Efficient Colour Workflow for Display and Printer Output in Offices based on the Hue Angles of Elementary Colours of CIE R1-47

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For recent publications of the TUB group see: http://130.149.60.45/~farbmetrik/XY91FEN.html

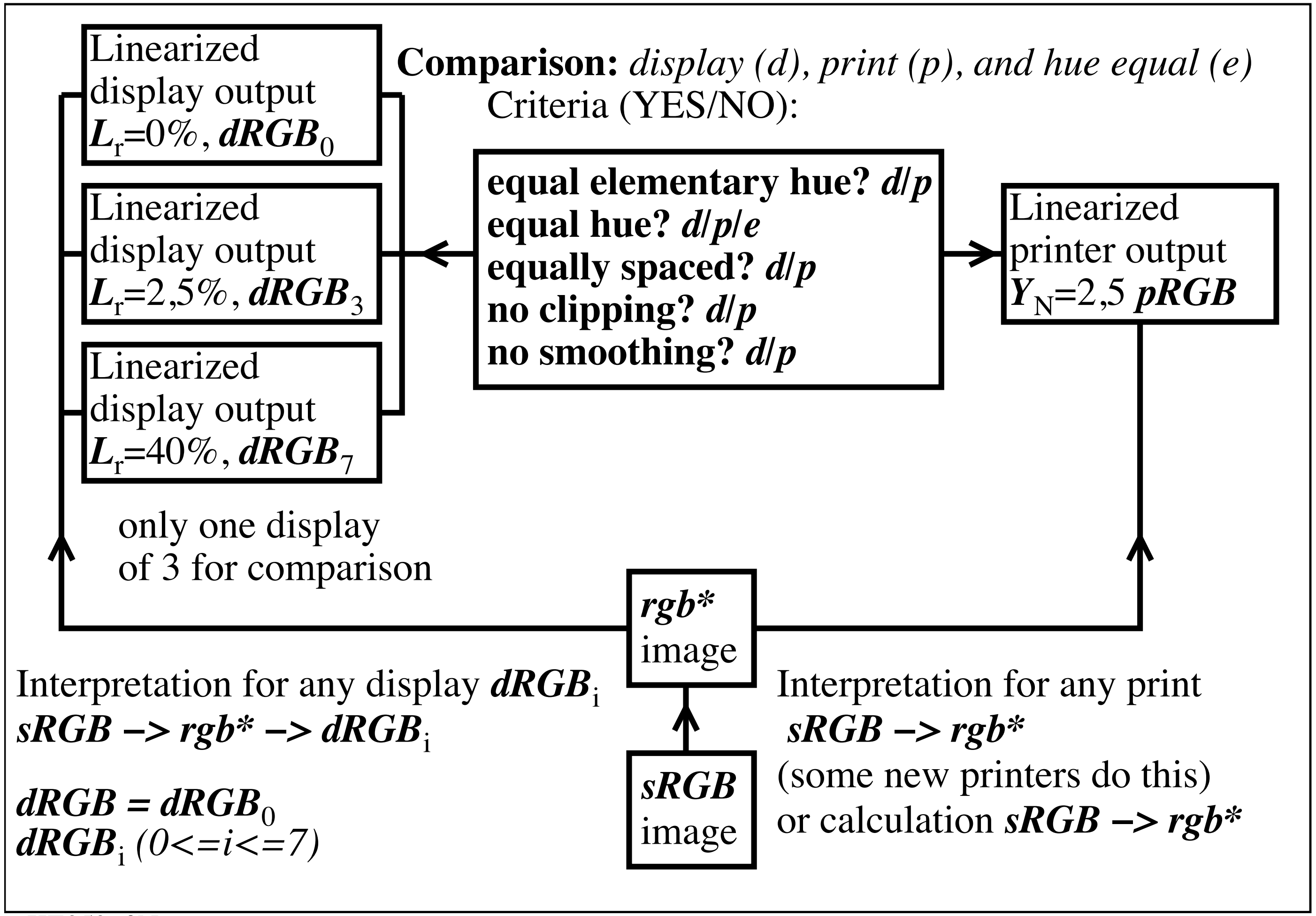
Abstract

The report CIE R1-47:2009 “Hue Angles of Elementary Colours” is used to define an efficient colour workflow for displays and printers in offices compared to an workflow of ISO 15076-1 in Annex A which is called the *ICC* workflow. This paper defines an efficient description of the device gamut by visual human *rgb** coordinates. For example elementary Red *R* is defined by a visual criteria Red *R* as neither yellowish nor blueish.

In addition for the most chromatic colours of a device one of the three coordinates *rgb** has the value 1 and one other the value 0. For example the yellow red colours have the values *rgb**= 1 *x* 0 with *x*=0 for elementary Red *R* and *x*=1 for elementary Yellow *J*. Therefore for all yellow red colours *x* is in the range 0<=*x*<=1.

In CIEXYZ space and in any hue plane any colour of a display are located exactly within a colour triangle. The colours of this triangle are defined by the three colours Black *N*, most chromatic X, and White W. In CIELAB space the three colours N - X - W are still approximately on a colour triangle for any CIELAB hue h_{ab} in any hue plane L^*, C^*_{ab}.

Often the display output serves as reference for the printer output. In CIELAB space this leads to an affine transformation which transfers the hue triangle of a display into a hue triangle of a printer for any hue. This is visually a very efficient transfer and there is only one solution.



KE250–3N

Figure 1: Workflow *rgb* interpretation as elementary colours *rgb and *rgb** linearization**

Figure 1 shows the workflow with *rgb* interpretation of the *sRGB* image as elementary colour data *rgb** (*rgb->rgb*).* The *rgb** data are used for linearization and this will produce on all devices (three displays (d) and one printer (p)) the elementary hues, the equal hues, the equal spacing, and *no* clipping. Some displays and printers already produce the elementary hue output instead of the device hue output or the elementary and device hue output is very similar.

