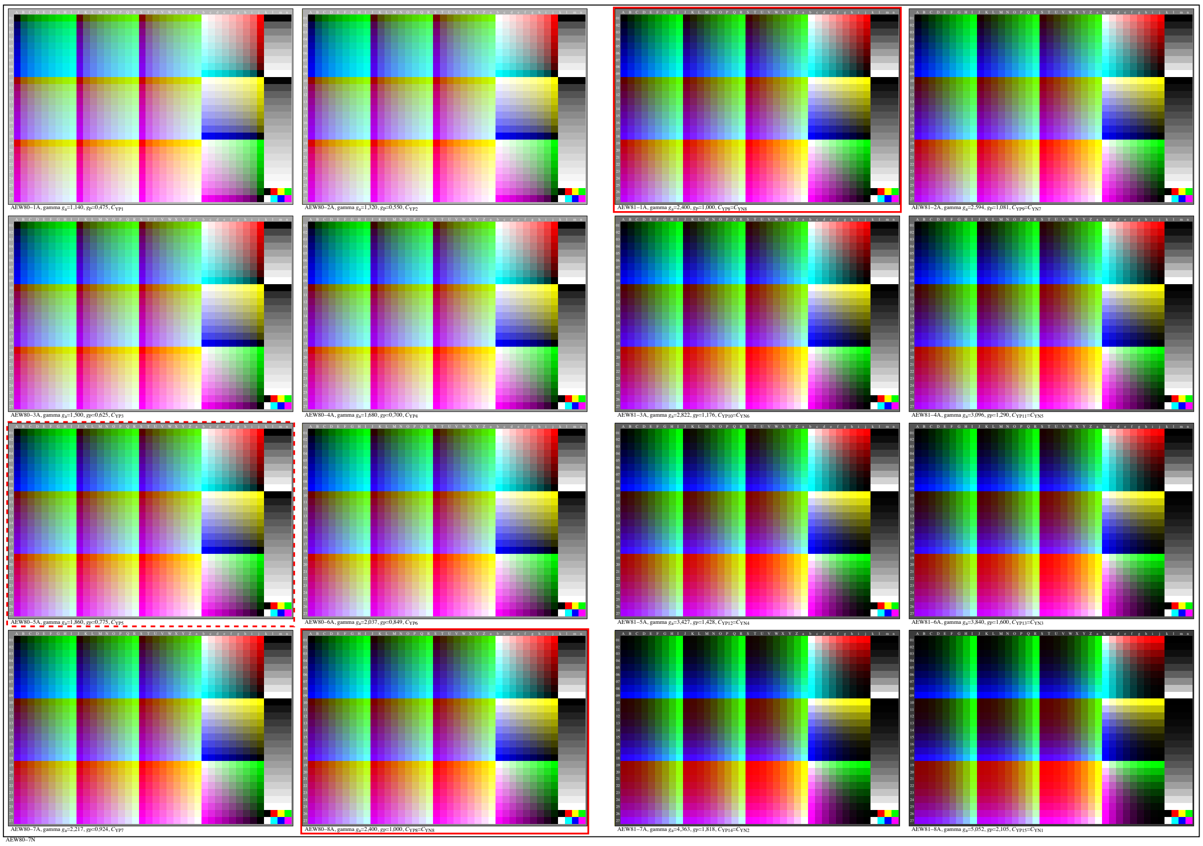


Figure 6: 16 reduced ISO-test charts AE49 with relative gamma in the range 0,475 <= g_P <=2,105, see http://farbe.li.tu-berlin.de/AEW8/AEW80-7N.PDF

Figure 6 shows on the *left* the eigth ISO-contrast steps C_{YP1} to C_{YP8}, and on the *right* the eight ISO-contrast steps C_{YN8} to C_{YN1}. The contrasts on the *right* are additionally called C_{YP8} to C_{YP15}. They include the contrast *High Dynamic Range (HDR)*, which is important in professional photography. For display and printing applications, usually the rgb_d-colour values must be changed according to the equation [2].

The g_P change is mandatory for the display output. Without reflection in the dark room the relative gamma value is g_P = 1,000. With increasing reflection on the display a smaller g_P is required. For HDR a larger g_P is required.

For the print output the reflection is always the same in relation to the white paper. However, the output of grey colour steps can only be done by the black ink *N* (100% UCR) or only by *CMY* (0% UCR). As a rule 100% UCR requires another g_P compared to 0% UCR.

In this case the printer manufacturers shall consider changes of g_P. Therefore they can make for example the output darker or lighter by a change of g_P in the printer driver or profile. By a change of g_P the printer manufacturers can steer consumption of colour materials. A lower g_P increases the consumption.

For example the print of DIN EN ISO 9241-306:2018 leaded in the following results: The contrast step C_{YP1} (top left, Fig. 6) appears in the print like the contrast step C_{YP8} (bottom left, red frame). The standard contrast step C_{YP8} (bottom left, red frame) looks like the contrast step C_{YP15} (bottom far right), i.e. like a strongly under exposed slide.

The output quality is described by the ISO-regularity index g^* according to ISO/IEC 15775 on a scale between 0 to 100. It is valid $g^* = 100$, if all grey steps have the same visual difference. It is valid $g^*=0$, if two of the 16 grey steps are *indistinguishable*.

When printing DIN EN ISO 9241-306:2018, four dark grey steps were indistinguishable and therefore $g^* = 0$ applies. The *minimum ergonomic* quality requirement of ISO 9241-306 and ISO/IEC 15775 for the discrimination of all 16 grey steps is *not* met.

When printing the older version DIN EN ISO 9241-306:2009, all 16 grey steps had approximately the same difference with the regularity index $g^* = 90$. Therefore the *maximum* ergonomic quality requirement of ISO 9241-306:2009 was *met approximately.*

The goal is an ergonomic colour output. In many cases, both the colour output in print and on the display require a change of gamma to produce an ergonomic colour output.

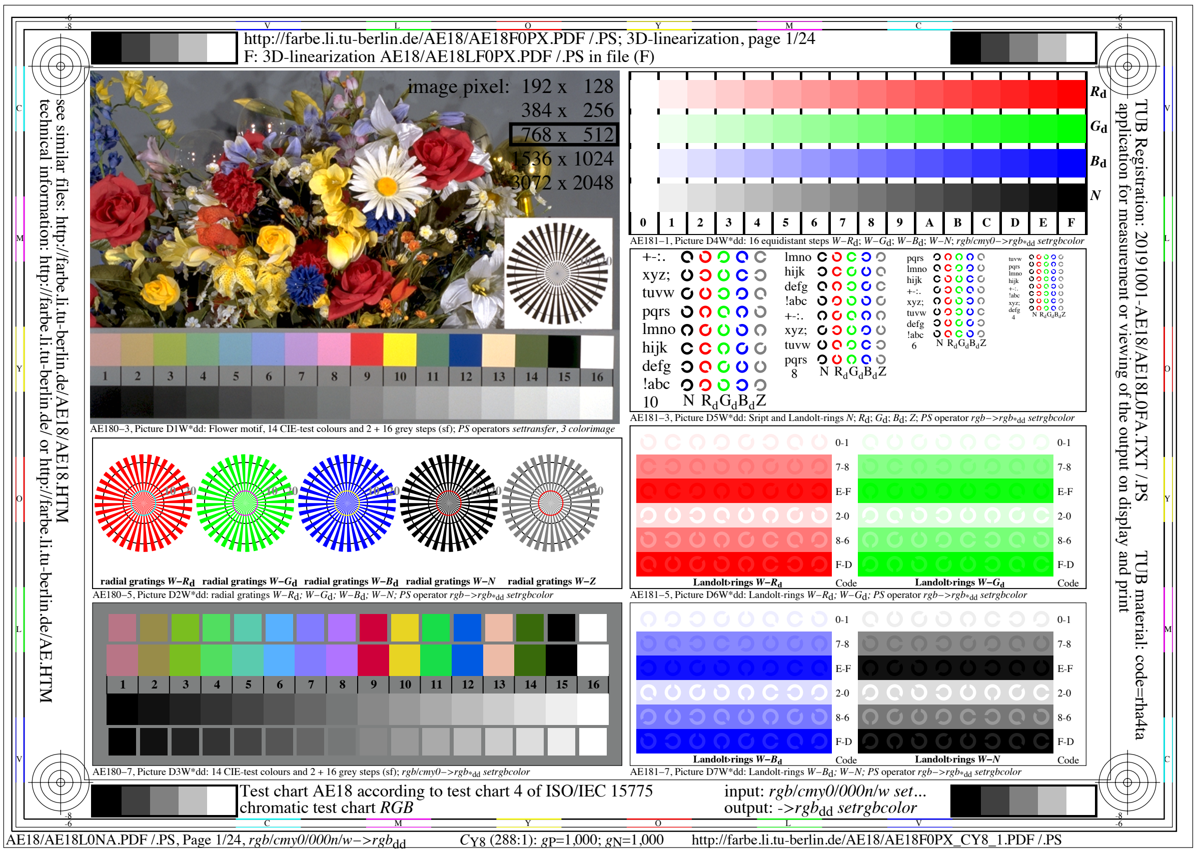


Figure 7: TUB-test chart AE18 with relative ISO gamma g_P = 1,000 (ISO-contrast step C_{YP8}), use the ISO file http://standards.iso.org/iso/9241/306/ed-2/AE18/AE18F0PX.PDF.

