

Natural colour connection space (NCCS) between input and output for office systems

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<http://www.ps.bam.de/BAMAG1.PDF>

Abstract

The *Ostwald* and the *Natural Colour System (NCS)* use a three dimensional **double cone with a circular base** for the order of about 5 Million surface colours which observers may distinguish. The NCS system uses three colorimetric coordinates: blackness, chromaticness and elementary hue (n_{ce}^*) for the colour order. This paper defines the colorimetric coordinates tab^* (triangle lightness, red-green and yellow-blue chromaticness) and tch^* (triangle lightness, chromaticness and hue) of a colour double cone. All colorimetric coordinates show a linear relationship to the CIELAB data for a linearized colour device.

Colour order systems use three coordinates out of a variety of about 15. Depending on the application one triple (three coordinates) out of many different triples are used. Up to now in the field of Image Technology for input and output of colours by office devices there seem to be no application programs which use the many colour order coordinates of architecture, art, design and industrial applications.

The coordinates olv^* and $cmY0^*$ and the new double cone coordinates tch^* are additionally a new basis for a long term storage of colours in documents (ISO TC 171) and for the viewing of colour displays (ISO TC 159) at daylight work places. The encoding and decoding of the spaces is of interest for digital cameras and photography (ISO TC42). The simple NCCS has many advantages for the colour workflow between colour input and output in the office area (ISO/IEC SC28). If in future the new coordinates are used then this may have some influence on the area of professional printing (ISO TC 130).

1. Introduction

This paper is intended to be a discussion paper for several New Work Item proposals in the international standard groups ISO/IEC SC28 and other ISO committees and in the national standard group DIN NI 28 to define, scan, view and print colour. The colorimetric colour coordinates $cmY0^*$ and olv^* of ISO/IEC 15775, ISO/IEC TR 19797 and ISO/IEC DTR 24705 are used as a start point to define user friendly colorimetric device colour coordinates for input, output and communication. The colour coordinates of the above documents (olv^* and $cmY0^*$) and the new defined coordinates (lab^* , tab^* , tch^* , trj^* , n_{ce}^* and others) are all linearly related to the CIELAB coordinates. If the eight **device coordinates CMYOLVNW** are known in the CIELAB space then there are linear transformations between any triple of CIELAB coordinates (LAB^* or LCH^*) and any triple of device colour coordinates for instance the coordinates n_{ce}^* (device blackness, chromaticness and elementary hue) in both directions. Similar coordinates are used in the *Swedish Natural Colour System (NCS)*.

Further it is proposed to use for coding the coordinates of the offset space of ISO/IEC 15775 as default. At present some ISO and IEC standards use the *sRGB* coding of a CRT television space as default. In TC 42 there is the tendency to use the *rgb* data of the *Adobe RGB* colour space.

Most of the present coordinates used in image technology have a **non linear** connection to the CIELAB data. This is a large disadvantage. For instance the *Adobe RGB* colour data have a linear relationship to the CIE XYZ data. and there is a cube root relation to the CIELAB data. Therefore for the same accuracy compared to the spacing in olv^* one needs at least in *Adobe RGB* twice as much bits for storage and transmittance of images. A coding in olv^* shows linear data 0, 1/15, 2/15, ... 15/15 in the file for 16 step equally spaced colour series. This is not the case for the *Adobe RGB* data which need for example for the grey scale the digital data 0, $(1/15)^2$, $(2/15)^2$, ..., $(15/15)^2$ in the file. The *sRGB* data of an equally spaced grey scale are linearly related to CIELAB which is an advantage of *sRGB*. But there are large problems in the blue green area with the *sRGB* coding. For example for a 16 step equally spaced colour scale of printing between white and cyan blue the coding differences vary by a factor 8 in the *sRGB* space. However, the coding differences of the olv^* data are constant which is a large advantage for definition and communication.

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The coordinates tch^* (triangle device lightness, chromaticness and hue) define for the offset colour space a double cone with a circular base. The new coding uses for the grey and colour scales as default only 7 out of 8 bit. Then all offset colours are located within the 7 bit colour gamut boundary. There is an extended 8 bit boundary (an extended double cone) which allows to store 4 times more colours (two times in vertical and circular direction) outside the 7 bit boundary. This allows to store highlight, fluorescent, more chromatic and saturated colours which can not be reproduced within the 7 bit gamut boundary. The colorimetric transformations store these colours and the colour information will remain for forward and inverse transformations. Every point inside the 8 bit boundary defines colorimetric coordinates for example the coordinates LCH^* in the CIELAB space and $cmY0^*$ in the CMYN space.

The new 7/8 bit coding is appropriate for the office area. One can store in the CIELAB space for the lightness L^* 128 grey steps. One can recognize a lightness difference of $\Delta L^*=1$ and therefore this is an appropriate choice for the 77 grey steps of the offset grey scale. According to ISO/IEC 15775 there is the user requirement to reproduce at least 16 gray steps and with an accuracy of $\Delta L^* = 3$ (this corresponds to less than 32 grey steps).

The device output of ISO/IEC-test chart files which include colours defined in the CIELAB colour space and the corresponding device dependent colour spaces shows a lot of problems. The corresponding colours produce **very different** output or **no output difference** on monitors and printers. Sometimes for the present **standard software** the monitor output is **very different** (about 20 CIELAB) and there are **no** output differences on printers or vice versa. If a **PostScript MTL code** (Measurement, Transfer and Linearization, see ISO/IEC TR 19797) is added to the code of an ISO/IEC-test chart (the **NP** file) then the output of the new **FP** file produces the same output as expected by users and CIE colorimetry. CIELAB colours and corresponding device dependent colours are used in files to test the compatibility class of the colour workflow in the office.

Remark: The output of this paper produces large color differences (often 20 CIELAB) for the **NP** files on most printers and monitors. The large colour differences for corresponding colours of different colour spaces are **not** intended by users and CIE colorimetry. The output of the **FP** files produces **no** colour differences as intended.

In summary: Based on the new **double cone colorimetric coordinates tch^*** and its **linear connection property to the CIELAB colour space** the door seems open for many new Technical Reports, Technical Specification and Standards in the field of Image Technology. The content will allow an improved connection between the colour fields of art, design, architecture and the field of image technology by user friendly coordinates.

2. Colour order systems and colour in information technology

There are many colour order systems with different colour coordinates. For different applications many different colour coordinates are useful. Not only three but a variety of colour attributes and colour coordinates are necessary for the communication of colours.

Application of colour in daily life or in Information Technology (IT):	
Design, architecture, art, industrial products Measured for CIE standard illuminant D65 colour order system: name and coordinates RAL Design System (CIELAB): LCH^* , lightness, chroma, hue Munsell Colour System: VCH^* , lightness (Value), Chroma, Hue Natural Colour System (NCS): nce^* : blackness, chromaticness, elementary hue	Information technology of printers Measured for CIE "other" illuminant D50 Device system name and coordinates: Printer system (illuminant D50): cmY , content of "cyan", "magenta", "yellow" Display system (standard illuminant D65): $rgb/sRGB$, content of "red", "green", "blue" <i>IT colour coordinates confuse the users!</i> <i>Nearly no connection to colour order systems!</i>
New: Application connection by coordinates olv^*, cmY^*, tch^*, tce^*, ... and linear relation to LAB^* CIELAB: LAB^* : lightness, red–green and yellow–blue chroma; LCH^* : lightness, chroma, hue Definition of device coordinates similar to coordinates of colour order systems lch^* : relative lightness, chromaticness, hue tch^* , tce^* : triangle lightness, chromaticness, hue or elementary hue nce^* : blackness, chromaticness, elementary hue	

LE430–3, Application connection with coordinates olv^* , cmY^* , tch^* , tce^* , nce^* , ... and linear relationship to LAB^*

Figure 1: Application of colour in color order systems and in information technology (IT).

Fig. 1 shows the application of colours in color order systems and in information technology (IT). There is a missing link which is shown by a vertical black rectangle.

The main problems are the cmY and rgb colour coordinates used in image technology. It is very hard to understand

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for users that a colour must be described by different contents between 0 and 1 of cyan, magenta and yellow or by different contents of red, green and blue. Some programs allow to use application specific coordinates (relative lightness, red-green and yellow-blue chromaticness). The definitions are often in conflict with the colorimetric definitions of this paper, for example there is only one CIE relative lightness to be defined by

$$l^* = (L^* \cdot L_N^*) / (L_W^* \cdot L_N^*)$$

It takes a short time to recognize that in the system cmy the three values 0 produce the white and three values 1 produce the black colour. It is opposite for the system rgb. It is very confusing for the users that by different application programs three values 0.5 in both systems may produce a mean grey, a dark grey, a light grey, all shades of brownish and greenish colours, and... and... depending on the computer operating system, the application program, the colour workflow and the printer or monitor system.

