CIE and ICC colorimetry for 16 step colour scales equally spaced in CIELAB

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This paper is a comment to the draft **ISO/WD 15076, 2003-01-24**: “Image Technology - ICC Colour Management - Architecture, profile format, and data structure”. In this draft there seem to be a very special ICC *L** definition compared to the CIE *L** definition, which may produce many difficulties in applications and this is discussed.

16-step CIELAB scales on monitors by different ambient light reflection

The 16-step colour series of the ISO/IEC-test charts according to Draft TR ISO/IEC 24705:2003 are equally spaced in the CIELAB colour space, e. g. on papers or monitors. On monitors the 16-step equal spacing in the CIELAB colour space is destroyed for dark grey colours by any additional reflection of the ambient office lighting on the monitor surface. The changes of the grey scales for different ambient light reflection are shown in Fig. 1. It is shown in Table 1 and 2 that the spacing of the 16 step colour series on the monitor must be changed to receive a final equal spacing for the four different reflections of the ambient lighting on the monitor surface. Reflection prints with variable amounts of gloss or matt surfaces show similar changes of black and other lightness data.

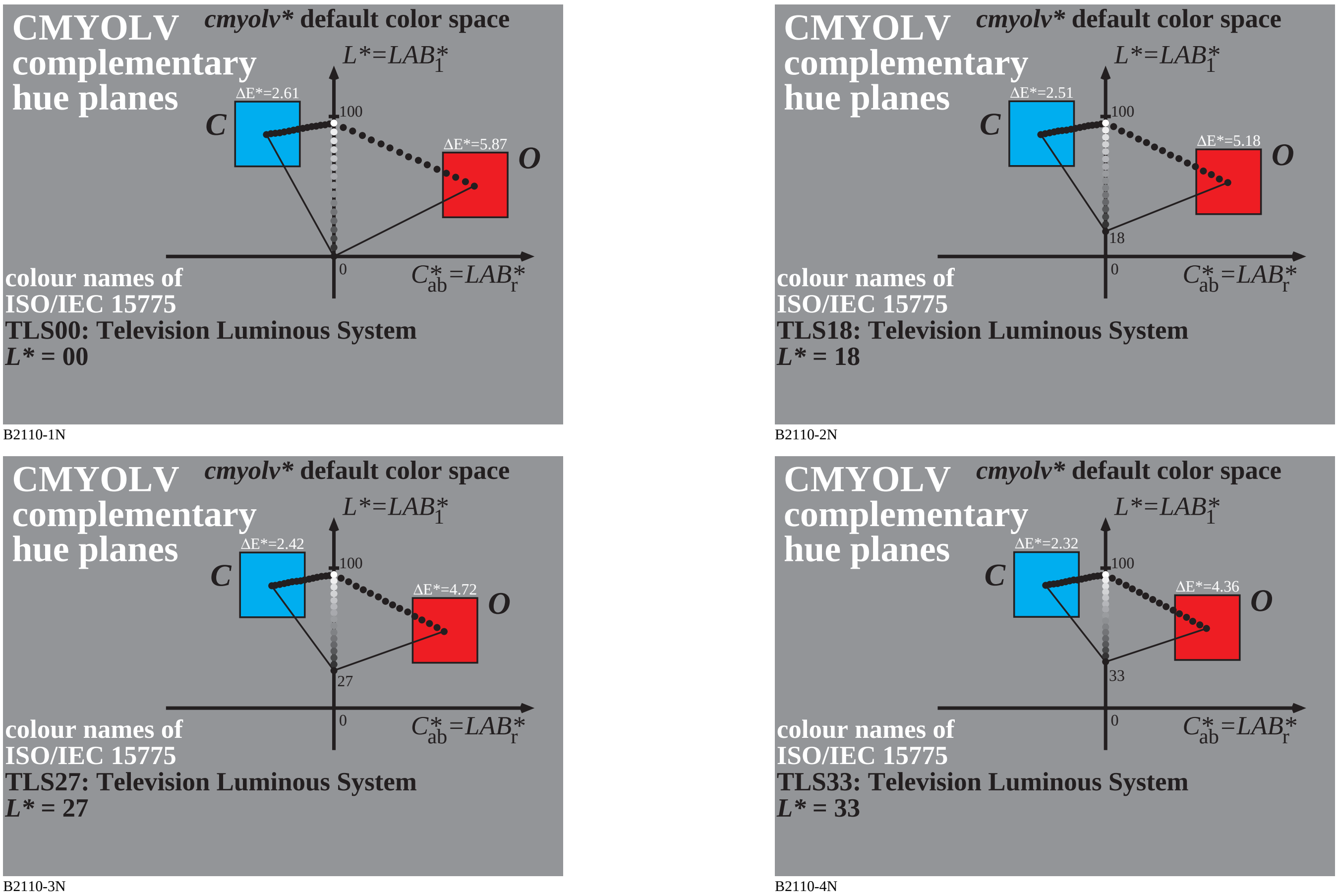

Figure 1: Complementary monitor colours C and O for L^*_N = 0, 18, 27, 33

In Fig. 1 there is a drastic colour change of the monitor colours by the reflection of the ambient office lighting on the monitor surface. The CIELAB lightness of the black is L^*=0, 18, 27 and 33 for the luminance reflectance Y_r =0, 2.5, 5.0, and 7.5 respectively. The CIELAB chroma of the two colours Orange-red O and Cyan-blue C is reduced with increasing ambient light reflections. The colour difference of one step is reduced from 5.87 to 4.36 for O.

It is intended in the International Technical Report ISO/IEC 24705 to produce equally spaced 16-step series in the relative CIELAB space for all ambient light conditions in the office. Only lightness is considered in the following.

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Lightness for 16-step scales on monitors by different ambient light reflection

The following Table 1 gives basic data about the changes by the ambient lighting.

The luminance transmittance Y_t of the monitor is always measured with the measuring instrument on top of the monitor surface. The normalisation $Y_t = 88.59 - Y_r$ is used. The four luminance reflectance Y_r =0, 2.5, 5.0, and 7.5 are considered.

> NOTE: The reflection of the monitor surface may change by a factor 10, e. g. between Y_r=0.25 and Yr=2.5 depending on the surface coating of the monitor and by a smaller factor by the reflection of the white, grey or black walls perpendicular to the monitor surface.