Figure 7 shows the ISO-test chart AE18 with an ISO/IEC image and 16 grey steps.

Section 2 covers the colour output in offset printing and with colour printers.
Section 4 covers the colour output on displays.

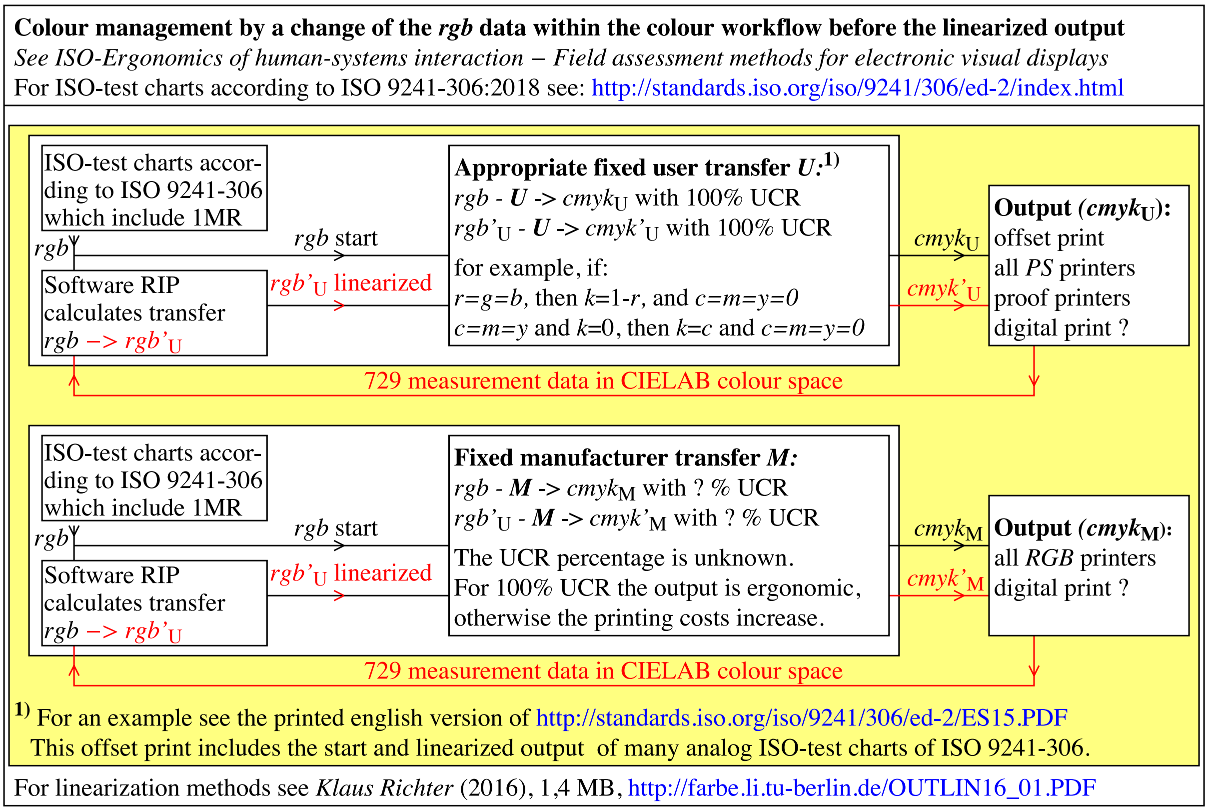
In addition to the ISO-test charts with 1080 colours, ISO 9241-306 defines 5 additional test charts, which are used for output in offset printing as well as with printers and displays. All ISO-test charts of ISO 9241-306 are defined for both the device and elementary hue output.

2. Ergonomic colour output for offset printing and with printers

The colour outputs in offset printing and with most printers use as colour material inks and toners.

A reproduction with a photographic exposure process on photographic paper is not considered here. However, similar methods apply.

Market research by *Lyra Research* has calculated annual sales of 100 billion dollars for consumables and 60 billion dollars for printer hardware for the 2006 financial year (Source Lander (2008), p. 93, first paragraph). Saving consumables is certainly not an essential goal of the printer manufacturers. Conflicts are created with consumers who wish to have an ergonomic output according to colorimetric criteria. This usually requires less consumables.



AEY91–7N

Figure 8: Transfer of *rgb*$_d$ to *cmyk*$_d$ colour values for offset and printer output

In Figure 8 the test charts according to ISO 9241-306 are used. Three test charts (AE09, AE18, and AE28) are approximately identical to the digital and analog test charts according to ISO/IEC 15775 for colour copiers, and the test charts according to ISO/IEC TR 24705.

A transfer of *rgb*$_d$ to *cmyk*$_d$ colour values by users or software companies is desired in order to produce an ergonomic output according to the criteria in section 1. This is possible with proof printers for the offset area and with *PostScript* printers, see Figure 8 upper part.

RGB printers in the lower price range (consumer area) contain a manufacturer-specific transfer from rgb_d to $cmyk_d$ colour values. Users may be able to print test charts darker or lighter. The user cannot change the manufacturer-specific colour separation from rgb_d to $cmyk_d$, see Figure 8 lower part.

An ergonomic printer output is therefore usually not possible with *RGB* printers. However, some *PostScript* printers in this area allow output of $cmyk_d$ files with 100% UnderColourRemoval (UCR). In this case, the achromatic grey colours are printed only with the printing colour black.

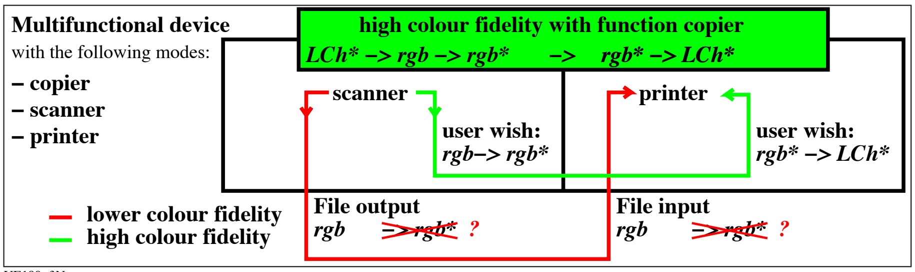
For example, if a medium grey is printed with 0% UCR (only with *C, M,* and *Y*), the user will have 6 times higher costs, if each of the three chromatic printing colours is twice as expensive as the achromatic printing colour black *N*. For ISO-colour test charts with many colours, manufacturers can make profits by selling consumables, if they avoid 100% UCR and/or produce darker outputs compared to the ergonomic requirements.

A fixed manufacturer transfer *M* in Figure 8 (lower part) can therefore be used to prevent ergonomic printer output with 100% UCR. An example seems to be the printed edition of DIN EN ISO 9241-306:2018 compared to the printed edition of DIN EN ISO 9241-306:2009, see section 1.