There is a need for a user friendly colorimetric definition. In the office area according to ISO/IEC 15775 the output tolerance should be within about 3 CIELAB.

3. PDF format as a colour document standard and a colour compatibility test

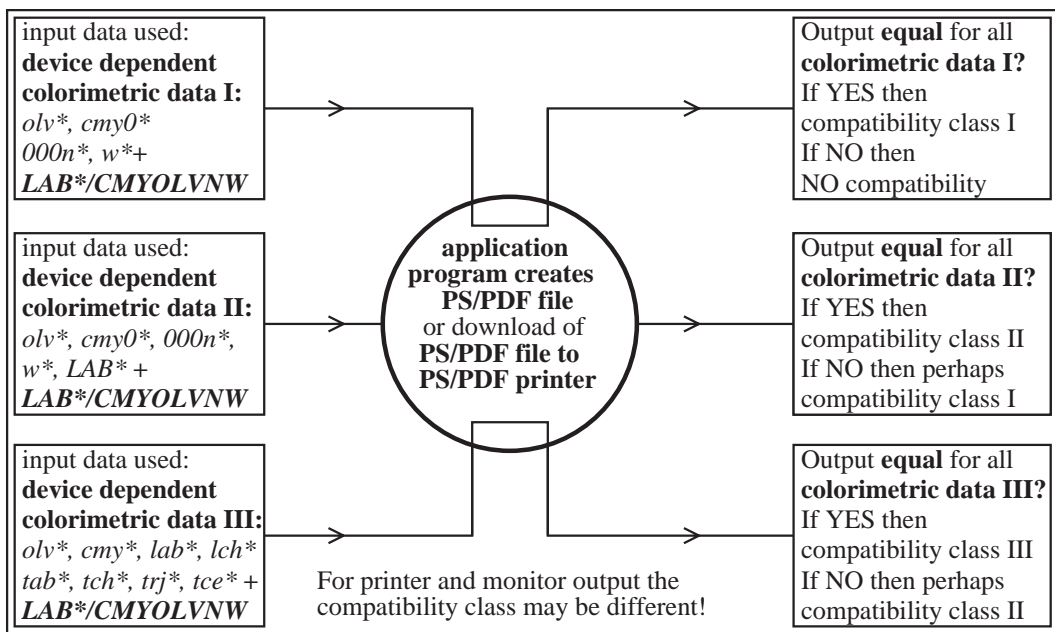
Any user needs application programs, file formats and colour coordinates which can produce an intended output. The PDF file format is beginning to become the potential file format for the long term storage of documents including the grey and colour steps used in documents (ISO/CD 19005 of TC 171 Document Management).

5 steps of grey series black - white (N - W)	Colour space, colour space coordinates and PostScript operator calculations according to ISO/IEC 15775:1999-12			
Linear mixture between black and white in CIELAB colour space	L* CIE w* = l* setgray	CMYN (CMYK) 000n* setcmykcolor	CMYN (CMYK) cmy0* setcmykcolor	OLV (RGB) www* setrgbcolor
1,00 N + 0,00 W (black N)	0,00	0,00 0,00 0,00 1,00	1,00 1,00 1,00 0,00	0,00 0,00 0,00
0,75 N + 0,25 W	0,25	0,00 0,00 0,00 0,75	0,75 0,75 0,75 0,00	0,25 0,25 0,25
0,50 N + 0,50 W	0,50	0,00 0,00 0,00 0,50	0,50 0,50 0,50 0,00	0,50 0,50 0,50
0,25 N + 0,75 W	0,75	0,00 0,00 0,00 0,25	0,25 0,25 0,25 0,00	0,75 0,75 0,75
0,00 N + 1,00 W (white W)	1,00	0,00 0,00 0,00 0,00	0,00 0,00 0,00 0,00	1,00 1,00 1,00

LE420-1, colorimetric relationship of cmy0*, www*, w*, 000n* for a 5 step grey scale: black - white

Figure 2: Colorimetric colour coordinates for a five step grey scale

Fig. 2 shows four different colorimetric colour coordinates of a five step grey scale. The coordinates of the 5 step grey scale can be described by at least 4 different simple coordinates. Some printers show the same output and others show between 2 and 4 different grey scales. In some cases the output on the displays is different and the output on printers is the same and vice versa.



LE440-7, Test of the compatibility class of application program which creates and/or download to printer

Figure 3: Test of compatibility class for application program which creates PDF/PS files

Fig. 3 shows the test for the compatibility class of an application program which creates PDF/PS files or for the download of PDF/PS files to a printer or display system. There are many application programs which produce the

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compatibility class I, for example the PDF/PS Reader and Output software *GostScript/GostView* which is in the internet freely available for the computer operating systems Windows, Mac, and Unix.

For the software default settings the present software versions of *Adobe Acrobat*, *Adobe Reader*, *Adobe Photoshop*, *Adobe Illustrator* show NO compatibility. However, for the different colorimetric coordinates there seem to be some solutions after a change of the present default settings. Older versions for example *Adobe Photoshop 3.5 on Unix* and *Adobe Display PostScript* and *Display PostScript on Silicon Graphics*, *Mac OS X Server (Software Yap)* and *Compac Open VMS (software Decwrite)* show the compatibility to class I.

There is the need to use colorimetric device dependent coordinates, for example the coordinates $cm\dot{y}0^*$. The three values of $cm\dot{y}^*$ have a clear defined linear relationship to CIELAB coordinates. The equations are defined in ISO/IEC TR 19797:2004.

According to this Technical Report the three values 0.5 of either $cm\dot{y}0^*$ or $ol\dot{v}^*$ and the one value $n^*=w^*=0.5$ of $000n^*$ and w^* should produce

1. the same grey colour
2. a grey colour which is visually in the middle between black and white

If at least the first property is true then the application program agrees to compatibility class I. If NOT there is NO compatibility.

5 steps of colour series cyan blue - white (C - W)	Colour space, colour space coordinates and PostScript operator calculations according to ISO/IEC 15775:1999-12		
Linear mixture between cyan blue and white in CIELAB colour space	CIELAB LAB^* (absolute) LAB^* setcolor	CMYN (CMYK) $cm\dot{y}0^*$ (relative) $cm\dot{y}0^*$ setcmykcolor	OLV (RGB) $ol\dot{v}^*$ (relative) $ol\dot{v}^*$ setrgbcolor
1,00 C + 0,00 W (cyan blue C)	58.62 -30.62 -42.74	1,00 0,00 0,00 0,00	0,00 1,00 1,00
0,75 C + 0,25 W	67.82 -23.21 -30.86	0,75 0,00 0,00 0,00	0,25 1,00 1,00
0,50 C + 0,50 W	77.02 -15.80 -18.98	0,50 0,00 0,00 0,00	0,50 1,00 1,00
0,25 C + 0,75 W	86.21 -8.39 -7.11	0,25 0,00 0,00 0,00	0,75 1,00 1,00
0,00 C + 1,00 W (white W)	95.41 -0.98 4.76	0,00 0,00 0,00 0,00	1,00 1,00 1,00