According to Table 1 for equal spacing on the monitor and in the case of **no** reflection the black sample (hex code F) and the first grey step (hex code E) must have the luminance transmittance Y_t = 0,0 and Y_t = 0,7 which corresponds
$Y_N = Y_{Fcode}$ = 0.00 and Y_{Ecode} = 0.70 and the lightness
$L^*_N = L^*_{Fcode}$ = 0.00 and $L^*_E = L^*_{Ecode}$ = 6.36 (compare Table 1).

For equal spacing and in the case of **standard** reflection of the ambient lighting (Y_r = 2.5) the black sample (hex code F) and the first grey step (hex code E) must have the luminance transmittance Y_t = 0.0 and Y_t = 1,33. For the grey step with the hex code E this is **twice** as large compared to the luminance transmittance with **no** reflection. The luminance reflectance Y_r = 2.5 must be added to the luminance transmittance Y_t to calculate the actual luminance reflectance Y. Then the black sample (hex code F) and the first grey step (hex code E) have the actual luminance reflectance Y which corresponds to
$Y_N = Y_{Fcode}$ = 2.52 and Y_{Ecode} = 3.85 and the lightness
$L^*_N = L^*_{Fcode}$ = 18.01 and L^*_{Ecode} = 23.17 (compare Table 1).

System TLSxx	actual CIE Lightness $L^*_{CIE} = f(Y)$				actual Luminance reflectance Y				Luminance transmittance Y_t				Transmission factor Y_t / Y_{tmax}			
Code	L^*_N= 00	18	27	33	L^*_N= 00	18	27	33	L^*_N= 00	18	27	33	L^*_N= 00	18	27	33
00, F	0.0	18.01	26.85	33.05	0.0	2.52	5.04	7.56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
01, E	6.36	23.17	31.42	37.21	0.7	3.85	6.83	9.65	0.7	1.33	1.79	2.09	0.008	0.015	0.021	0.026
02, D	12.72	28.33	35.99	41.36	1.52	5.58	9.0	12.09	1.52	3.06	3.96	4.53	0.017	0.036	0.047	0.056
03, C	19.08	33.49	40.56	45.52	2.77	7.77	11.59	14.92	2.77	5.25	6.55	7.36	0.031	0.061	0.078	0.091
04, B	25.44	38.65	45.13	49.68	4.56	10.46	14.64	18.15	4.56	7.94	9.6	10.59	0.051	0.092	0.115	0.131
05, A	31.8	43.81	49.7	53.84	7.0	13.71	18.17	21.82	7.0	11.19	13.13	14.26	0.079	0.13	0.157	0.176
06, 9	38.16	48.97	54.27	57.99	10.18	17.57	22.23	25.95	10.18	15.05	17.19	18.39	0.115	0.175	0.206	0.227
07, 8	44.52	54.13	58.84	62.15	14.2	22.1	26.86	30.58	14.2	19.58	21.82	23.02	0.16	0.227	0.261	0.284
08, 7	50.89	59.29	63.42	66.31	19.17	27.34	32.09	35.72	19.17	24.82	27.05	28.16	0.216	0.288	0.324	0.348
09, 6	57.25	64.45	67.99	70.47	25.18	33.36	37.95	41.42	25.18	30.84	32.91	33.86	0.284	0.358	0.394	0.418
10, 5	63.61	69.61	72.56	74.62	32.32	40.2	44.49	47.68	32.32	37.68	39.45	40.12	0.365	0.438	0.472	0.495
11, 4	69.97	74.77	77.13	78.78	40.7	47.91	51.74	54.55	40.7	45.39	46.7	46.99	0.459	0.527	0.559	0.58
12, 3	76.33	79.93	81.7	82.94	50.42	56.56	59.74	62.05	50.42	54.04	54.7	54.49	0.569	0.628	0.655	0.672
13, 2	82.69	85.09	86.27	87.1	61.58	66.18	68.53	70.2	61.58	63.66	63.49	62.64	0.695	0.74	0.76	0.773
14, 1	89.05	90.25	90.84	91.25	74.27	76.84	78.13	79.04	74.27	74.32	73.09	71.48	0.838	0.864	0.875	0.882
15, 0	95.41	95.41	95.41	95.41	88.59	88.59	88.59	88.59	88.59	86.07	83.55	81.03	1.0	1.0	1.0	1.0