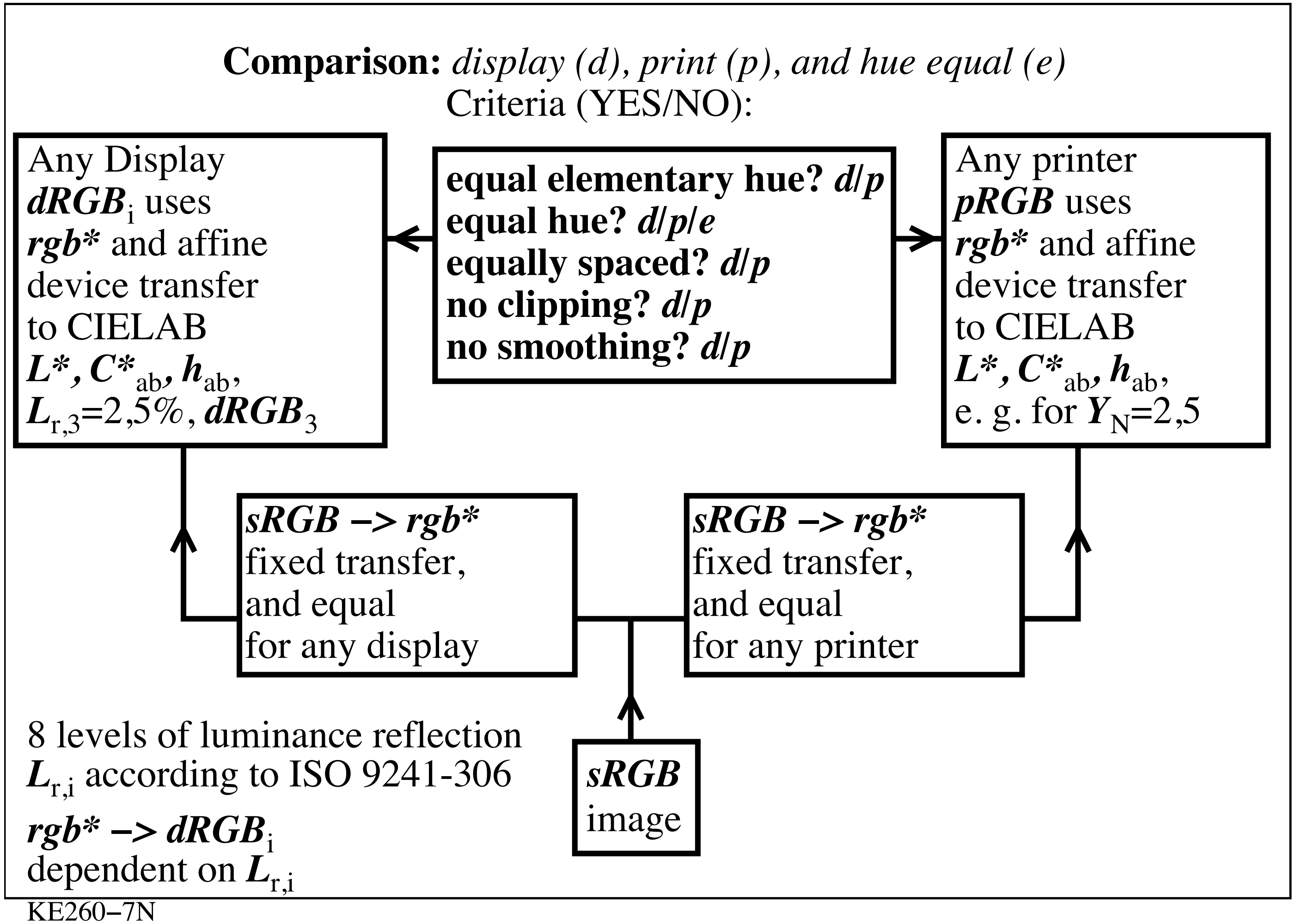


Figure 2: Workflow *rgb* interpretation as elementary colours *rgb and *rgb** linearization**

For the *sRGB* image figure 2 shows the workflow with *rgb* interpretation as elementary colours *rgb** (*rgb->rgb*),* and *rgb** linearization. The *rgb** data are used for linearization which will produce on the standard display with 2,5% luminance reflection and the printer the elementary hues, the equal hues, the equal spacing and *no* clipping. Figure 2 indicates, that the transfer between *sRGB* and *rgb** is *independent and equa*l for any display or printer output.

rgb –> rgb* and CIE data of a elementary hue circle according to CIE R1-47:2009 for sRGB display L_r=2,5%

3 colours of the elementary hues RJGB: $h_{ab,a}$ = 25.4 , 92.3 , 162.2 , 271.7

Code	L^*_a	a^*_a	b^*_a	$C^*_{ab,a}$	h_{ab}	rgb –> rgb*
r00j=R	53.0	72.6	34.5	80.4	25.4	1.00 0.00 0.00
0,5(R+N)	35.5	36.3	17.2	40.2	25.4	0.50 0.00 0.00
0,5(R+W)	74.2	36.3	17.2	40.2	25.4	1.00 0.50 0.50
j00g=J	83.8	−3.0	77.4	77.5	92.2	1.00 1.00 0.00
0,5(J+N)	50.9	−1.5	38.7	38.7	92.2	0.50 0.50 0.00
0,5(J+W)	89.6	−1.5	38.7	38.7	92.2	1.00 1.00 0.50
g00b=G	85.4	−61.5	19.7	64.6	162.1	0.00 1.00 0.00
0,5(G+N)	51.7	−30.7	9.8	32.3	162.1	0.00 0.50 0.00
0,5(G+W)	90.4	−30.7	9.8	32.3	162.1	0.50 1.00 0.50
b00r=B	60.9	1.6	−53.5	53.6	271.7	0.00 0.00 1.00
0,5(B+N)	39.4	0.8	−26.7	26.8	271.7	0.00 0.00 0.50
0,5(B+W)	78.1	0.8	−26.7	26.8	271.7	0.50 0.50 1.00