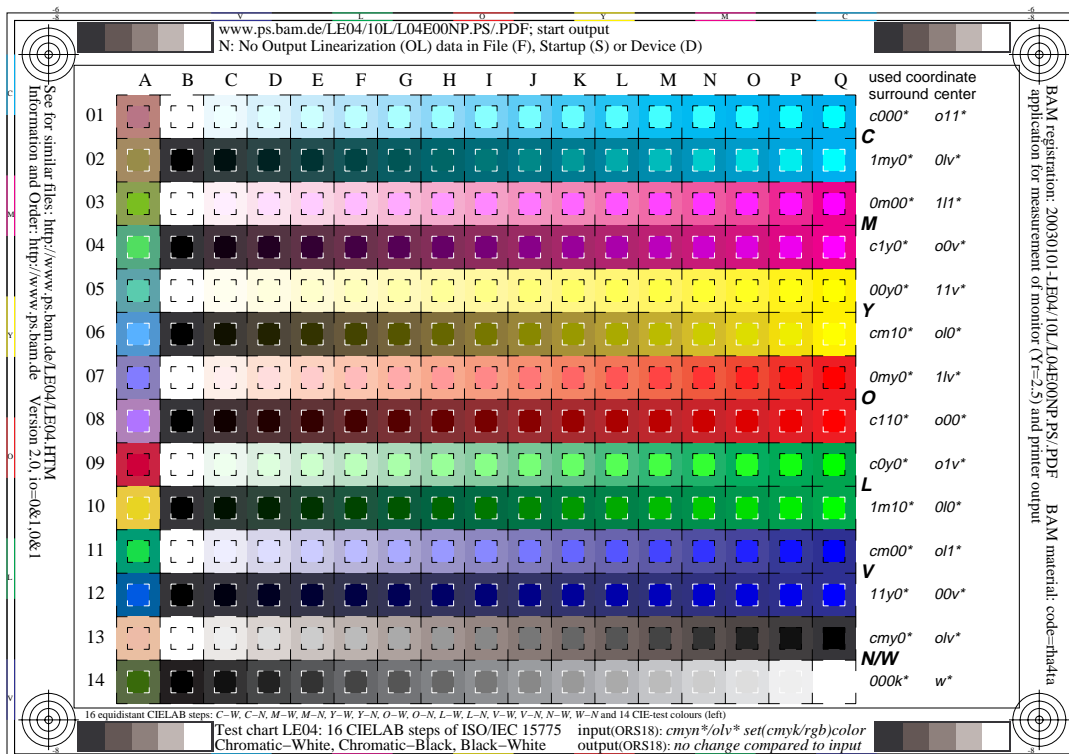
LE421-1, colorimetric relationship of $cm\dot{y}0^*$, $ol\dot{v}^*$, LAB^* for a 5 step scale: cyan blue – white

Figure 4: Colorimetric colour coordinates for a five step scale between white and cyan blue

Fig. 4 shows the colorimetric colour coordinates for a five step scale between white and cyan blue. If all the coordinates are used in one PDF file and the output of the three colour series is the same, then this is an indication for compatibility class II. For an example test file which uses the LAB^* data see the URL (200 kByte)

<http://www.ps.bam.de/DE92/>

The MTL code version 2.0 of ISO/IEC TR 19797 shows the compatibility class II and the next version 3.0 of the MTL code is intended to show the compatibility class III.



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Figure 5: Test chart with the colour coordinates (cmv^* , olv^* , $000n^*$, w^*) for the compatibility class I test

Fig. 5 shows a test chart with the colour coordinates (cmv^* , olv^* , $000n^*$, w^*) for the compatibility class I test. The outer squares are defined by the coordinates cmv^* and the inner squares by the coordinates olv^* (using the 1 minus relation). It depends on the PDF Reader, the PDF Viewer or the PDF/PS printer if the output is equal (compatibility class I) or not.

The version 2 of the MTL code used in ISO/IEC TR 19797 allows to use additionally the LAB^* (CIELAB) data for the production of the same output which is the property of class II. The version 3 of the MTL code will allow that the user may take a triple of data out of the many colorimetric data lab^* , $lch^* tab^*$, $tch^* trj^*$, tce^* , nce^* . The PDF files will for any triple of data lead to the same output (property of class III).

The question if a grey colour with the three values 0.5 of the colorimetric coordinates olv^* is visually in the middle between black and white is not answered by the test of Fig. 5. But after linearization of the 16 step output according to ISO/IEC TR 19797 this additional goal will be reached. There are many other problems to solve in the office area.

4. Sixteen step colour scale, elementary hue circle and location in CIELAB

There is a variety of colour spaces which can be used for input and output. Any user has to spend a lot of time to learn about the different spaces and to train the relationship of the different spaces which depends on application.

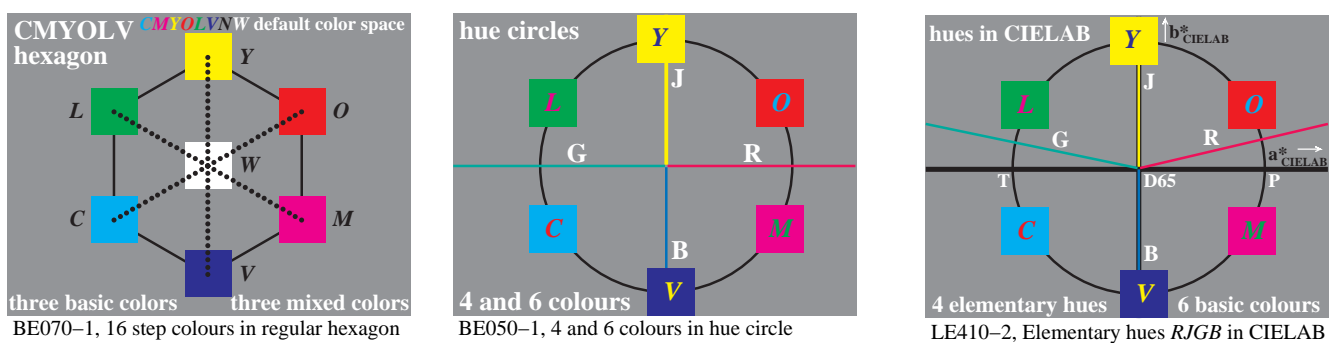


Figure 6: Colours CMYOLV and RJGB in hue circles and in plane (a^* , b^*) of CIELAB

Fig. 6 shows the six chromatic colours **CMYOLV** and Black **N** (=noir) and White **W** of standard offset printing (left). The four elementary hue colours **RJGB** are different from the six reproduction colours (middle). The elementary hues **R** and **G** are not located on the red-green chroma axis of CIELAB a^* nor the device colours **O** (Orange red) and **L** (leaf green) of offset printing or television.

Remarks: According to the International Standard ISO/IEC 15775 the letters **j** (=jeanne=yellow), **r** (red), **g** (green), and **b** (blue) are reserved for the elementary hues and the letters **olv^{*}** (orange red, leaf green, violet blue) are used with a star to indicate the linear relationship to CIELAB. The **olv^{*}** coordinates are used for the reflective colours and are used in a similar way as the coordinates **rgb** of the luminous television colours. The **cmv^{*}** coordinates are alternate coordinates compared to **olv^{*}**.

All the 16 step colour series between white and the six chromatic colours CMYOLV (see Fig. 6) and black are equally spaced in the CIELAB colour space. Laser printers produce the six chromatic colours by between 3 and 6 colorants. (6 are used by the printer of a company *Oc*). The result is very similar compared to the six colours CMYOLV of the present analog ISO/IEC-test charts which has been produced by standard offset printing.

Standard non fluorescent offset paper was used to produce the **analog ISO/IEC-test charts which are equally spaced in CIELAB coordinates**. There are productions of DIN and JBMA (Japan Business Machines Association) in reflective and transparent mode. The German DIN production has been measured with the CIE 45/0 measurement geometry for CIE standard illuminant D65 and the CIE 1931 standard observer at BAM (*Laboratory S.13*). The mean colour difference of CMYOLV compared to the standard data is 2.5 CIELAB, see the standard DIN 33866-X [1] and the International Standard ISO/IEC 15775 [2].

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5. Device coordinates blackness, deepness, chromaticness and others

There is a large amount of device coordinates which are related to CIELAB. The coordinates are called colorimetric device coordinates. Fig. 15 will show later the relationship for the field of printing (PR) and television (TV).

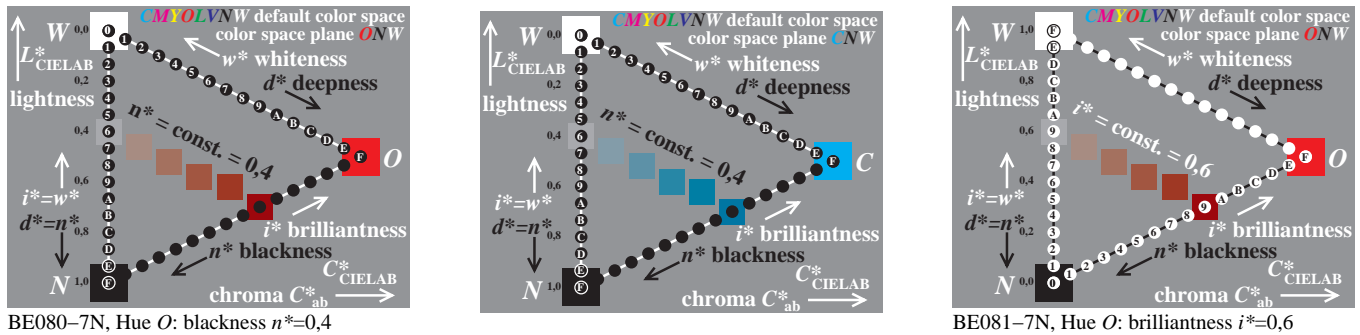


Figure 7: Relation of blackness - brilliantness and deepness - whiteness in plane (C*,L*) of CIELAB

In art, design and architecture the three coordinates blackness, chromaticness and elementary hue are used to describe the colour appearance. In Fig. 7 the coordinates blackness < brilliantness and deepness < whiteness count in opposite direction. Each pair describes the same colours for example either by the blackness $n^* = 0,4$ or the brilliantness $i^* = 0,6$. There are three main colorimetric equations within a constant hue plane:

$$n^* = 1 \cdot i^*$$

$$d^* = 1 \cdot w^*$$

$$c^* = 1 \cdot n^* \cdot w^*$$

The last equation describes chromaticness c^* as function of blackness n^* and whiteness w^* . This is a modern form of the Ostwald (1925) equation which normalizes the sum of the black content, the white content and the chromatic content in any colour to one.