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Table 1: 16 step grey scales for four different ambient lighting conditions

Table 1 shows the lightness L^* and other CIE data for the 16-step equally spaced grey scales and for four different reflections of the ambient lighting. The “transmission” factor varies between 0 and 1.

There are four transparent ISO/IEC-test charts with transmission factors according to Table 1 which are very different for the dark grey colours. There are large changes for the grey step with the hex code E, e. g. by a factor 2 for the standard situation (L^*_N = 18) compared to the room with no monitor surface reflection (L^*_N = 0).

> NOTE 1 The black of the achromatic transparent ISO/IEC-test charts no. 3 produced by BAM has the density 4.0 which corresponds to a transmission factor of 0,0001. This corresponds to L^*_N = 0.00 in the room with no monitor surface reflection.

> NOTE 2 ISO/IEC-test charts in transmission mode are available for the four luminance reflectance Y_r = 0, 2.5, 5.0, and 7.5 by BAM.

> NOTE 3 The four transparent ISO/IEC-test charts serve as reference either on top of a monitor or a flat area lamp. With this ISO/IEC-test charts it is possible to determine the reflection properties of the monitor surface in the office. Usually only one of the four transparent ISO/IEC-test charts appears approximately equally spaced in any office and this determines one of the four luminance reflectance Y_r (=0, 2.5, 5.0 or 7.5).

> NOTE 4 For output linearization of the 16-step grey scale on the monitor a direct illuminance or luminance measurement of the 16 steps on the screen and of the reflection luminance Y_r is necessary. The TR ISO/IEC 19797 describes the linearization method for the monitor output based on visual and measurement data.