5 step equidistant grey scale: L^* = 18.0 , 37.3 , 56.7 , 76.0 , 95.4

Code	L^*_a	a^*_a	b^*_a	$C^*_{ab,a}$	h_{ab}	rgb –> rgb*
n000w=N	18.0	0.0	0.0	0.0	0.0	0.00 0.00 0.00
n025w	37.3	0.0	0.0	0.0	325.3	0.25 0.25 0.25
n050w	56.7	0.0	0.0	0.0	324.8	0.50 0.50 0.50
n075w	76.1	0.0	0.0	0.0	323.7	0.75 0.75 0.75
n100w=W	95.4	0.0	0.0	0.0	0.0	1.00 1.00 1.00

KE171−8N, LAB*la3, adapted=not adapted

rgb –> rgb* and CIE data of a elementary hue circle according to CIE R1-47:2009 for offset print

3 colours of the elementary hues RJGB: h_{ab} = 25.4 , 92.3 , 162.2 , 271.7

Code	L^*_a	a^*_a	b^*_a	$C^*_{ab,a}$	h_{ab}	rgb –> rgb*
r00j=R	48.7	66.7	31.8	73.9	25.4	1.00 0.00 0.00
0,5(R+N)	35.5	33.3	15.9	36.9	25.4	0.50 0.00 0.00
0,5(R+W)	72.5	33.3	15.9	36.9	25.4	1.00 0.50 0.50
j00g=J	86.1	−3.3	83.2	83.3	92.3	1.00 1.00 0.00
0,5(J+N)	54.2	−1.6	41.6	41.6	92.3	0.50 0.50 0.00
0,5(J+W)	91.2	−1.6	41.6	41.6	92.3	1.00 1.00 0.50
g00b=G	56.9	−61.5	19.6	64.5	162.2	0.00 1.00 0.00
0,5(G+N)	39.6	−30.7	9.8	32.2	162.2	0.00 0.50 0.00
0,5(G+W)	76.6	−30.7	9.8	32.2	162.2	0.50 1.00 0.50
b00r=B	41.2	1.3	−45.0	45.0	271.7	0.00 0.00 1.00
0,5(B+N)	31.7	0.6	−22.5	22.5	271.7	0.00 0.00 0.50
0,5(B+W)	68.8	0.6	−22.5	22.5	271.7	0.50 0.50 1.00

5 step equidistant grey scale: L^* = 22.2 , 40.7 , 59.3 , 77.8 , 96.3

Code	L^*_a	a^*_a	b^*_a	$C^*_{ab,a}$	h_{ab}	rgb –> rgb*
n000w=N	22.5	0.0	0.0	0.0	37.9	0.00 0.00 0.00
n025w	40.8	−0.3	−1.4	1.4	256.8	0.25 0.25 0.25
n050w	59.2	−0.3	−1.8	1.8	258.1	0.50 0.50 0.50
n075w	77.8	−0.2	−1.4	1.4	259.2	0.75 0.75 0.75
n100w=W	96.4	0.0	0.0	0.0	100.0	1.00 1.00 1.00

KE110−8N, Offset print, model separation cmyn6*

rgb –> rgb* and CIE data of a elementary hue circle according to CIE R1-47:2009 for photo printer

3 colours of the elementary hues RJGB: h_{ab} = 25.4 , 92.3 , 162.2 , 271.7

Code	L^*_a	a^*_a	b^*_a	$C^*_{ab,a}$	h_{ab}	rgb –> rgb*
r00j=R	34.1	61.4	29.2	68.0	25.4	1.00 0.00 0.00
0,5(R+N)	21.4	30.7	14.6	34.0	25.4	0.50 0.00 0.00
0,5(R+W)	63.4	30.7	14.6	34.0	25.4	1.00 0.50 0.50
j00g=J	83.9	−4.3	106.1	106.2	92.3	1.00 1.00 0.00
0,5(J+N)	46.2	−2.1	53.0	53.1	92.3	0.50 0.50 0.00
0,5(J+W)	88.3	−2.1	53.0	53.1	92.3	1.00 1.00 0.50
g00b=G	46.8	−58.9	18.9	61.8	162.1	0.00 1.00 0.00
0,5(G+N)	27.7	−29.4	9.4	30.9	162.1	0.00 0.50 0.00
0,5(G+W)	69.7	−29.4	9.4	30.9	162.1	0.50 1.00 0.50
b00r=B	38.1	1.3	−43.4	43.5	271.7	0.00 0.00 1.00
0,5(B+N)	23.4	0.6	−21.7	21.7	271.7	0.00 0.00 0.50
0,5(B+W)	65.4	0.6	−21.7	21.7	271.7	0.50 0.50 1.00

5 step equidistant grey scale: L^* = 8.6 , 29.6 , 50.6 , 71.6 , 92.6

Code	L^*_a	a^*_a	b^*_a	$C^*_{ab,a}$	h_{ab}	rgb –> rgb*
n000w=N	8.7	0.0	0.0	0.0	1.2	0.00 0.00 0.00
n025w	29.6	−0.3	−7.1	7.1	266.8	0.25 0.25 0.25
n050w	50.7	−2.8	−5.4	6.1	242.2	0.50 0.50 0.50
n075w	71.7	−1.8	−5.0	5.3	250.0	0.75 0.75 0.75
n100w=W	92.6	0.0	0.0	0.0	220.9	1.00 1.00 1.00

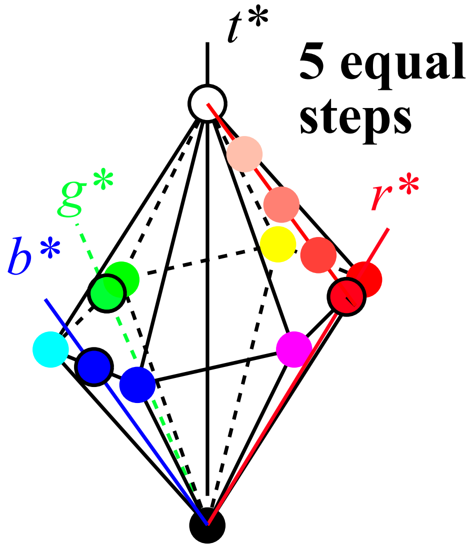
KE110−4N, photo printer, printer separation olv*

Figure 3: *rgb and CIE data of elementary colours *RJGB* and mixtures with *W* and *N*.**

Figure 3 shows *rgb** and CIE data of elementary colours ***RJGB*** and mixtures with White *W* and Black *N* for the standard $sRGB_3$ display with L_r=2,5%, standard offset print *pRGB,* and a photo printer *pRGB*.