In a diploma thesis of the Technical University of Berlin, Lander (2008) concludes on the printing technology of UnderColourRemoval (100% UCR):
"In summary, it can be said that the use of an intelligent separation based on the principle of UnderColourRemoval only leads to advantages; material as well as visual. This technology can be used with any device that can be steered either via a RIP in the workflow or in the device itself. Consistent use of the technology presented here will pay off the higher acquisition costs due to the lower consumption of toner or ink. The investment in a device with its own graphical interface, so that the CMYK device colours can be addressed directly, is worthwhile in the long term for almost all applications." (LAND08. PDF, page 94, last paragraph).
"With an annual turnover of 100 billion [1] dollars for consumables, which is contrasted with a turnover of 60 billion dollars of printer hardware, it is not surprising that material efficiency is not the focus of the printer manufacturers. According to market researchers, it is precisely the trend towards colour that is giving manufacturers billions in profits here." (LAND08. PDF, page 93, first paragraph). [1]Market research by Lyra Research for the financial year 2006.

The RIP computing power mentioned by Lander is now often fulfilled by a modern office computer. The available linearization methods meet the goals of the "colour loop" in Figure 2 with appropriate software.

In order to meet all the "colour loop" objectives described in Figure 2, scanners and colour cameras must also be included. The analog ISO/IEC 15775-test charts generated from linearized outputs of the digital test charts are copied, scanned, and printed in Multifunctional Devices (MFP), see Figure 9.



UE190–3N

Figure 9: Multifunctional device (MFP) with three functions: copier, scanner and printer

Figure 9 shows the achievement of a high colour fidelity with the copy function. Here for example the 16 equally spaced grey steps in the original also appear equally spaced in the copy.

With the analog ISO-test chart, the scanner creates an rgb_d file. If the rgb_d file is then printed, the quality of the printer output usually does not meet the *minimum* ergonomic requirements. This is due to the lack of linearization of the input and/or output which is marked in red in Figure 9.

3. Summary for print outputs with rgb_d and $cmyk_d$ data.

The ergonomic and colorimetric print output is performed according to visual criteria in the CIELAB colour space. This output in offset printing and on printers has material and visual advantages.

A laptop computer is often sufficient to calculate the four colour separations for the print (CIE R8-09:2015 or Richter (2016)). The colour measurement data of 729 (=9x9x9) colours of the ISO-test chart AE49 according to ISO 9241-306 serve for the steering of the output. The colour measurement of the start or linearized output of all 1080 colours of the ISO-test chart AE49 is now possible within minutes.

For many printers in the lower price segment an ergonomic output does not seem to be the aim of manufacturers. With *RGB* printers with only a rgb_d input possibility an ergonomic steering of the output (100% UCR) by users or developers is usually not possible.

Ergonomic output is possible with Proof and *PostScript* printers with the possibility of a $cmyk_d$ input. The higher acquisition costs of the Proof and *PostScript* printers are amortized by lower material consumption.

In offset printing an ergonomic output is possible and partially realized. For the *device-independent* hue output even when the printing materials are changed, further research on the advantages and possible disadvantages is necessary. This goal has so far been achieved by test charts in DIN 33872-6 and ISO 9241-306:AEx6 with x=1 to 5.

4. Ergonomic display-colour output for eight display reflections of the ambient light

The colour output on displays is steered with rgb_d colour values in the range 0 to 1. Therefore, the same ISO-test charts are used for the print and display area.

Conclusion 31/2007 ISO TC159/SC4/WG2
Ergonomics – Visual Display Requirements

ISO TC159/SC4/WG2 realizes that the colour spaces CIELAB and CIELUV of ***CIE Division 1*** will soon become ISO/CIE standards. In applications we use these CIE colour spaces and *device−dependent* relative RGB colour spaces. For users of visual display systems a *device−independent* RGB colour space is useful. This produces via software the elementary hues Red, Green and Blue for the RGB data 100, 010 and 001 and equally spaced output in CIE colour spaces for equally spaced RGB input. We recommend that ***CIE Division 1*** study the colorimetric definition of such a space, which can be used in visual display applications.

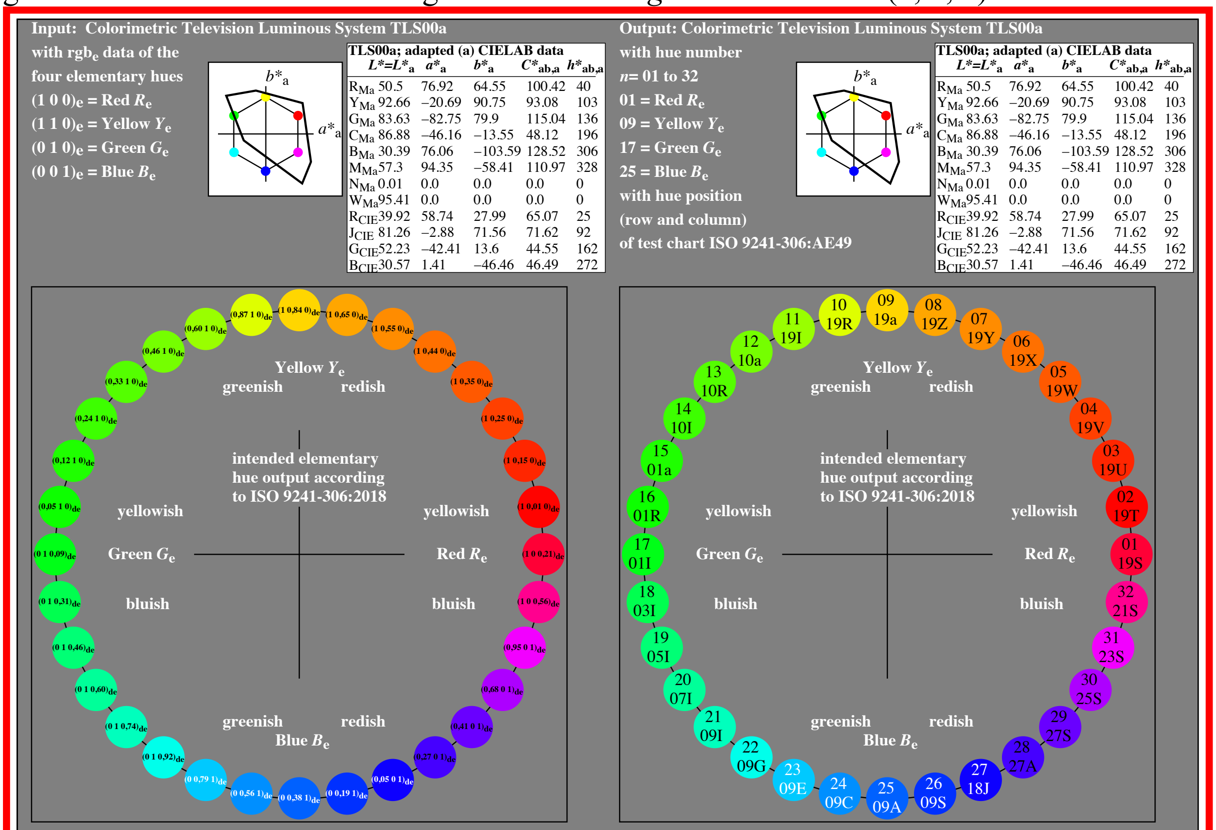
Remark: We have realized that an example colour space of this type is published in CIE X030:2006, p. 139−144.
Note: Compare page 2 of CIE R1-47, see http://web.archive.org/web/20160304130704/http://files.cie.co.at/526.pdf

EE850−1N

Figure 10: Ergonomic requirements from 2007 for display output with *rgb*-colour values

Figure 10 shows an ISO conclusion of 2007 with significant requirements for the display output. Based on this ISO requirements the CIE Division 1 *Vision and Colour* has published the Reportership Report CIE R1-47:2009. CIE R1-47 defines the CIELAB-hue angles h=26, 92, 162 and 272 degrees for the four elementary colours Red R_e, Yellow Y_e, Green G_e, and Blue B_e.

These four hue angles of CIE R1-47 are used in DIN 33872-1 to -5 and ISO 9241-306 for the steering of the *device-independent* hue output. For example, each display and print output generates the CIELAB colour angle h=26 for the rgb*-colour values (1, 0, 0).



AEF80-1N, Input file: http://farbe.li.tu-berlin.de/AEF8/AEF80-1N.PS, 1MR, gamma g_P=1,000, C_{YP8}=C_{YN8}

Figure 11: Elementary hue circle with rgb_{de}-colour values and the position in the ISO-test chart AE49), see http://farbe.li.tu-berlin.de/AEF8/AEF80-1N.PDF.