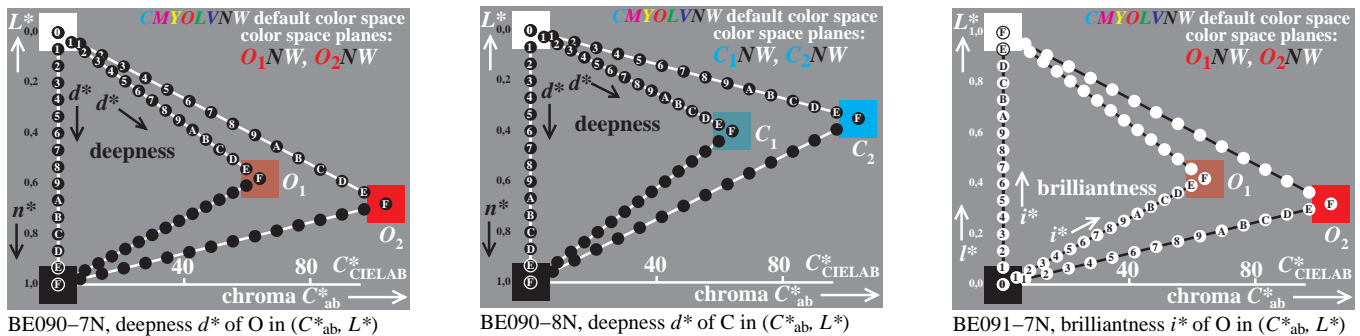


Figure 8: Two device colorants O and C with different chroma and lightness in (C*,L*) of CIELAB

Fig. 8 shows 16 step colour series between the three colours N , W and O . The 16 steps may be described either by the colorimetric coordinate deepness d^* or the colorimetric coordinate brilliantness i^* . There is a linear relationship to the coordinates (C^*,L^*) of CIELAB.

Usually in the field of image technology the printer devices use different colorants. The colorants O (orange red) or C (cyan blue) produce a raster on a white paper and according to Fig. 8 the colour series $W \cdot O$ or $W \cdot C$ appear on the white paper. In a constant hue plane any raster colour series is located approximately on lines defined by the connection of Black N (=noir), White W and Orange red O in the CIELAB space. According to Fig. 8 the two colorants have the same hue but they differ in CIELAB chroma C^*_{ab} by a factor 1.5 and in lightness.

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6. Double cone natural colour connection space (NCCS)

In the following we will study a transfer between the input colours of the device 1 which are located within the triangle NO_1W and the output colours of the device 2 which are located within the triangle NO_2W .

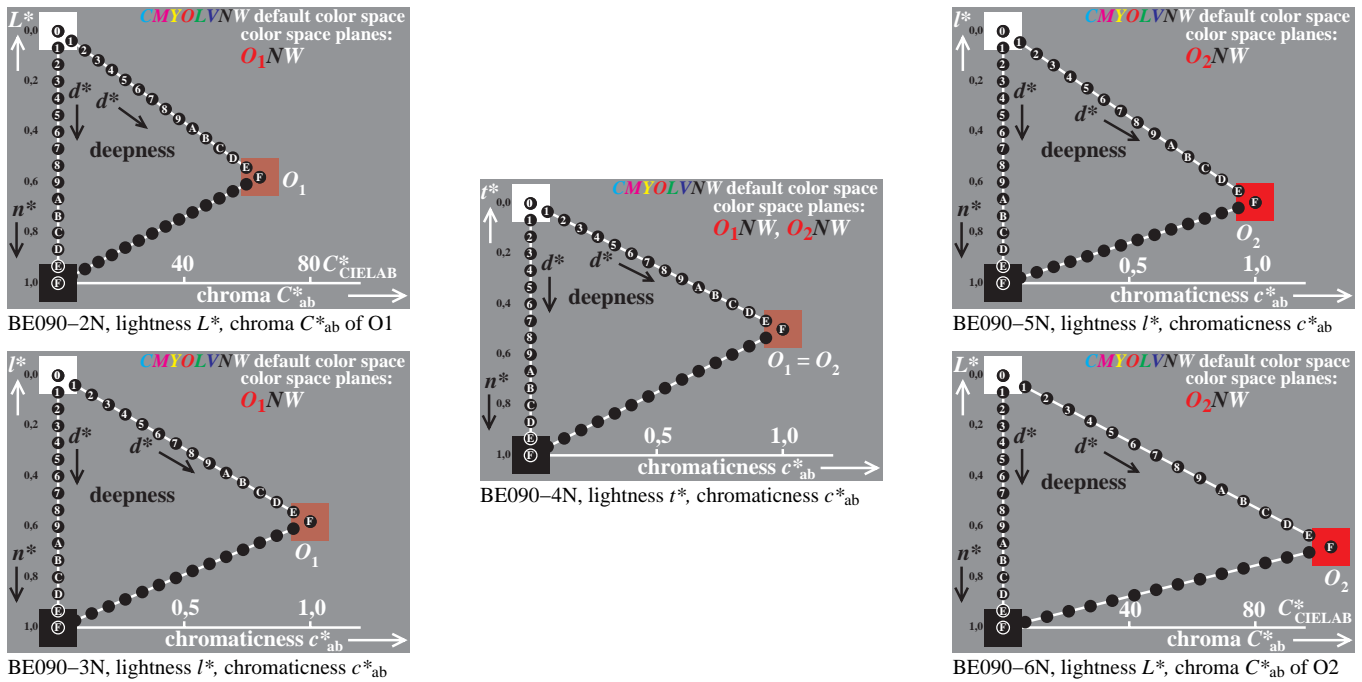


Figure 9: Transfer from input referred colours via the NCCS to input referred colours

Fig. 9 shows 16 step colour series in the hue planes O and in the five diagrams (C^*, L^*) (top left), (c^*, l^*) (bottom left), (c^*, t^*) (middle), (c^*, l^*) (top right), (C^*, L^*) (bottom right). In the diagram (c^*, t^*) (middle) which is a cut through the colour double cone NCCS both the chromaticness of O_1 and O_2 is normalized to 1,0 and the triangle lightness is given by $t^* = 0.5$. In the diagrams (c^*, l^*) (bottom left) and (c^*, l^*) (top right) the CIELAB relative lightness l^* of the two colorants is different from 0.5. The relative chromaticness and relative lightness is defined as

$$c^* = C^* / C^*_O \quad l^* = (L^* \cdot L^*_N) / (L^*_W \cdot L^*_N)$$

In Fig. 9 the relative chromaticness c^* is normalized to one and the relative lightness l^* of both oranges is about 0.4 and 0.3. In Fig. 9 the CIELAB chroma C^*_{ab} is about 70 for O_1 and about 110 for O_2 , see diagram (C^*, L^*) (top left) and diagram (C^*, L^*) (bottom right). Fig. 9 shows therefore a complete workflow between the input and output. If one compares the input and output colours, then the 16 step spacing differences remains constant in any diagram.