For the colour output the CIELAB hue angles h_{ab} are equal for the three colour outputs. However, for example the CIELAB lightness L^* of Green *G* and Blue *B* is much larger for the $sRGB_3$ display compared to the two print outputs *pRGB* of offset print and the photo printer.

6 Elementary (e) colours $rgb_e^*=rgb^*$ *in CIELAB: RJGB* and *NW*



Hexagon-triangle system based on elementary (e) colours: $rgb_e^*=rgb^*$
with **linear relations** between rgb_e −> rgb^* − LCH^*
(compare linear relations between rgb_{sRGB} *and* L^**)*

Equations rgb^* − LCH^* in both directions have been published, see:
Richter, CIE-Proceedings, Beijing, 2008, Volume 3 und DIN 33872-1

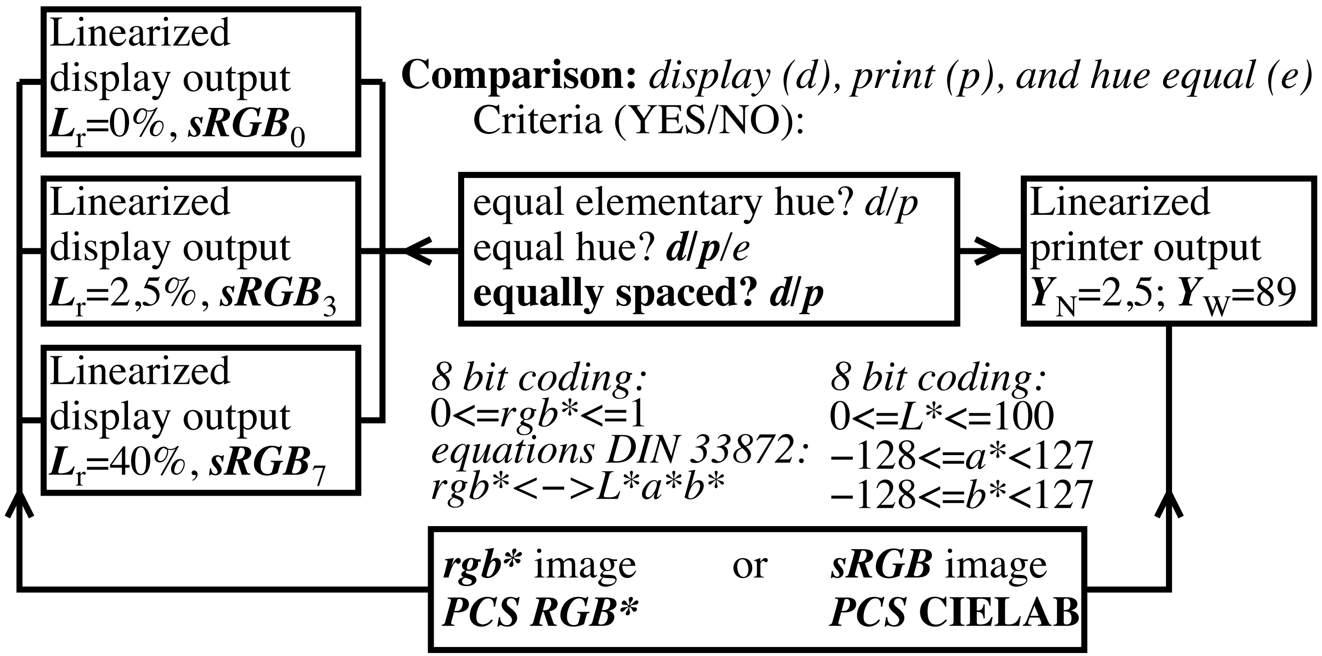
Three equations (tables) are needed for office applications:

rgb_e − $LCH^{*\prime}$	for a 9x9x9 grid of equally spaced rgb_e-input data
rgb^* − LCH^*	a 9x9x9 grid of equally spaced data rgb^* and LCH^*
rgb'^*− LCH^*	***Device output linearisation by*** rgb_e −> rgb'^*

KE291-5N

Figure 4: Elementary colour data *rgb and three sets of relations for device linearization**

Figure 4 shows elementary colour data *rgb** and three sets of relations for device linearization. A first table connects the rgb_e input data with the measurement data *LCH*'* of the start output, for the notation compare ISO/IEC 15775. The second relation *rgb** - *LCH** is an equation in both directions, see for example DIN 33872-1. The third relation shows the calculated *rgb'** input data for the output of the intended *LCH** data. Finally if the table rgb_e - *rgb'** is applied the intended equally spaced colour series will appear on the output device. These tables are available for offset print, different *rgb* displays and printers and different *cmyn* separations of *PS* printers. There are a few limitations: The start output *LCH*'* should produce continuous output series and all output colours shall be reproducible within any hue triangle. For examples of calculated *rgb'** data for different printers and separations see http://130.149.60.45/~farbmetrik/HE.HTM



Luminance reflection L_r	rgb* coding efficiency e_{3D}	CIELAB Lightness L^*_N	L^*_W	relative Lightness $l_r = (L^*_W - L^*_N)/95$	3D-Colour Gamut size $g_{3D} = [l_r]^3$	CIE coding efficiency e_{3D}(CIE 168)
0%	1,00	0	95	1,00	1,00	0,20 (sRGB)
2,5%	1,00	18	95	0,81	0,53	0,10
40%	1,00	70	95	0,26	0,02	0,004

KE231–3N,

Figure 5: Workflow and efficiency with Profile Connection space *(PCS) RGB and CIELAB.**

Figure 5 shows the workflow and efficiency with the *Profile Connection space (PCS) RGB** and CIELAB. If the *PCS RGB** is used, then the coding efficiency has the value 1,00 for the three luminance reflections. If the *PCS* CIELAB is used, then the coding efficiency reduces from the value 0,2 to 0,004. Therefore the *PCS RGB** of this paper produces a much higher coding efficiency. This coding efficiency has a constant value 1 for all display luminance reflections.