Fig. 11 shows on the *left* the rgb_{de}-colour values (de=device to elementary) for a 32-step elementary hue circle on a standard *sRGB* display. The *sRGB*-colour values rgb_{dd}=(1, 0, 0) produce the hue angle h=40. The *sRGB*-colour values rgb_{de}=(1, 0, 0,21) produce the intended ergonomic hue angle h=26.

Fig. 11 shows on the *right* the position (row and column) of the ISO-test chart AG46. The output of the ISO-test chart AG46 includes the ergonomic transfer rgb_{dd} to rgb_{de}. Instead of the device hue angle h=40 the elementary hue angle h=26 is produced on the horizontal axis.

In the application, this ergonomic requirement has largely *not* yet been implemented. A realization is also possible with labtop computers for all ISO-test charts according to ISO 9241-306 and many applications.

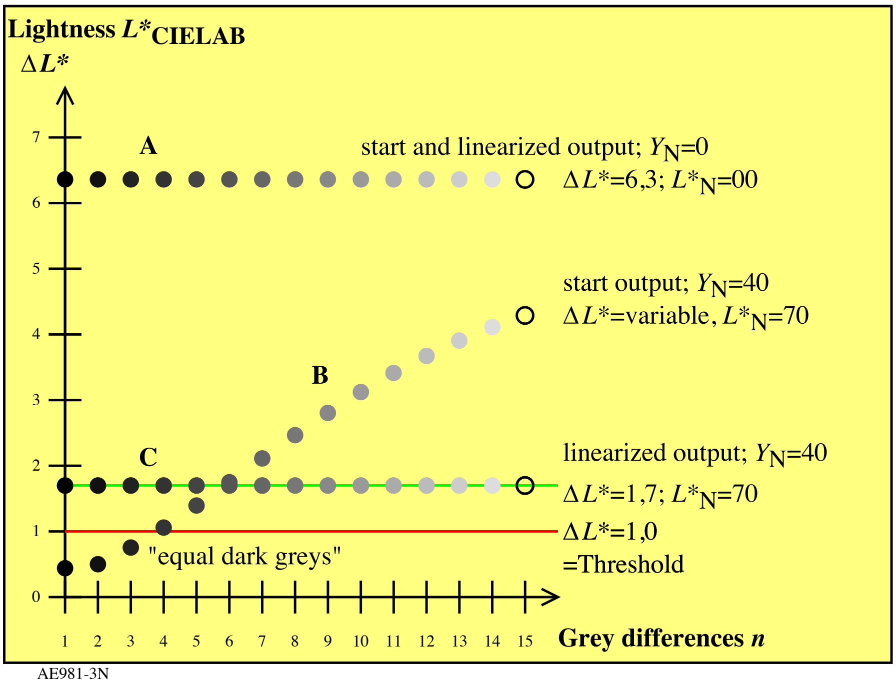


Figure 12: Lightness differences ΔL^* of *16* grey steps for display reflections Y_N=0 and 40

Figure 12 shows the change of the 15 lightness differences of the 16 grey steps. White W has the CIE tristimulus value Y_W=100. Black N has the tristimulus value Y_N=0 in the dark room and for example the tristimulus value Y_N=40 with a projector in an office with much daylight. In this case the viewed luminance of the display is produced by about equal luminance amounts of the projector and the daylight.

The equal lightness difference ΔL^*=6,3 of the 16 grey steps in the dark room changes to lightness differences between ΔL^*=0,4 and 4,5 in the office with much daylight. By output linearization according to equation [2] with the exponent of approximately g_P=0,5, all lightness differences have the intended constant value of ΔL^*=1,7. All the 16 grey steps are visible and appear equally spaced.

For the B series without output linearization, the lightness difference ΔL* is less than 1 for three grey steps. These three grey steps are *indistinguishable*, as the threshold of vision is ΔL*=1,0. The *minimum* ergonomic requirement according to ISO 9241-306 is not *met.*

For the C series the lightness difference ΔL*=1,7 is constant. The regularity index has the value g*=100. The *maximum* ergonomic requirement according to ISO 9241-306 for equal lightness difference of all 16 steps is *met.*

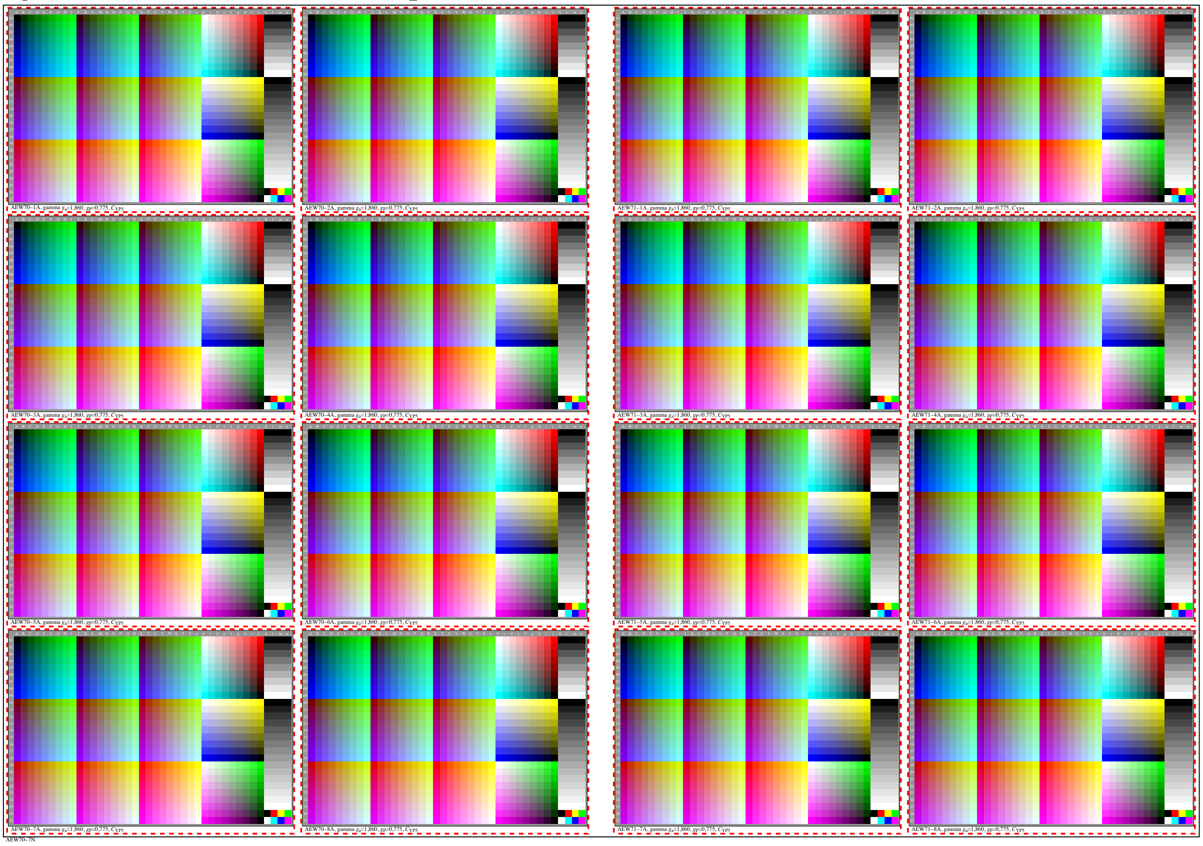
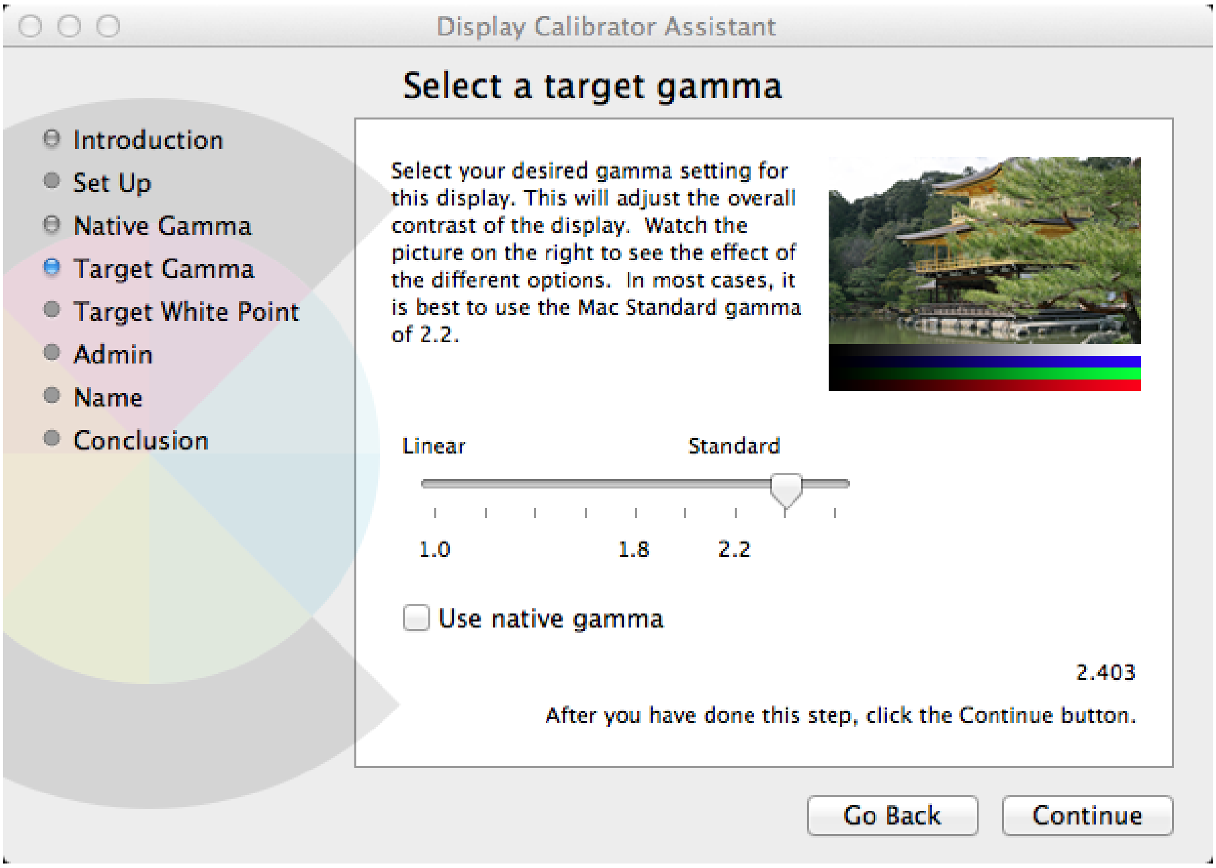