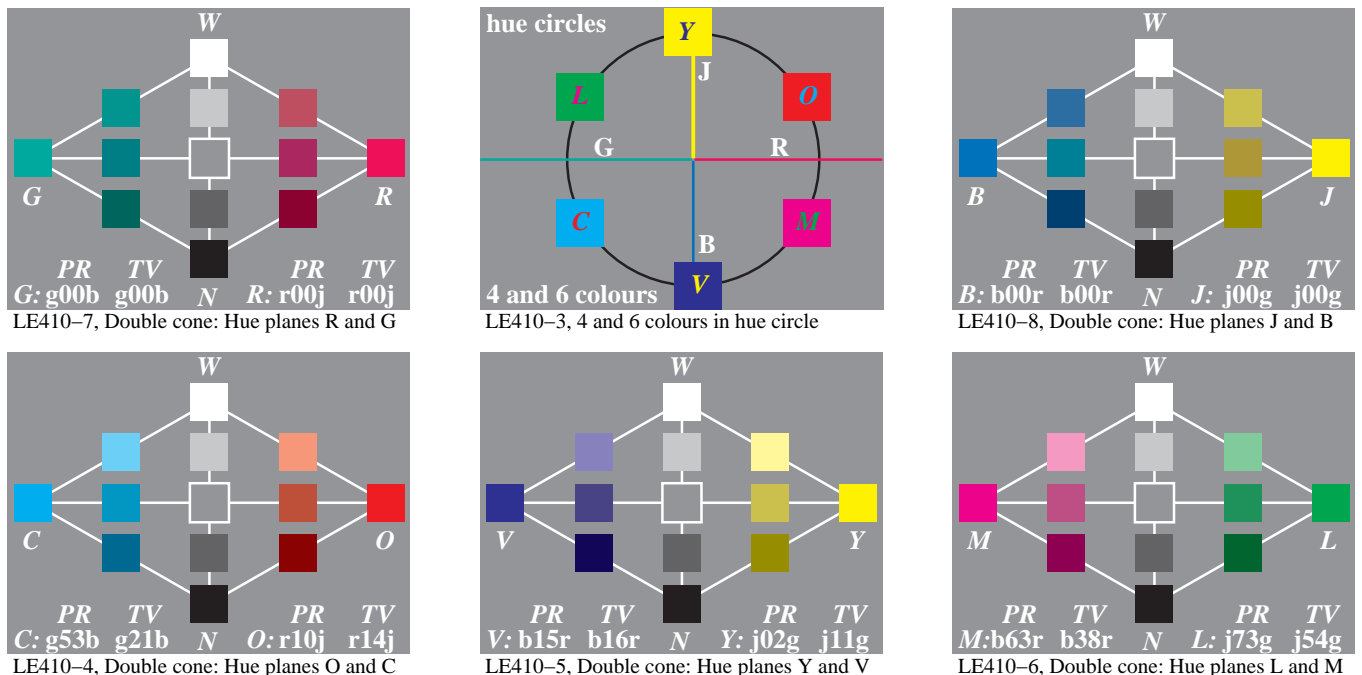


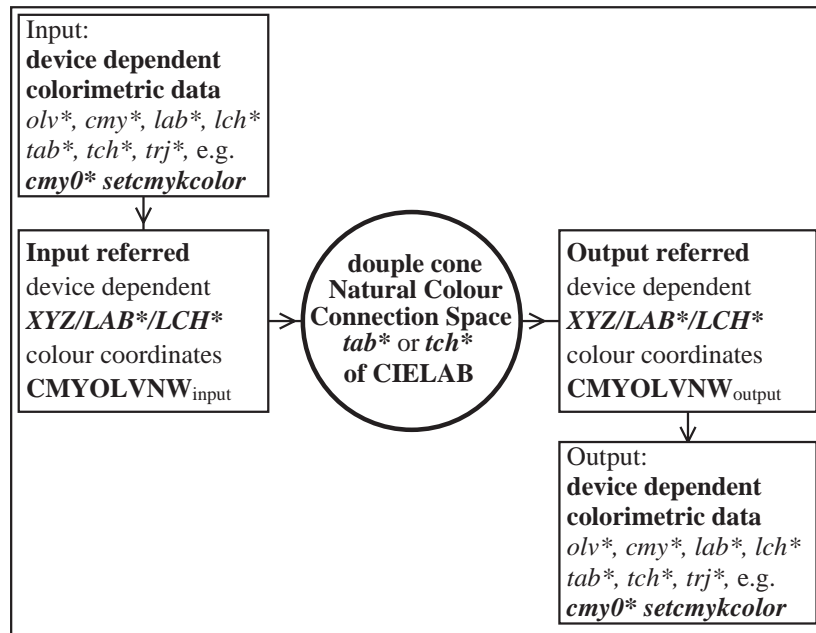
Figure 10: Different hue planes and the hue circle of the double cone NCCS

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Fig. 10 shows the hue circle of the double cone NCCS (top middle) and different hue planes. The triangle lightness is normalized to 0.5 and the chromaticness is normalized to 1.0 (compare the middle diagram of Fig. 10). If one compares the spacing in different hue planes, then the 5 step spacing differences are constant within all diagrams. The light yellow series $W < J$ is equivalent to the usually darker blue series $W < B$. This is one main property of the *Natural Colour System* (NCS) which describes the relative appearance of colours. For most users it is easy to guess the blackness, chromaticness and elementary hue of any colour. The blackness n^* of the series $W < J$ and $W < B$ is equivalent and zero. Therefore many uses require the device dependent coordinates nce^* as input coordinates. Coordinates similar to nce^* are used in the natural colour system NCS and they are approximately device independent.

7. Colour workflow via the double cone NCCS

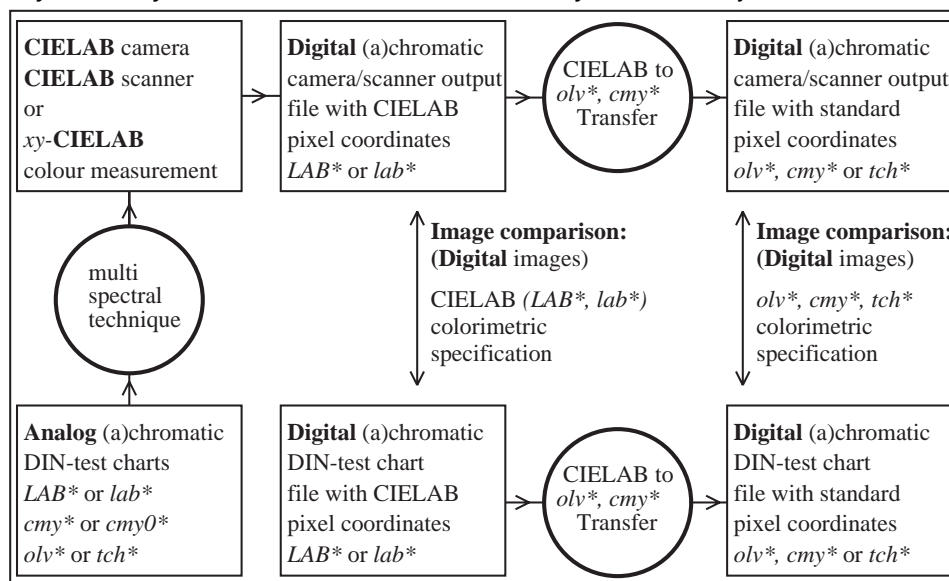
A simple workflow how to use the NCCS is given in the following



LE450-7, Transfer from device dependent $cmy0^*$ data; output via NCCS with new $cmy0^*$

Figure 11: Input and output referred $cmy0^*$ coordinates transferred via the NCCS

Fig. 11 shows the input and output referred $cmy0^*$ coordinates transferred via the NCCS. In the input and output file the PS operator $cmy0^*$ *setcmykcolor* is used. The coordinates $cmy0^*$ are usually different for the input and output.



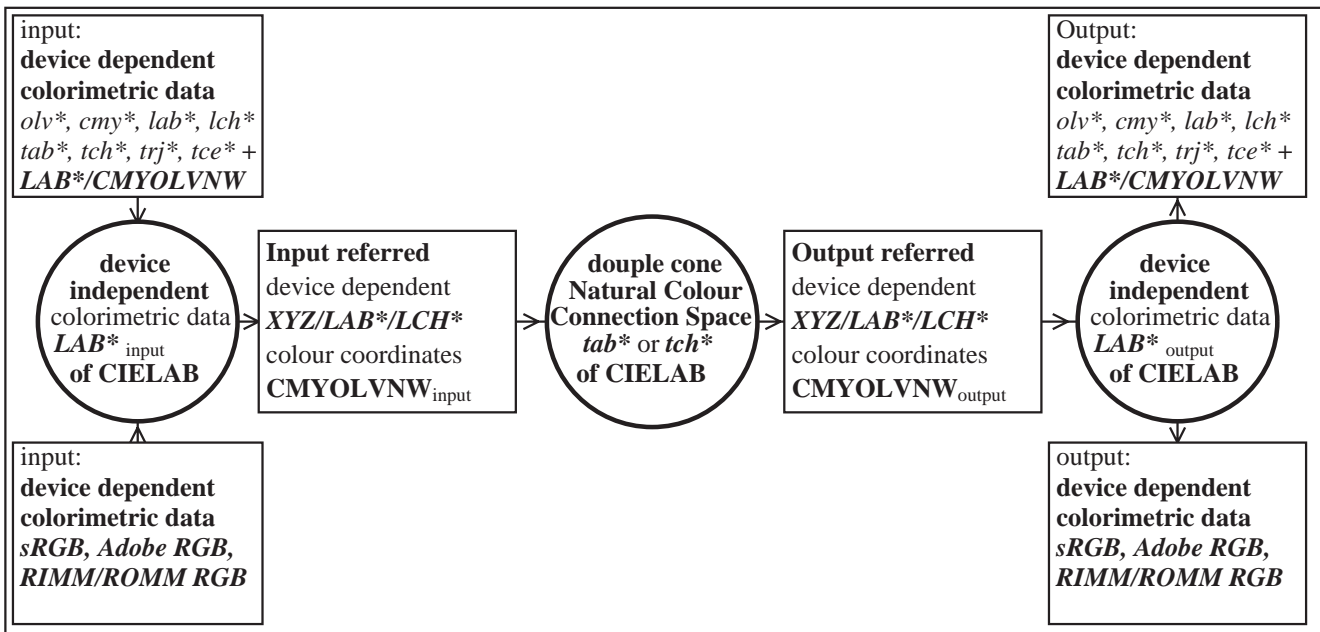
LE430-7, Transfer from device independent data LAB^* to device dependent data olv^* , cmy^* and tch^*