System TLSxx	actual CIE Lightness $L^*_{CIE} = f(Y)$				relative actual CIE Lightness $100\,(L^* - L^*_N)\,/\,(L^*_W - L^*_N)$				ICC Luminance reflectance $Y_a = 100\,(Y - Y_N)\,/\,(Y_W - Y_N)$				actual ICC Lightness $L^*_{ICC} = f(Y_a)$			
Code	L^*_N= 00	18	27	33	L^*_N= 00	18	27	33	L^*_N= 00	18	27	33	L^*_N= 00	18	27	33
00, F	0.0	18.01	26.85	33.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
01, E	6.36	23.17	31.42	37.21	6.67	6.67	6.67	6.67	0.79	1.55	2.14	2.58	7.18	12.89	16.22	18.27
02, D	12.72	28.33	35.99	41.36	13.33	13.33	13.33	13.33	1.71	3.56	4.74	5.59	13.9	22.15	25.99	28.37
03, C	19.08	33.49	40.56	45.52	20.0	20.0	20.0	20.0	3.12	6.09	7.84	9.08	20.53	29.65	33.65	36.14
04, B	25.44	38.65	45.13	49.68	26.67	26.67	26.67	26.67	5.15	9.22	11.49	13.07	27.15	36.41	40.39	42.87
05, A	31.8	43.81	49.7	53.84	33.33	33.33	33.33	33.33	7.9	13.0	15.72	17.6	33.77	42.76	46.6	49.01
06, 9	38.16	48.97	54.27	57.99	40.0	40.0	40.0	40.0	11.49	17.48	20.58	22.7	40.4	48.86	52.48	54.76
07, 8	44.52	54.13	58.84	62.15	46.67	46.67	46.67	46.67	16.03	22.74	26.11	28.41	47.02	54.81	58.15	60.26
08, 7	50.89	59.29	63.42	66.31	53.33	53.33	53.33	53.33	21.64	28.84	32.37	34.76	53.64	60.64	63.65	65.56
09, 6	57.25	64.45	67.99	70.47	60.0	60.0	60.0	60.0	28.42	35.83	39.39	41.78	60.26	66.39	69.03	70.72
10, 5	63.61	69.61	72.56	74.62	66.67	66.67	66.67	66.67	36.48	43.77	47.22	49.51	66.89	72.08	74.33	75.77
11, 4	69.97	74.77	77.13	78.78	73.33	73.33	73.33	73.33	45.94	52.74	55.9	57.99	73.51	77.72	79.56	80.73
12, 3	76.33	79.93	81.7	82.94	80.0	80.0	80.0	80.0	56.92	62.78	65.47	67.24	80.13	83.33	84.73	85.62
13, 2	82.69	85.09	86.27	87.1	86.67	86.67	86.67	86.67	69.51	73.96	75.98	77.3	86.75	88.91	89.85	90.46
14, 1	89.05	90.25	90.84	91.25	93.33	93.33	93.33	93.33	83.83	86.35	87.48	88.21	93.38	94.46	94.94	95.25
15, 0	95.41	95.41	95.41	95.41	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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Table 2: 16 step grey scales for four different ambient lighting conditions

Table 2 shows the absolute and relative CIE lightness *L** and the luminance reflectance and relative lightness of ICC. Equal differences in relative CIE *L** data give large differences for ICC *L** data and vice versa.

Summary

1. It is expected that only the relative CIE *L** definition for colours with different contrast ratio between black and white on monitors and prints will correspond to the visual assessment.

2. The ICC method which calculates the relative CIE luminance reflectance instead of the **relative CIE lightness** may be a source of the many difficulties in applications.

3. For equal CIE scaling the ICC scaling shows differences by a factor three in the above examples.

4. For office devices equal CIELAB scaling is a fundamental user requirement which is a basic of the standards ISO/IEC 15775:1999, DIN 33866-1 to -5. and the Draft Technical Reports (TR) ISO/IEC 24705:2003 and ISO/IEC 19797:2003. The **relative CIE lightness** data (coding) in a file and the measured output agree in these standards for devices which are linearized in relative CIELAB.

5. Many device manufacturers have already adjusted their device drivers to produce the equally spaced CIELAB output for office conditions.

6. It seems appropriate to use in ISO/WD 15706 of TC 130 the **relative CIE lightness definition** instead of the special ICC lightness definition. A change of ISO/WD 15706 of TC 130 will lead to agreement with the user requirement of equally spaced output in CIELAB and the above standards.

NOTE It is mentioned in ISO/WD 15076 that an ICC version for D65 instead of D50 is under development. For **office applications** with approximately the same luminance and the same chromaticity D65 on the white monitor and paper **no** chromatic adaptation transform and **no** luminance transform is necessary. It may be possible to simplify the ICC Colour Management for the office conditions and it may be possible to produce a new rendering intent with the equally spaced output of the 16-step colour scales (similar as by the MTL code, see [5]) as default.

References:

[1] ISO/IEC 15775:1999-12: Information Technology - Office machines - Method of specifying image reproduction of colour copying machines by analog test charts - Realisation and Application, 50 pages

[2] DIN 33866-1 to -5, edition:2000-07 – Information technology - Office machines - Colour image reproduction equipment - Method for specifying image reproduction of colour devices by digital and analog test charts, Part 1 to 5 for Classification and principles. Copiers, Printers, Scanners, and Monitors. This standard includes four analog DIN-test charts no. 1 to 4 with the 16 step series of Fig. 1 all equally spaced in CIELAB.

[3]Draft Technical Report ISO/IEC 19797:2003, Device output of 16-step colour scales, output linearization method (LM) and specification of the reproduction properties, see on the following SC28 or BAM web-sites

[4]Draft Technical Report ISO/IEC 24705:2003, Method of specifying image reproduction of colour devices by digital and analog test charts, see on the following SC28 or BAM web-sites

http://www.jbmia.or.jp/sc28

[5] K. Richter, Linearized printer output of corresponding colours by the MTL code, (96 kByte, 2 pages),

http://www.ps.bam.de/BAMLIN.PDF

For further information see e. g. the section publications by the URL
http://www.ps.bam.de