Figure 13: 16 identical ISO-test charts AE49 with the relative ISO gamma g_P = 0,775 (ISO-contrast step C_{YP5}), see http://farbe.li.tu-berlin.de/AEW7/AEW70-7N.PDF.

Figure 13 shows 16 identical ISO-contrast steps C_{YP5} according to ISO 9241-306. The ISO-contrast step C_{YP5} is the standard contrast step with 2,5% reflection in relation to the white display.

At the office workstation, windows and lamps can partially be mirrored in the display, and can then disturb the visual assessment of the ISO-contrast step in Figure 6. Also the printer output can cause visual differences at the 16 positions on an A4 page.

Therefore, before a visual determination of the ISO-contrast step with Figure 6 on printers or displays, the regularity of the output with Figure 13 should always be checked and documented.



AEX51-7N

Figure 14: Modification of the entire display output by a gamma value with a slider

Figure 14 shows a slider of the Operating System *Mac OS X Version 10.7.8 (2010)* for the change of the absolute gamma values in the range 1,0 <= g_a <=2,6.

The gamma range 1,0 <= g_a <=2,6 in Figure 14 allows to produce an equal spacing of the four colour series shown in the figure. The gamma value of the slider for an ergonomic output of the four series and the image must be determined experimentally.

In a dark room (without a display reflection), the four colour series appear approximately equally spaced, if the absolute gamma value is g_a = 2,4 according to IEC 61966-2-1.

The issues of ISO 9241-306 from 2008 and 2018 describe how to store and apply nine profiles from this absolute gamma range 1,0 <= g_a <=2,6 with Δg_a =0,2.

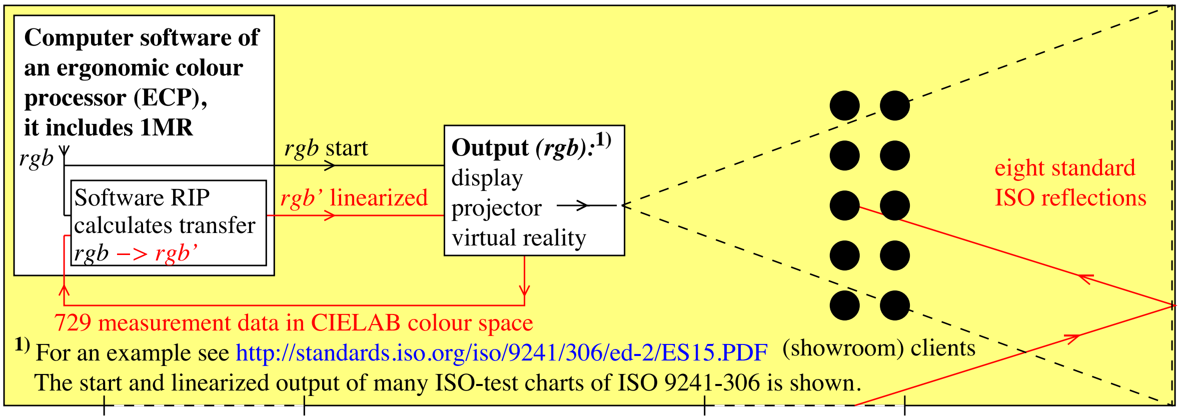
By clicking on one of the nine profiles, the entire screen is changed and one can always select the ergonomic output, for example with the ISO-test chart AE49 according to ISO 9241-306 at the workplace.

After more than 15 years, the slider was removed in the operating system *Mac OS X version 10.15 (2019)*. For nine test profiles one can download the file
http://farbe.li.tu-berlin.de/AGX0/LCD_XX.zip

The test profiles can be used with the computer-operating systems *Mac* and *Windows*. They show the intended change of gamma in the range 1,0 <= g_a <= 2,6 for the whole display output. However, since *Mac OS X version 10.15 (2019)* these test profiles produce a disturbing chromatic tint for the achromatic grey steps with $r^*=g^*=b^*$.

Colour management by change of the *rgb* data within the colour workflow before the linearized output
See ISO-Ergonomics of human-systems interaction – Field assessment methods for electronic visual displays
For ISO-test charts according to ISO 9241-306:2018 see: http://standards.iso.org/iso/9241/306/ed-2/index.html

The computer with an **Ergonomic Colour Processor (ECP) includes the 1-Minus-Relations (1MR).** It is valid: r=1−c, g=1−m, b=1−y. [1]. The output is equal for: r=g=b=0,5 or c=m=y=0,5 or k=0,5 or w=1−k=0,5. [2]
If the 1MR is active, then the output of the ISO-test chart shows **equal output** in each colour square of: http://standards.iso.org/iso/9241/306/ed-2/AE49/AE490-7N.PDF and independent of the use of *rgb* or *cmyk*.



In a general case the Software Image Processor (RIP) transfers 16,7 (256x256x256−1) million *rgb* to *rgb'* data.

In ISO 9241-306 the Software Image Processor (RIP) calculates the *rgb'* data by the equation $rgb' = rgb^n$ [3]
For eight standard ISO reflections it is valid: n = 1,000, 0,925, 0,850, **0,775,** 0,700, 0,625, 0,550, 0,475.
The bold standard value ***n*=0,775** is the standard ISO reflection in offices (2,5% of black compared to white).

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Figure 15: Visual optimization of display and print output

Figure 15 requires optimization of the display output as a function of daylight reflection on the projector display. Depending on the reflection on the projector display, a different linearization with the relative gamma value in the range 0,475 <= g_p <= 1,0 is required.

The relative gamma values g_P are usually different for all displays depending on the reflection of the ambient light. Therefore a flexible and ergonomic change of the gamma values is required. This also applies to digital web-conference systems. The have the goal to optimize the output on office and mobile displays.

If the settings of the displays in the dark room does not correspond to the absolute gamma g_a = 2,4 according to IEC 61966-2-1 or the relative gamma g_P = 1,000, a flexible change in the gamma values can compensate for this error.

If the setting or exposure of the computer or photographic cameras does not meet the standard conditions, a flexible change in gamma values can usually compensate for this error.