Figure 12: New CIELAB cameras and scanners and transfer of LAB^* to $cmy0^*$

Fig. 12 shows new CIELAB cameras and scanners. The scanner output coordinates need a transfer from LAB^* to $cmy0^*$ within the workflow. If in a practical case the analog ISO/IEC-test charts according to ISO/IEC 15775 are used

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as the analog original for the scanner system then the LAB^* data of the eight offset colours CMYOLVNW are the colours $CMYOLVNW_{input}$ in the following figure. This figure gives a more technical description including $sRGB$ and other colour spaces. Different coordinates are shown and may be used for the calculations and connections between the input and output referred colour spaces via the double cone NCCS



LE450-3, Transfer to device independent LAB^*/LCH^* data; output via the Natural Colour Connection Space tab^*/tch^*

Figure 13: Input and output referred colour coordinates transferred via the double cone NDCS

Fig. 13 shows the input and output referred colour coordinates which are transferred via the NCCS. The many different colour spaces are shown at the left top. With the eight LAB^* data of the input referred device dependent colour space (usually standard offset, see ISO/IEC 15775) there is a transfer to LAB^* or LCH^* of CIELAB.

The left bottom box shows transformations from $sRGB$ (see IEC 61966-2-1), $Adobe RGB$ and $RIMM/ROMM RGB$ (see ISO/DIS 22028-2 and -3) to CIELAB. In case of $sRGB$ the eight LAB^* data of the input device are the standard television colours (see ISO/IEC 15775:1999). In some cases it is hard to decide which eight LAB^* data are appropriate for the transformation. If for document and colour management any file comes with the eight device colours CMYOLVNW defined by LAB^* data then the LAB^* data of any colour can be calculated for example from the file data cmy^* .

If the **input referred** device dependent LAB^* data are known then any LAB^* or LCH^* data can be transferred to the tab^* or tch^* data of the **double cone NCCS**.

If the **output referred** device dependent LAB^* data are known then any of the tab^* or tch^* data of the **NCCS** can be transferred to the intended LAB^* or LCH^* output data.

In photography there is often a wish to produce a more pleasant picture for example it is intended to make the sky more blue and the grass more green. This can be reached if for example the chromaticness in the NCCS is modified by a square root function. This function transfers the chromaticness $c^*=0.5$ to $c^*=0.7$ and remains colours with $c^*=0$ and $c^*=1$ unchanged.

It is of course also possible to maintain the LAB^* data between input and output. This is the usual goal of ICC colour management and produces many problems. Usually the input and output spaces are different and then this will cut the colours in some regions of the colour space. Often there is a cloud of colours on an undefined input or output referred colour space. It is hard to manage if not impossible the input and output in these cases

8. The three natural requirements for the colour rendering intent

In offices usually printed material is scanned and printers and displays are used for the reproduction. Therefore usually clear input and output referred colour spaces exist.

There are many colour rendering intents (see CIE Report, 2004) but there is one most natural intent between the

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input and output referred colour spaces. This natural intent is defined by at least three user requirements. These requirements maintain the following three different properties between any input and output referred colour space.

1. Equal spacing of 16 step colour scales may not change between input and output
2. Hue may not change between input and output
3. Relative chromaticness may not change between input and output

The first property maintains the recognition of any 16 step colour scale for any device output. The second property is of high importance for the rendering intent of skin tones in photography. The last property maintains chromaticness. The CIELAB lightness L^* or the CIE relative lightness I^* may change between input and output. This is of less importance for visual recognition because observers are trained to recognize the same colour in light and shadow areas.

9. Reflection of elementary hue surface colours and of black and white

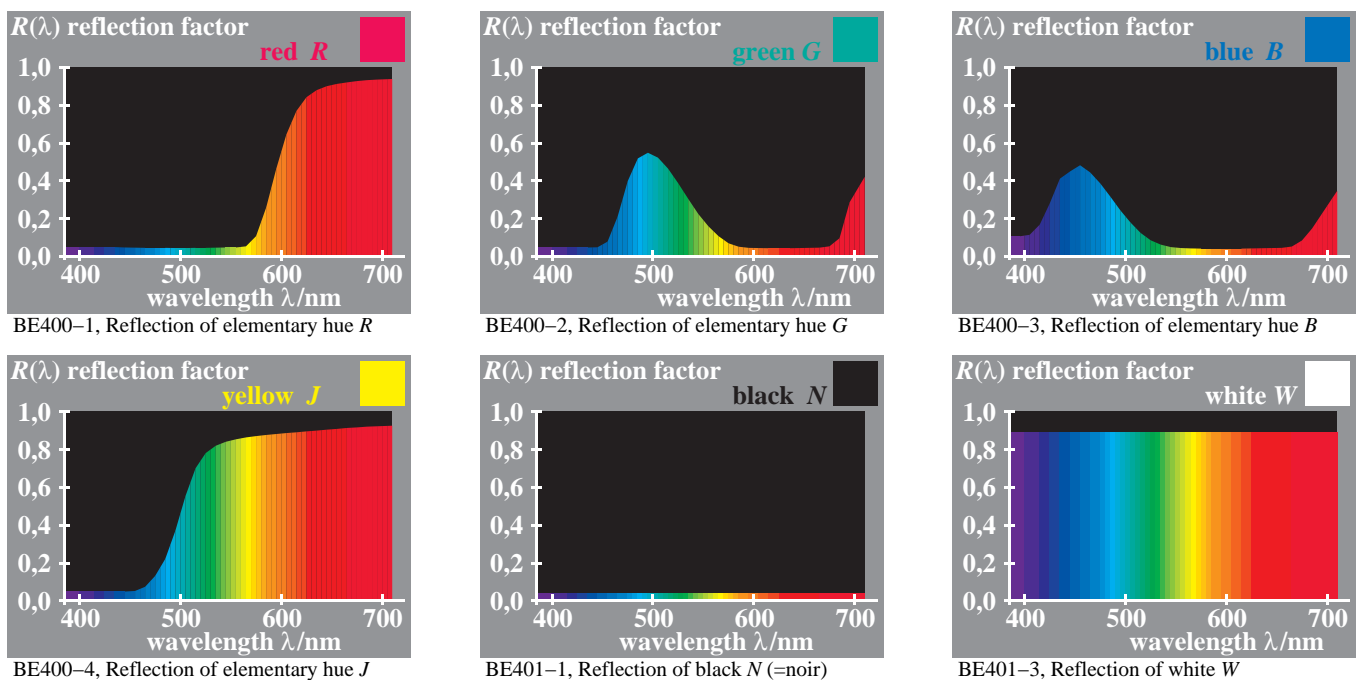


Figure 14: Spectral reflection of elementary hue colours $RJGB$ according to *Miescher* and of black and white

Fig. 14 shows the spectral reflection of elementary hue colours $RJGB$ according to *Miescher* and of black and white. White paper and black matt paper has a spectral reflection of about 89% and 4%.

Experiments show that many naive observers compare the chromatic content and the hue of any colour with memory colours of maximum chromaticness and the elementary hue memory colours. Additionally the natural gamut boundary is similar for different observers. Further the colour gamut of offset printing is similar to the boundary of the memory colours.