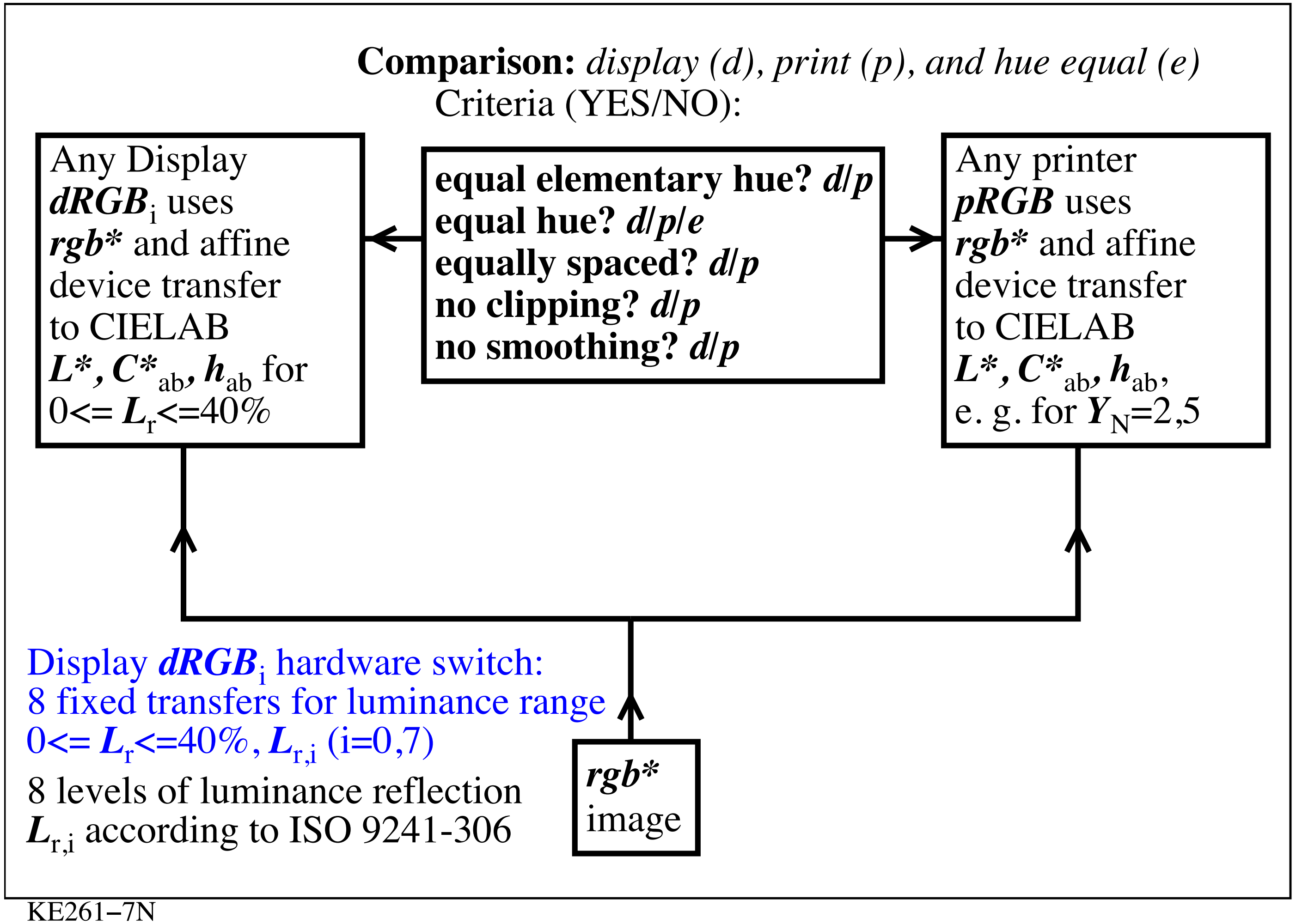


Figure 6: Workflow *rgb* interpretation as elementary colours *rgb and *rgb** linearization**

Figure 6 shows the workflow with *rgb* interpretation of the *rgb** image as elementary colours *rgb** (*rgb->rgb*)*, and *rgb** linearization. The rgb_e -> *rgb** data tables of Fig. 4 within the devices may be used for linearization which will produce on both devices the elementary hues, the equal hues, the equal spacing and no clipping. If 8 data tables are within the display a hardware switch allows to choose visually the equal output spacing for example with the ISO-test chart according to ISO

9241-306, see the ISO-test charts (200 KB, 1 page) and (1800 KB, 16 pages) for a hardware switch and a software solution respectively

http://www.ps.bam.de/ME16/10L/L16E00NP.PDF

http://www.ps.bam.de/ME15/10L/L15E00FP.PDF

Annex D of ISO 9241-306 includes a solution with the computer operation system *MAC OS 10.4.* The equal output spacing is the requirement for a “trusted” output. The trusted output does not allow any colour enhancement, any clipping or smoothing. However, in other cases there may be a user wish to make the output more chromatic compared to the original.