The same output for colour values *rgb** and *cmyk** according to the 1-minus-relation (1MR) required by the *PostScript* programming language and the colour metric is at present often *not* met at the operating system level and in software products.

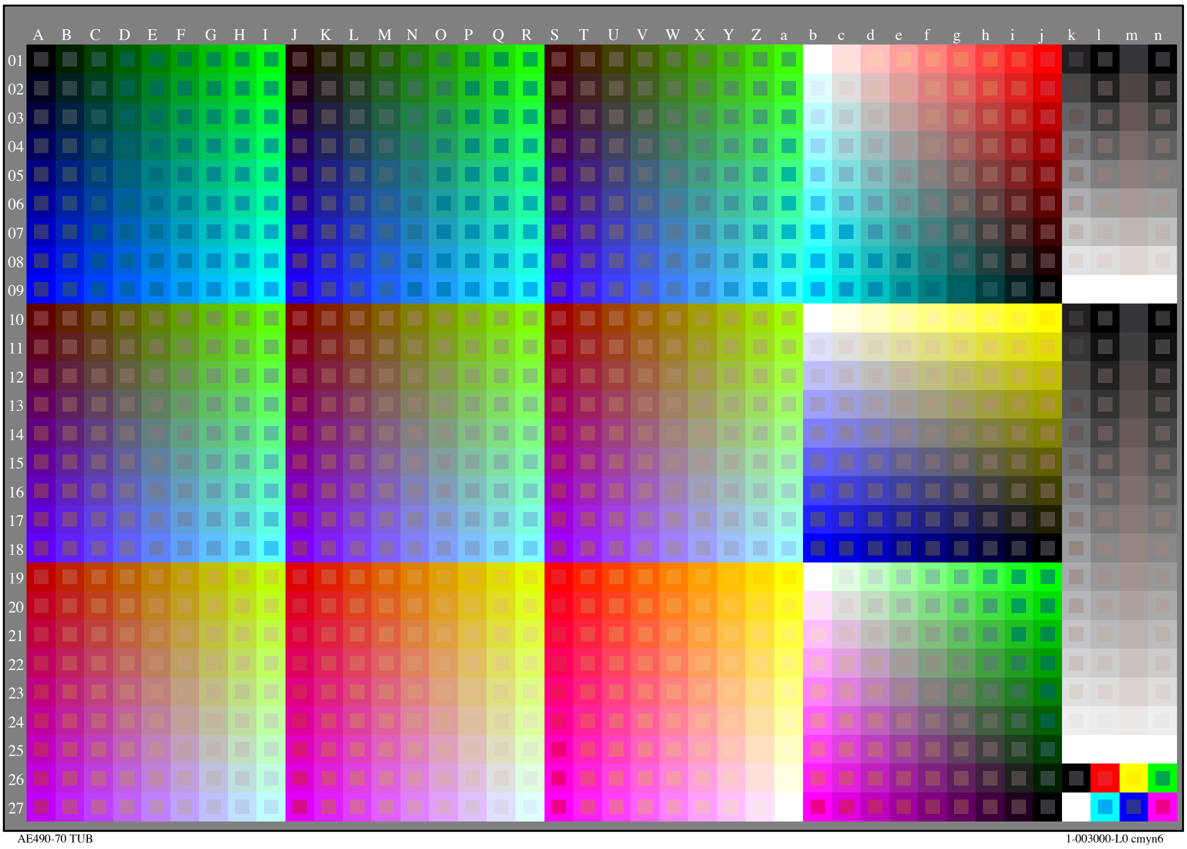

Figure 16: TUB file with *rgb and *cmyk** data according to the 1-Minus-Relation (1MR),** use the ISO file http://standards.iso.org/iso/9241/306/ed-2/AE49/AE490-7N.PDF

Figure 16 shows an TUB file with *rgb** and *cmyk** data according to the 1-Minus-Relation (1MR) in the outer and inner squares. The 1MR property is fulfilled, if the 1080 inner and outer squares are equal. One can use the ISO file of Fig. 16 to verify the 1MR property. There is layout software, for example *Unix Latex* and *Windows Adobe FrameMaker 8*, which show *equal* display output. There are *PostScript* printers, for example of *OKI,* which show *equal* output for the option *ICC-colour management OFF* and *different* output for *ON*.

For example within the ISO file of Fig. 4 with the 1080 colours and usually all the other ISO-test charts, the ergonomic transformation from *cmyk** to *rgb** is already included in the image files *or* the inner squares are not drawn.

In Figure 16, the six chromatic outer and inner device colours (d=device) R_d, Y_d, G_d, C_d, B_d, and M_d are different. An example are the measured outer and inner 8bit green values (0, 255, 0) and (0, 152, 74). This output shows that the cmy0* colour values (255, 0, 255) produce the completely incomprehensible *rgb**-colour values (0, 152, 74) instead of (0, 255, 0).

The different device transformations from *rgb* to *cmyk* which are shown here contradict to ergonomics and shall therefore be avoided in colour information technology. For example, the ergonomic *rgb**-colour values $r^*=g^*=b^*=0{,}5$ according to ISO 9241-306 give the medium grey colour between black *N* and white *W*. The complementary *cmy0**-colour values with $c^*= m^*=y^*=0{,}5$, and *000k** with $k^*=0{,}5$ shall produce the same colour output.

In the application often the device colour values $c_d=0{,}4$, m_d =0,4 and $y_d=0{,}3$ produce approximately the same colour output. These data are experience value for a special printing process. The *cmy0*-colour values are old experience values for a specific printing process.

Their present use in software contrasts with the *PostScript* programming language as well as ergonomics and colour metrics, which use corresponding complementary colours.

5. Summary for display outputs with *rgb**-colour values.

Ergonomic and colourimetric display output is performed according to visual criteria in the CIELAB colour space. This ergonomic display output has visual advantages.

Further advantages result from a *device-independent* hue output according to the ergonomic elementary colours Red R_e, Yellow Y_e, Green G_e, and Blue B_e with the CIELAB-hue angles 26, 92, 162 and 272 degrees (CIE R1-47:2009, DIN 33872-4:2010 and ISO 9241-306:2018). This *device-independent* hue output has hardly been realized so far. ISO 9241-306 supports a download of all ISO test charts with a *device-independent* hue output for the standard display sRGB according to IEC 61966-2-1.

For the calculation of the linearization without and with a *device-independent* hue output, see CIE R8-09:2015 or with the same technical content *Richter* (2016). ISO 9241-306 describes, how the eight display outputs are created by a gamma change. This change is possible with any laptop computer for the eight display reflections at the workplace.

The display output is steered with the colour measurement data of 729 (=9x9x9) colours of the test chart AE49 according to ISO 9242-306. The colour measurement of the start or linearized output of all 1080 colours of the ISO-test chart AE49 is possible within 45 minutes.

One measurement in a dark room produces the 1080 colour values. The colour values for seven other display reflections may be calculated from these colour values. However, in applications the eight ISO-contrast steps C_{YP8} to C_{YP1} according to ISO 9241-306 approximate already the changes for eigth different display reflections.

6. ISO-test files for printers, displays, workflow, and software

A test output is recommended for the ISO-PDF files AE49 (Fig. 4, Fig. 13, Fig. 16) and AE18 (Fig. 7) in vector graphics (VG):

ISO file, 24 pages, 1,7 MB, for eight ISO-contrast steps C_{YP8} to C_{YP1}.
http://standards.iso.org/iso/9241/306/ed-2/AE49/AE49F0PX.PDF.

ISO file, 24 pages, 14,4 MB, for eight ISO-contrast steps C_{YP8} to C_{YP1} which includes the ISO/IEC image "Flower motif".
http://standards.iso.org/iso/9241/306/ed-2/AE18/AE18F0PX.PDF.

ISO file, 1 page, 0,12 MB, for ISO-contrast step C_{YP8} with the 1-minus-relation of the *rgb** and *cmyk**-colour values for the outer and inner squares.
http://standards.iso.org/iso/9241/306/ed-2/AE49/AE490-7N.PDF.

For the test of equal outputs, see http://farbe.li.tu-berlin.de/AEW7/AEW70-7N.PDF.
For the test of the output gamma, see http://farbe.li.tu-berlin.de/AEW8/AEW80-7N.PDF.