However the six basic chromatic colours of printing are different compared to the for elementary hue memory colours (compare Fig. 6). All these properties allow to define a colorimetric model which can calculate blackness, chromaticness and hue in relation to the CIELAB chroma C^*_{ab} of the eight device colours $CMYOLVNW$ and the four elementary hue colours $RJGB$. Fig. 14 shows the spectral reflection of the elementary hue colours determined by *Miescher* with a 400 step colour circle with 28 observers under daylight D65. In the CIELAB space the hue angle of the four elementary hue colours $RJGB$ is similar compared to the elementary hue colours of the NCS system. In the *Munsell* color order system the elementary hues have approximately the hue 4R, 5Y, 5G and 5PB. The CIE test colours no. 9 to 12 are based on these hues of the *Munsell* colour order system and are used in ISO/IEC 15775

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10. Display output by different room light reflections on the display surface

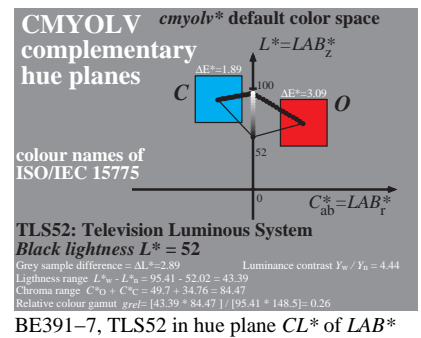
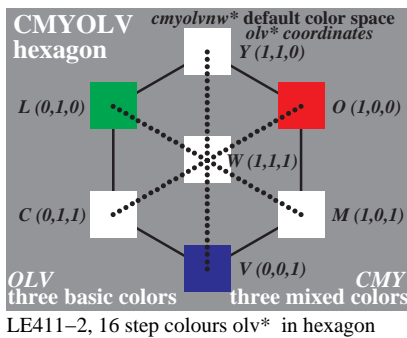
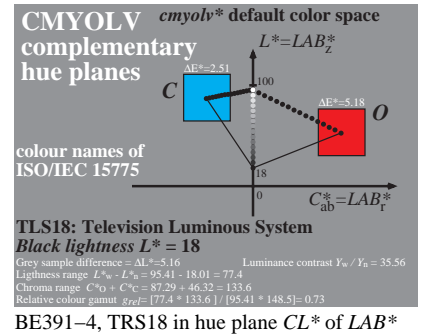
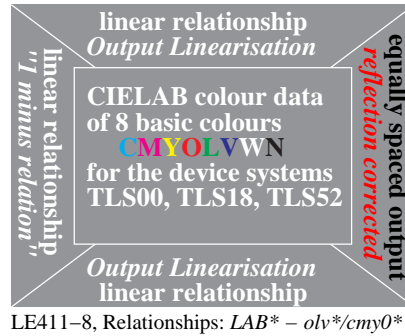
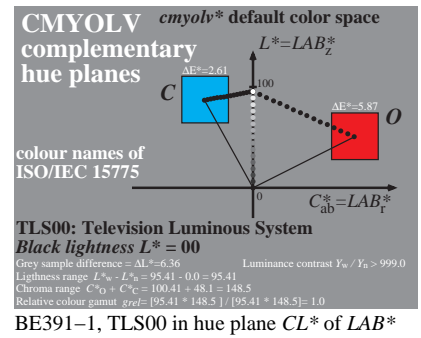
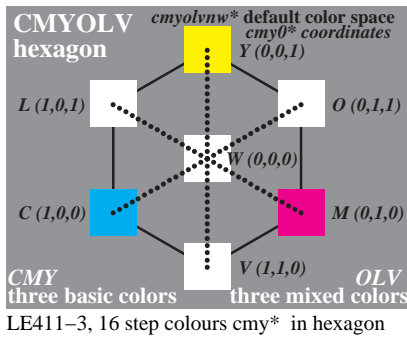


Figure 15: Color workflow for display output from cmy0* or olv* to lch* coordinates

Fig. 15 shows either the *cmy** or *olv** definition of colours in the file (left side). The user requires an equally spaced output on the display for different room light reflections on the display surface. Any surface colour or glass display surface of a monitor reflects approximately between 2,5% (semi glossy surface) and 5% (matt) for the CIE geometry 45/0 which corresponds to an illumination under 45 degree and an observation under 0 degree. A reflection of 2,5% reduces increase the black lightness L^* from zero to 18 and reduces the lightness range from $L^*_W=95$ to the lightness range $L^*_W/L^*_N=85-18=77$. The lightness range in the reduced to 80% (77/97) and the colour gamut of the hue plane is reduced to 76% (magnify the right figures by the PDF reader to study the different values of gamut reduction). For example in ISO TC 159 a room reflection of about 40% is the minimum requirement at work places for the images of data projectors. This reduced the colour gamut to about 10%. It is obvious that an absolute reproduction is not appropriate in this case. The workflow via the NCCS will produce an appropriate output.

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11. Linear and non linear relations between input and output colour spaces

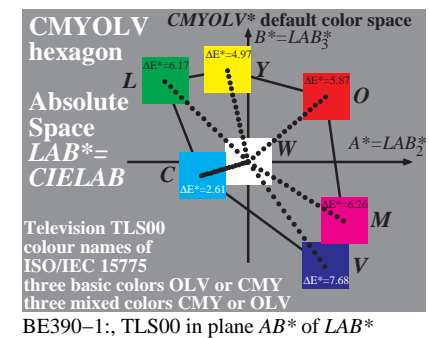
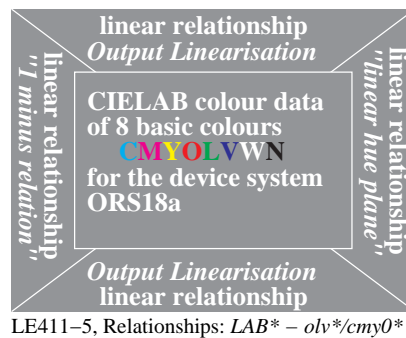
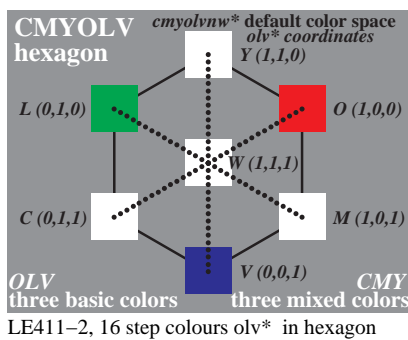
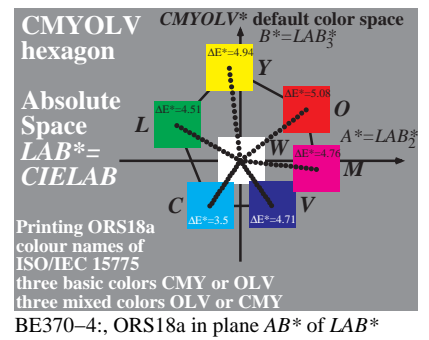
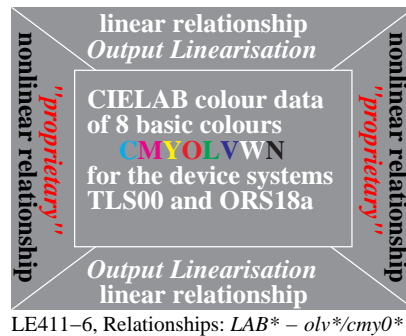
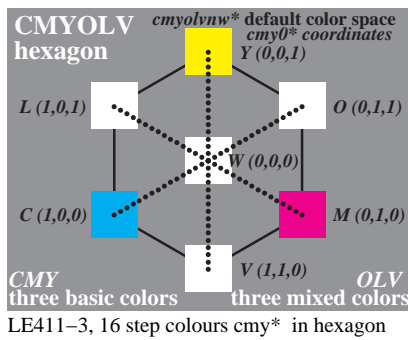


Figure 16: Colour workflow for printer and display output from $cmy0^*$ or olv^* to LAB^{} coordinates**

Fig. 16 shows the colour workflow for printer and display output from $cmy0^*$ or olv^* to the AB^* coordinates of LAB^* (CIELAB).

In application there are many problems and a colour chaos may appear on printers and/or displays.

Instead of the linear ($\hat{O} \times$ relation) there are company specific relations between olv^* (rgb) and $cmy0^*$ ($cmyk$) coordinates. This is one reason for a possible compatibility class I failure shown in Fig. 3.

Additionally there are company specific relations between the AB^* coordinates of printing (PR, top right) and television (TV, bottom right). The non linear relations are indicated by black and red characters in the top middle of Fig. 16.

It is a large improvement to have linear relations between input and output and additionally between the coordinates on the input side (olv^* and $cmyk^*$) and on the output side (AB^*_{PR} and AB^*_{TV}).