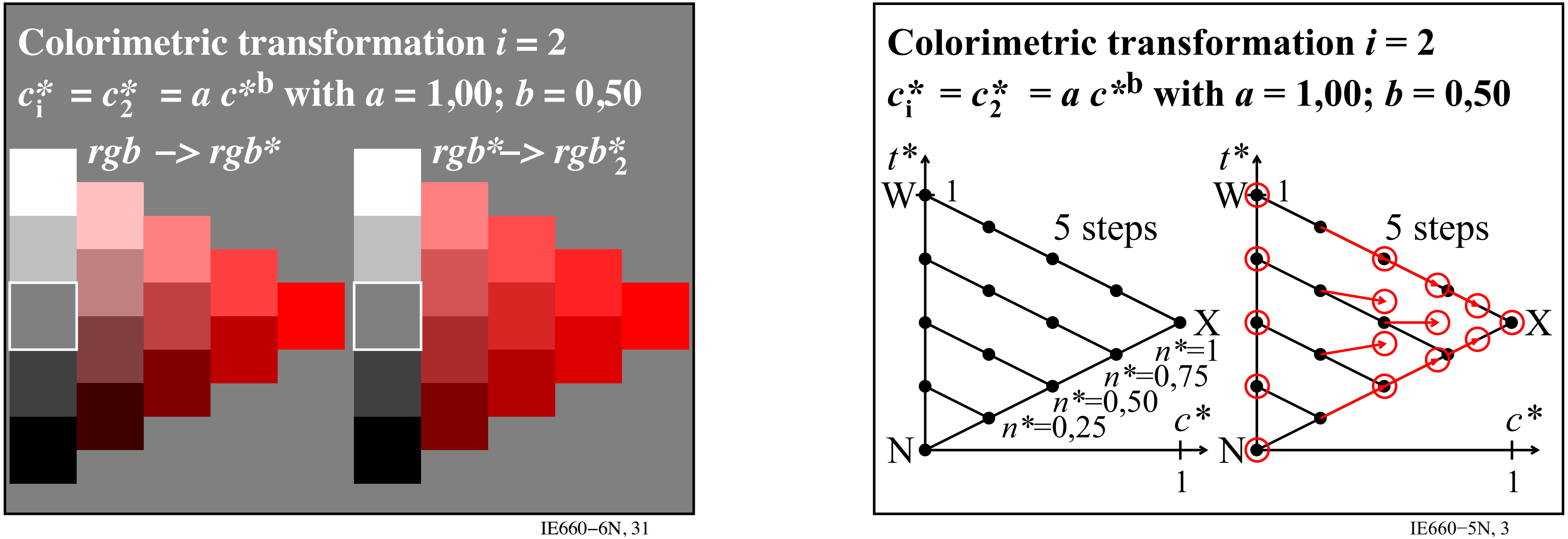


Figure 7: Chroma enhancement by $c^{*\prime}=c^{*2}$ and visualization in hue triangle *N - X - W*

Figure 7 shows the chroma change by a formula $c^{*\prime}= c^{*2}$. The changed colours are still located within the colour triangle and can therefore be reproduced. The achromatic colours and the most chromatic colour are not changed. This transfer is used for photographic chroma enhancement.

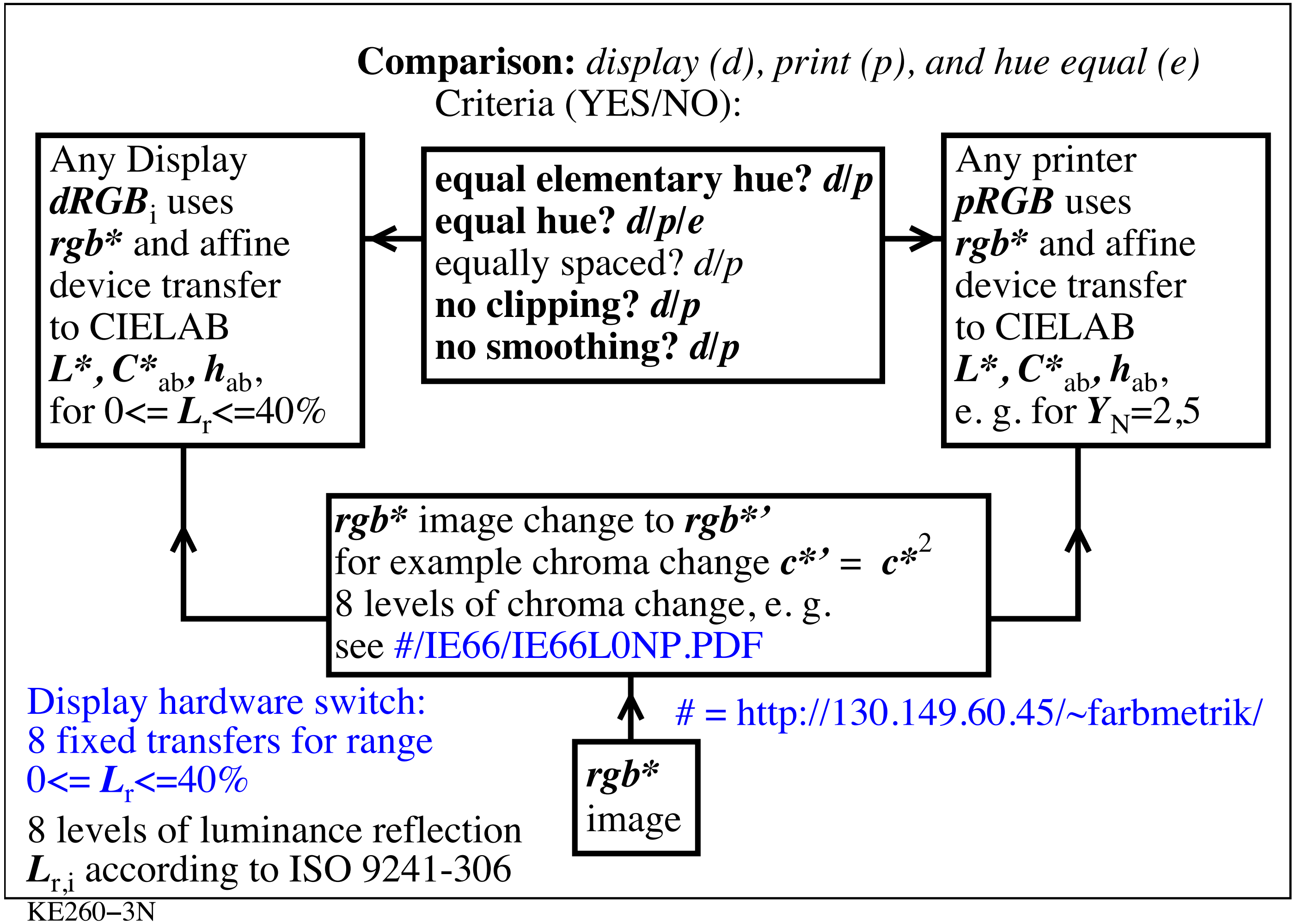


Figure 8: Workflow, *rgb output linearization, and change of chroma by a simple formula**