With these PDF files and all other ISO 9241-306 files an output is possible on all printers, in offset printing, on displays, for any workflow, and with appropriate software, for example *Adobe Reader* and *Mac Preview*. For scanners and in photography the analog test charts according to ISO/IEC 15775 are used for input linearization, see CIE R8-09:2015 or *Richter* (2016).

If the extension PS or TXT is used instead of the extension PDF, all hand-coded commands and explanations of the *PostScript* programming language are downloaded within the file.

The two outputs of the ISO files AE49 and AE18 each generate 24 pages for eight ISO-contrast steps C_{YP8} to C_{YP1}. Only one of these eight contrast steps usually produces the optimal ergonomic output, for example the pages 10 to 12 of the ISO-contrast step C_{YP5}. On the chosen three pages all the ergonomic questions shall be answered.

In addition to the standard output on the printer or display, the output on *PostScript* printers or displays is of particular importance to users. For example, all *PostScript* printing devices allow ergonomic output with 100% UCR (grey is only printed from the printing colour black).

The output of AE49 or AE18 is equal with the *PS* and *PDF* files, if the *PostScript* devices work according to the *PostScript* programming language, see *Adobe PostScript Manual*. This shall be proofed because of many *PostScript* emulations in applications. The same output of *PS* and *PDF* files is based on the same operators (with shorter names in *PDF*) in the two programming languages *PS* and *PDF (Portable DocumentFormat*).

To check the properties of *PostScript* print devices, the *PS* and *PDF* files can be loaded directly to the printer. The output is therefore *independent* of the workflow or software of the operating system. Then the output depends only on the *PostScript* software within the printer or printing system.

To check the properties of devices with *Display-PostScript,* the *PS* and *PDF* files produce an output directly on the display, for example by a double-click. The output should be *independent* of the workflow and the *Display PostScript* software of the display operating system.

For example, the *Display PostScript emulation Mac Preview* does not pay attention to the PS operator {g_P *exp settransfer*}. Therefore in the *Mac-WinWord* applications the display output of an imported *PS* and *PDF* file is different, if the value of g_P is different to 1.

The software *MacPreview* includes a default option *smoothing* for the *rgb** data in the PS file. Instead of 9 or 16 steps, this often creates a continuous colour change of the output on displays and in print. The similar software *Adobe Distiller* has an option *smoothing* (NO/YES) with the default option NO. Therefore the 9 or 16 steps are distinguishable.

For many application examples, see
http://farbe.li.tu-berlin.de/AEA_I.HTM

For example, go to
http://farbe.li.tu-berlin.de/AEXI.HTM

Or see additional literature
http://farbe.li.tu-berlin.de/XY91FEN.html

7. Annex: Related Standards and Technical Reports

Input	Output	Input and output media and applications: Input	Output	Application	Technical Report (TR) or Standard	Method & Test: Linearization
–	–	–	–	**Basis**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-1**[3)]	**DIN 33866-1** **DIN 33872-1**
analog[2)]	**analog**	ISO/IEC-file series equally spaced in *rgb** ISO/IEC-test chart (hardcopy) series equally spaced in *LCh**	Hardcopy	**Copier**	**ISO/IEC 15775**[2)] **under revision** (2020)	**DIN 33866-2** [2)] **JIS X 6933**[1) 2)]
analog[2)]	**digital**	ISO/IEC-test chart (hardcopy) series equally spaced in *Lch**	File	**Scanner**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-3**[3)]	**DIN 33866-4**
digital[1)]	**analog**	ISO/IEC-test chart (File) series equally spaced in *rgb**	Hardcopy	**Printer**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-2**[3)]	**DIN 33866-3** **DIN 33872-2,4**
			Softcopy	**Display**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-4**[3)] **ISO 9241-306:2018**[1)]	**DIN 33866-5** **DIN 33872-2,4**

1) Digital ISO-test files for free download from: http://standards.iso.org/iso/9241/306/ed-2/index.html
2) Analog ISO-test charts are available from 3 sources: DIN 33866-2, JIS X 6933, *Richter, 2012*, offset print (3600dpi), siehe *Colour and Colour Vision*, compare as file http://standards.iso.org/iso/9241/306/ed-2/ES15.PDF
3) Free download of content of ISO documents for example for new standard projects, see many URLs in: http://farbe.li.tu-berlin.de/EE68/EE681-3N.PDF. 4) Withdrawn in 2019.

ISO/IEC-input linearization method

Input	Output	Application	Technical Report (TR) or Standard
Original scene + CIE colours	ISO/IEC Image File	Reference Image File	**ISO/IEC 15775**[2)] under revision (2020) ISO/IEC TR 24705[3)4)]

ISO/IEC-output linearization method, OUTLIN16_01.PDF

Input	Output media	Application	Technical Report (TR) or Standard
ISO/IEC File	Hardcopy	Printer	**ISO/IEC TR 19797**[3)4)]
ISO/IEC File	Softcopy	Display	**ISO 9241-306:2018** 8 viewing conditions
ISO/IEC File	Softcopy Hardcopy Hardcopy	Display Offset Printer	**CIE R8-09:2015** (CIE internal) + http://farbe.li.tu-berlin.de/OUTLIN16_01.PDF

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Figure 17: Relationship of standards in the field of colour-information technology

Figure 17 shows the connection of standards in the field of colour-information technology, for example of copiers, scanners, printers and displays with basics. The series DIN 33866-1 to -5:2000 describe this range.

It was tried to develop with ISO DIS 19839-1 to -4:2003 a corresponding ISO series. This goal failed, partly because today's rapid transfers from rgb_d to rgb_d' and to $cmyk_d$ were not available in 2003.

Many manufacturers of printers, scanners and copiers in the office are still hardly interested in ergonomic and colorimetric solutions. This is probably also the reason why ISO/IEC TR 24705:2005 with the technical content of DIS 19839-1 to -4 was withdrawn in ISO/IEC SC28 "Office Equipment" in 2019.

Input	Output	Input and output media and applications Input	 Output	 Application	Technical Report (TR) or Standard	Method & Test: Linearization
–	–	–	–	**Basis**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-1**[3)]	**DIN 33866-1** **DIN 33872-1**
analog[2)]	**analog**	ISO/IEC-file series equally spaced in *rgb** ISO/IEC-test chart (hardcopy) series equally spaced in *LCh**	Hardcopy	**Copier**	**ISO/IEC 15775**[2)] **under revision** (2020)	**DIN 33866-2** [2)] **JIS X 6933**[1) 2)]
analog[2)]	**digital**	ISO/IEC-test chart (hardcopy) series equally spaced in *Lch**	File	**Scanner**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-3**[3)]	**DIN 33866-4**
digital[1)]	**analog**	ISO/IEC-test chart (File) series equally spaced in *rgb**	Hardcopy	**Printer**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-2**[3)]	**DIN 33866-3** **DIN 33872-2,4**
			Softcopy	**Display**	**ISO/IEC TR 24705**[3)4)] **former DIS 19839-4**[3)] **ISO 9241-306:2018**[1)]	**DIN 33866-5** **DIN 33872-2,4**

1) Digital ISO-test files for free download from: http://standards.iso.org/iso/9241/306/ed-2/index.html
2) Analog ISO-test charts are available from 3 sources: DIN 33866-2, JIS X 6933, *Richter, 2012*, offset print (3600dpi), siehe *Colour and Colour Vision*, compare as file http://standards.iso.org/iso/9241/306/ed-2/ES15.PDF
3) Free download of content of ISO documents for example for new standard projects
ISO/IEC TR 24705:2005 for basis, printer, scanner, display. 4) Withdrawn in 2019.
http://web.archive.org/web/20060104024850/http://www.jbmia.or.jp/sc28/sc28docs/j28n689.zip
ISO/IEC 15775:1999/AMD 1:2005 for copier
http://web.archive.org/web/20060116221659/http://www.jbmia.or.jp/sc28/sc28docs/j28n648.zip
ISO/IEC TR 19797:2004 for output linearization
http://web.archive.org/web/20060116212434/http://www.jbmia.or.jp/sc28/sc28docs/j28n687.zip
ISO/IEC DIS 19839-1 to 4:2004 for basis, printer, scanner, display
http://web.archive.org/web/20030325005802/http://www.actech.com.br:80/sc28docs/j28n512.pdf
http://web.archive.org/web/20030325050829/http://www.actech.com.br/sc28docs/j28n513.pdf
http://web.archive.org/web/20030325100829/http://www.actech.com.br/sc28docs/j28n514.pdf
http://web.archive.org/web/20030426234527/http://www.actech.com.br/sc28docs/j28n515.pdf
Definitions for the CIELAB – cmy* relationship in 19839-1 to 4
http://web.archive.org/web/20030325200357/http://www.actech.com.br/sc28docs/j28n516.pdf

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Figure 18: Availability of standards and technical reports in the field of colour-information technology

Figure 18 shows the connection and availability of standard documents in the field of colour information technology.