Figure 8 shows the workflow with *rgb* interpretation of the *rgb** image as elementary colours *rgb** (*rgb->rgb*),* and *rgb** linearization. By a **chroma transfer** the *rgb** data are changed. Both devices produce the elementary hues, the equal hues and no clipping. However equal spacing does not appear, the chroma differences are large near the achromatic axis and small near the maximum chroma. A hardware switch can for example produce 8 transfers (see test file in Fig. 7).

Additional remarks:
There are ISO-test charts according to ISO/IEC TR 24705 which allow to test the output properties of displays and printers, see for the test charts: http://www.ps.bam.de/24705E

There are DIN-test charts according to DIN 33872 (in print) which allow to test the properties of the workflow between the digital file and the output on displays and printers, see http://www.ps.bam.de/33872E

The DIN-test chart according to DIN 33872-6 allow to test if *no* smoothing occurs.

The DIN-test chart according to DIN 33872-5 allow to test if there is elementary hue agreement.

The DIN-test chart according to DIN 33872-2 and -3 allow to test if there is equal spacing of the chromatic and achromatic output respectively.

Summary

The report CIE R1-47:2009 “Hue Angles of Elementary Colours” is used to define an efficient *rgb** colour workflow for displays and printers in offices compared to the *ICC*-workflow of ISO 15076-1. In addition an efficient description of the device gamut by visual human *rgb** coordinates is described. The efficiency of the *rgb** workflow is constant and has the equal value 1 for any luminance reflection of the display. If colour management according to ISO 15076-1 is applied and if 8 bit coding in *ICC-LAB* is used, then the efficiency reduces between 0,2, 0,1, and 0,004 for the luminance reflections between 0%, 2,5%, and 40% respectively. Therefore a large improvement is reached if the proposed *Profile Connection Space PCS RGB** is used.

For many application in offices colour management without a PCS and still the high efficiency is possible, for example if the device manufacturers have included the transfer rgb_e - *rgb'** in their device. Display manufacturers may include the transfer for 8 luminance reflections, compare Figure 6. A similar hardware switch may allow to produce 8 chroma transfers between more chromatic and achromatic, compare Fig. 8.

Instead of the hardware solutions there are already software solutions, see for example Annex D of ISO 9241-306.

References

CIE R1-47:2009, Hue angles of elementary colours (35 pages, 2,1 MB), see the CIE web site under “Meetings”
http://div1.cie.co.at

CIE 168:2005: Criteria for the Evaluation of Extended-Gamut Colour Encodings

DIN 33872-1 to -6 (in print), Information technology - Office machines - Method of specifying relative colour reproduction with YES/NO criteria
- Part 1: Classification, terms and principles
- 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 discriminibility
- Part 6: Test charts for output properties - Testing of the equivalent spacing and of the regular chromatic spacing

For additional information see the PDF file (41 pages, 1,4 MByte) with the title
Colorimetric supplement to DIN 33872-1 to -6
http://www.ps.bam.de/D33872-AE.PDF
For the test charts according to DIN 33872-1 to -6 see
http://www.ps.bam.de/33872E

ISO 9241-306:2009, Ergonomics of human-system interaction - Part 306: Field assessment methods for electronic visual displays
For the test charts according to ISO 9241-306 see
http://www.ps.bam.de/9241E

ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: CIE Colorimetry — Part 4: 1976 L*a*b* Colour Space (CIELAB)

ISO 15076-1:2005, Image technology colour management -- Architecture, profile format and data structure -- Part 1: Based on ICC.1:2004-10

ISO/IEC 15775:1999, Information technology – Office machines – Method of specifying image reproduction of colour copying machines by digital and analog test charts – Realisation and application

ISO/IEC TR 19797:2004, Device output of 16-step colour scales, output linearization method (LM) and specification of the reproduction properties
For the test charts according to ISO/IEC TR 19797 see
http://www.ps.bam.de/19797E

ISO/IEC TR 24705:2005, Method of specifying image reproduction of colour devices by digital and analog test charts
For the test charts according to ISO /IEC TR 24705 see
http://www.ps.bam.de/24705E

Annex A
Abbreviations used for the workflow of this paper

The abbreviations display (d), print (p) and standard (s) lead to image coding in the spaces: ***dRGB, pRGB,*** and ***sRGB.***

ISO 9241-306 defines 8 luminance reflections: $\boldsymbol{L}_{r,i}$ = 0, 0,6, 1,2, 2,5, 5, 10, 20, 40% *(i=0 to 7).*

This leads to 8 image data sets ***dRGB***$_i$ and/or ***sRGB***$_i$ and 8 luminance reflections $\boldsymbol{L}_{r,\,i}$ *(i=0 to 7)*.

Fig. 1 includes ***YES/NO questions*** for the ***comparison softcopy - hardcopy***.
The three displays and the printer fulfills all the ***YES criteria*** according to the workflow.

Fig. 2 shows for the ***sRGB*** image the workflow with *rgb* interpretation as elementary colours ***rgb**** (*rgb->rgb*),* and ***rgb**** **linearization**.

The *rgb** data are used for linearization which will produce on both devices the *elementary hues, the equal hues, the equal spacing and no clipping*.

The DIN-test chart according to DIN 33872-6 allow to test if *no* smoothing occurs. In addition DIN-test chart according to DIN 33872-5 may be used for the equal elementary hue test.

Fig. 2 includes the technical property, that the *rgb** data are equal for the display device and the printer device. In addition they are equal for all display devices ***dRGB***$_i$ and the standard display devices ***sRGB***$_i$ (i=0 to 7).

Annex B
Intended output by “absolute” *ICC*-colour management according to ISO 15076-1

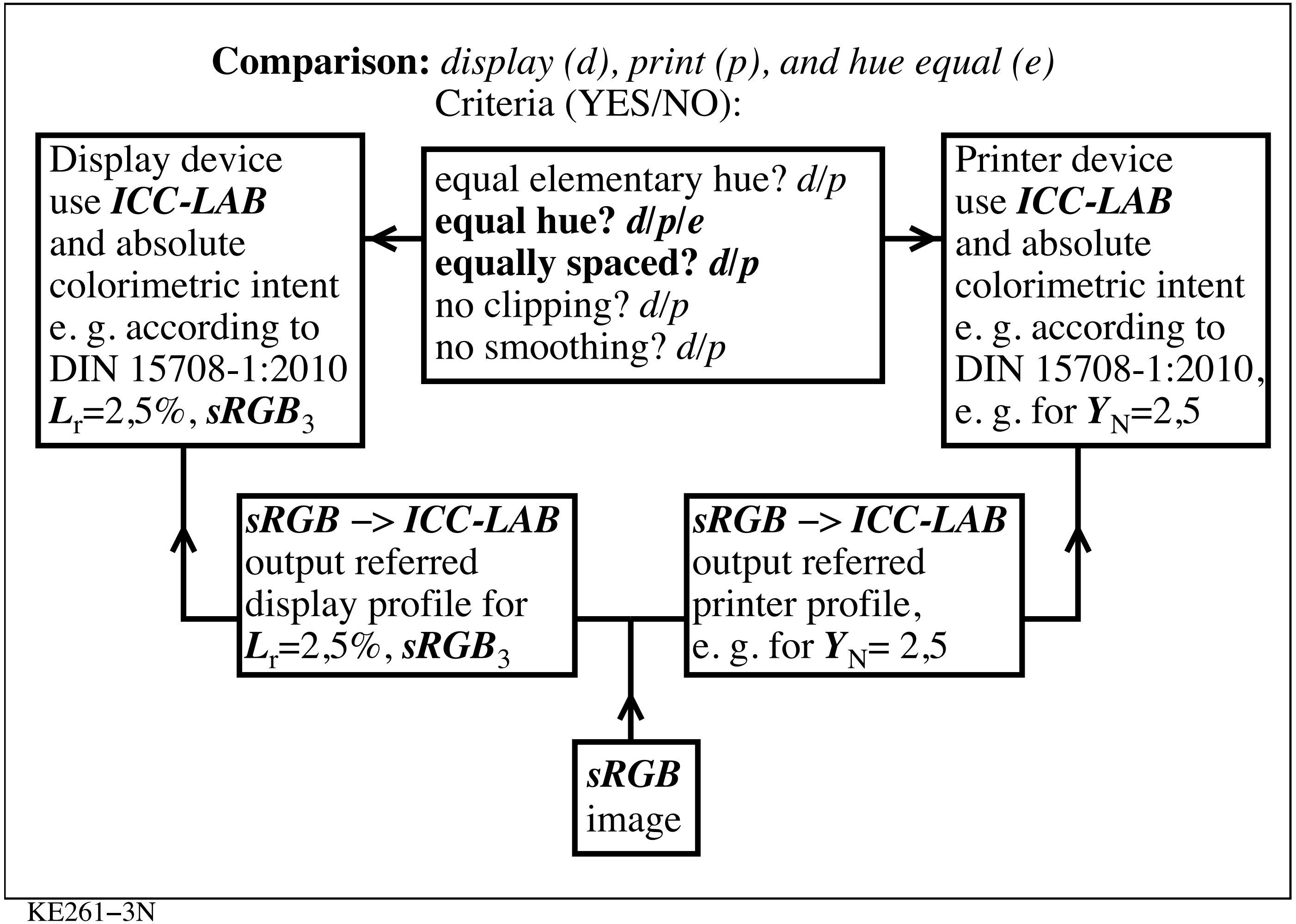


Figure 9: Workflow *sRGB* interpretation as output referred device colours *ICC-LAB*

For the *sRGB* image Figure 9 shows the workflow *rgb* interpretation as output referred device colours *ICC-LAB*. For 8 display reflections 8 *ICC-LAB* profiles are necessary. According to ISO 9241-306 the gamma value changes from 2,4 for L_r=0% to about 1,1 for L_r=40%.

The main part of this paper describes the output gamut boundary of any display or printer by an equation in both directions similar to the following equations for any hue plane:

rgb^* <-> L^*, C^*_{ab}, h_{ab}.

In addition in both directions there is an equation

sRGB <-> L^* C^*_{ab}, h_{ab}

and an equation

sRGB <-> *ICC-LAB*

Remark: ICC-LAB is not identical to CIELAB. For example there are differences in normalization (media white in ICC instead of perfect white diffuser in CIELAB equations).

All relations together allow to make *ICC*-profiles for colour management according to ISO 15076-1. If the *ICC-LAB* data are calculated for the 9 step colour series in an elementary hue plane and sent to the display or printer device with the task to reproduce the *ICC-LAB* data by ”absolute” colour management, then the equally spaced colour series in CIELAB will appear on the display or the printer.

Examples of this kind of ”absolute” colour management are given in the new standard DIN 15708-1:2010 with the title: Electronic still picture - Quality check of digital RGB input data - Part 1: Output on printing devices.

For the DIN-test charts according to DIN 15708-1 see
http://130.149.60.45/~farbmetrik/_Referenzkeil_DIN_15708-1/