The technical content of DIS 19839-1 to -4:2003 and ISO/IEC TR 24705:2005 is still freely available on the Internet.

The content could be used together with DIN 33872-1 to 6:2010 and ISO 9241-306:2018 for new ergonomic and colorimetric standards in the field of colour information technology.

The ergonomic goal of a *broad application* of the interdisciplinary "ISO-colour loop" in Fig. 2 can therefore be realized step by step. Many advantages are applicable which are described within this paper.

Since 2019 the ISO and IEC *Code of Conduct* and the CIE *Code of Ethics* require standards and developments to increase the *Net Benefit of the International Community.*

The trend to decrease the regularity index *g** according to ISO/IEC 15775 and ISO 9241-306 for the output on printers and on displays during the last ten years conflicts with ergonomic and colorimetric requirements. This trend reduces the *Net Benefit of the International Community.* Therefore new approaches are necessary to reach the ergonomic goals in the field of information technology. The power of consumer organizations may convince companies to invest more in standards and developments which increase the *Net Benefit of the International Community.*

8. Literature

Richter, Klaus (2020), Goals, Problems and Realization of a Colour Loop:
ISO-Colour File – Print – Scan – back to ISO-Colour File, 24 pages, 2 MB
http://farbe.li.tu-berlin.de/_CLE_20.PDF

Richter, Klaus (2019), Colour Themes in the CIE and Applications, Annual Meeting of the German Colour Science Society (DfwG), Leipzig, October 2019, 21 Slides, 900 KB, see
http://farbe.li.tu-berlin.de/_DfwGE_19.PDF

Richter, Klaus (2018), Colourimetric scan, display, and print for archiving based on the ergonomic International Standard ISO 9241-306:2018 at work places, 2 pages, publication ARCH2019_Richter_PG_111.pdf within the book Archiving2019, Lisbon, Portugal, Society for Imaging Science and Technology.

ISO 9241-306:2018, Ergonomics of human-system interaction - Part 306: Field assessment methods for electronic visual displays, available in English, French and German, developed in ISO TC 159/SC4/WG2 "Ergonomics - Visual Display Requirements", ISO-project editor: *Klaus Richter.* The **digital** ISO-test charts are available for free download on the ISO Standards Maintenance Portal *(ISMP)* in the formats PDF and *PostScript* (PS, TXT), see
http://standards.iso.org/iso/9241/306/ed-2/index.html
Modification of the ISO-test chart AE49 with 1080 colours and ISO/IEC-image for eight ISO-contrast steps according to ISO 9241-306:2018, see
http://farbe.li.tu-berlin.de/1080E.html

Richter, Klaus (2016), Output Linearization Method *OLM16* for Displays, Printers, and Offset Print (61 pages, 1.3 MB, format A4), with revised links in 2019, with approximately the same technical content as the Reportership Report CIE R8-09:2015 (CIE internal), see
http://farbe.li.tu-berlin.de/OUTLIN16_01.PDF

Richter, Klaus (2013), Colours and colour vision - Elementary colours in colour information technology, 85 pages, 130 colour images, 15 ISO/IEC, CIE and DIN test charts, format A5 or A4, available in six languages: English, German, French, Spanish, Italian and Norwegian, see
http://farbe.li.tu-berlin.de/color/index.html or in english
http://standards.iso.org/iso/9241/306/ed-2/ES15.PDF

Information about International and National Standards, Technical Reports, and Meetings in the field of Image Technology (2010), see
http://farbe.li.tu-berlin.de/A/4STAE.html

Richter, Klaus (2009), Relative Elementary Colour System RECS as analog and digital colour atlas, 18 pages with approx. 2000 colour samples according to DIN 33872-1 to 6 and 18 pages with ISO/IEC test charts according to ISO/IEC 15775, ISO/IEC TR 24705, and ISO 9241-306:2018, format A4, see
http://farbe.li.tu-berlin.de/A/RECS.html

DIN 33872-1 to -6:2010 Information technology - Office machines - Method of specifying relative colour reproduction with YES/NO criteria
- Part 1: Classification, terms and principles, only on CD-ROM,
- Part 2: Test charts for output properties - Testing of discriminability of 5 and 16 step colour series,
- Part 3: Test charts for output properties - Testing of equality for four equivalent grey

definitions and discriminability of the 16 grey steps,
- Part 4: Test charts for output properties - Testing of equality for two equivalent colour definitions with 5 and 16 step colour series,
- Part 5: Test charts for output properties - Testing of elementary hue agreement and hue discriminability,
- Part 6: Test charts for output properties - Testing of the equivalent spacing and of the regular chromatic spacing.
For free download of the DIN-test charts according to DIN 33872-1 to -6, see
http://farbe.li.tu-berlin.de/A/33872E.html
Modification of the DIN-test charts according to DIN 33872-1 to 6 for eight ISO-contrast steps according to ISO 9241-306:2018, see
http://farbe.li.tu-berlin.de/33872E.html

Lander, Stephan (2008), Visual and Material Efficiency by Colorimetric Colour-Printer Output (in German), Diploma Thesis, TU Berlin 2008, Institute for Lighting Technology (183 pages, 16 MB), see
http://farbe.li.tu-berlin.de/LAND08.PDF

ISO/IEC TR 24705:2005
Information technology – Office machines – Machines for colour image reproduction – Method of specifying image reproduction of colour devices by digital and analog test charts,
For ISO/IEC-test charts according to ISO/IEC TR 24705 and ISO/IEC 15775, see
http://farbe.li.tu-berlin.de/A/24705TE.html
For modifications of these ISO-test charts for eight ISO-contrast steps according to ISO 9241-306:2018, see
http://farbe.li.tu-berlin.de/15775E.html

DIN 33866-1 to -5:2000
Information technology - Office machines; colour image reproduction equipment -
Part 1: Method of specifying image reproduction of colour devices by digital and analog test charts; classification and principles
Part 2: Method of specifying image reproduction of colour devices by analog input and analog output for colour image reproduction devices: "analog-analog" (copiers), realization and application
Part 3: Method of specifying image reproduction by digital input and analog output as Hardcopy with colour image reproduction devices "digital - analog" (printers); realization and application
Part 4: Method of specifying image reproduction of colour devices by analog input and digital output for colour image reproduction devices: "analog-digital" (scanners), realization and application
Part 5: Method of specifying image reproduction of colour devices by digital input and analog output as softcopy with colour image reproduction devices: "digital-analog" (monitors), realization and application
For free download of some of the DIN-test charts according to DIN 33866-1 to -5, see
http://farbe.li.tu-berlin.de/A/33866E.html

ISO/IEC 15775:2000
Information technology - Office equipment - Method of specifying image reproduction of colour copying machines by analog test charts,
For ISO/IEC-test charts according to ISO/IEC TR 24705 and ISO/IEC 15775, see
http://farbe.li.tu-berlin.de/A/24705TE.html

For Modifications of these ISO-test charts for eight ISO-contrast steps according to ISO 9241-306:2018, see
http://farbe.li.tu-berlin.de/15775E.html

Richter, Klaus (1999) "Computer Graphics and Colour Metrics - Colour Systems, PostScript and Device-Independent CIE Colours". This book in German teaches the technical basics for the standards of ISO/IEC, CEN and DIN with 500 colour images, VDE publishing house with CD-ROM, 1999, 288 pages, ISBN 3-8007-1775-1, format A5, 2,6 MB, for free download see
http://farbe.li.tu-berlin.de/BUA4BF.PDF

IEC 61966-2-1, Multimedia systems and equipment — Colour measurement and management — Part 2-1: Colour management; Default RGB colour space; sRGB

PostScript language reference manual, Adobe Systems Incorporated, 3rd ed., 3,2 MB, see
https://www.adobe.com/jp/print/postscript/pdfs/PLRM.pdf