12. From input to output via the double cone NCCS

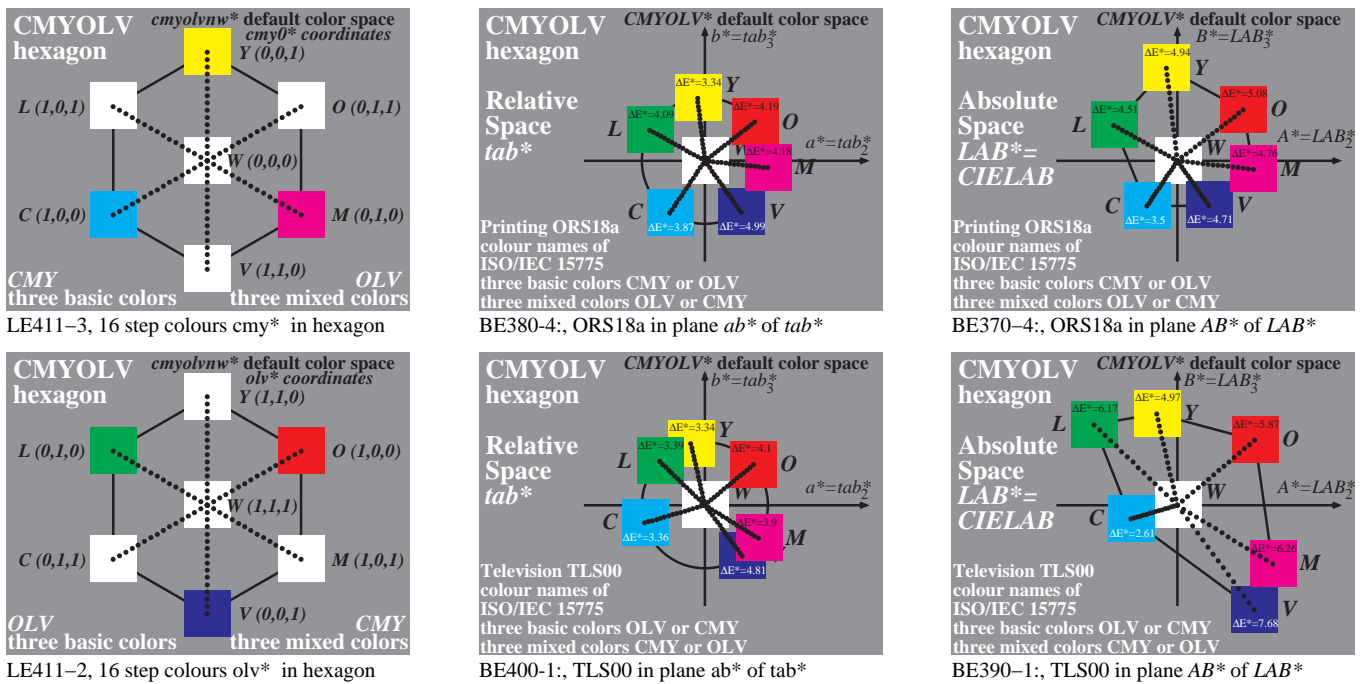


Figure 17: Color workflow for printer and display output from olv^* or $cmy0^*$ to LAB^* coordinates

Fig. 17 shows the colour workflow for printer and display output. There change of the colorimetric coordinates olv^* or $cmy0^*$ via the relative colorimetric coordinates lab^* to the absolute colorimetric coordinates LAB^* is shown.

The possibility to calculate the LAB^* output coordinates will allow in a later stage to look for a exact colorimetric match. In this case the *Landolt*-rings will not be recognized for the input space ORS18 and the output space TLV00 and vice versa.

It is of special interest to study for example the workflow between the offset space ORS18 as input and the television space TLS00 as output. For example for the reproduction of the series between white *W* and cyan blue *C* of printing there is the user requirement to maintain the hue (compare section X.). In the CIELAB space the cyan series has a hue angle of about 240 degrees in the ORS18 space and a hue angle of about 200 degrees in the TLS00 space. Therefore a mixture colour between cyan blue *C* and violet blue *V* of television will reproduce the Cyan blue of printing. On the monitor *C* is produced by an equal amounts of *L* and *V*. Therefore more *V* is necessary compared to *L* to maintain the hue of printing.

For reproduction on monitors we have to consider the reflection of the daylight in the office on the monitor surface.

13. From offset space ORS18 to different television spaces TLSxx

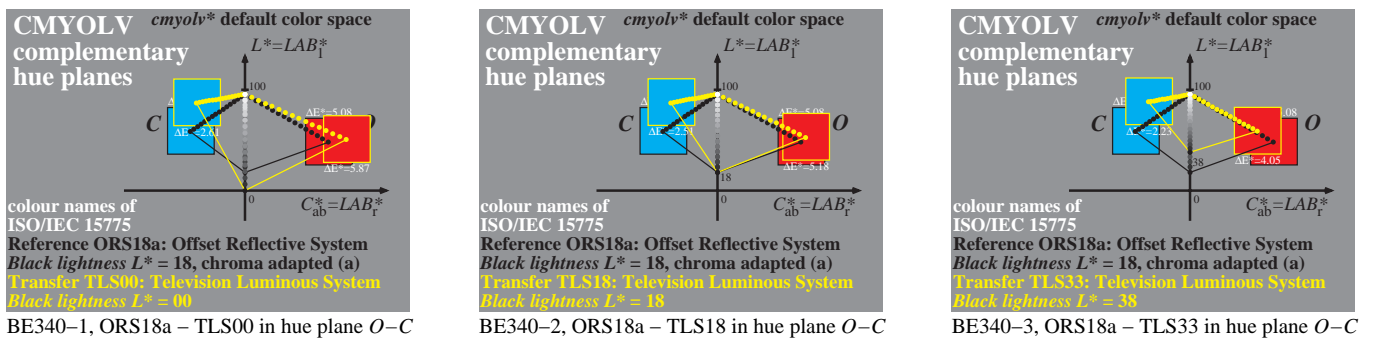


Figure 18: Colour reproduction between the reference space ORS18 and TLSxx (xx=00, 18, 52)

Fig. 18 shows the colour reproduction between the reference space ORS18 and TLSxx (black lightness $L^*=00, 18, 52$). In the Television Luminous Space TLS18 one can reproduce by absolute colorimetry only 10 steps of the 16 step scale $W < C$ of offset printing. This is a large disadvantage of the space TLSxx. With a room reflection $Y_r=20$ the black lightness is $L^*=52$. Usually only a relative reproduction is of value for this applications.

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14. Encoding and decoding of 7/8bit and 6/8bit colorimetric colour data

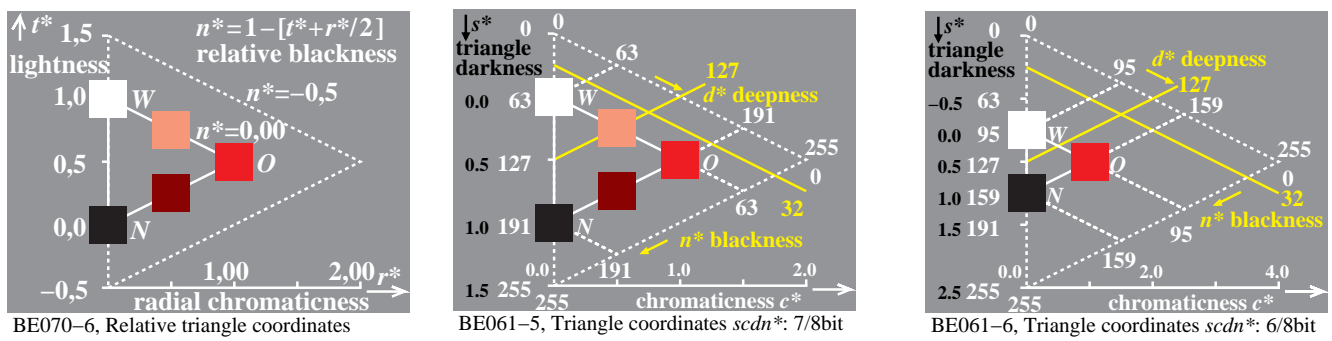


Figure 19: Colour encoding of the grey scale by 7/8bit and 6/8 bit.

Fig. 19 shows examples of a new proposed colour encoding by 7/8bit and 6/8 bit for the grey scale instead of the standard encoding 8/8bit. Then the encoding outside the device colour gamut may be used for highlight colours, fluorescent colours and very chromatic colours, for example the effect colours used in the automotive industry. One important property of this encoding is that the inverse transformation applied to the colour data will produce back the original colour data. This is usually not a property and a big disadvantage of many of the present application programs. For many software programs the colorimetric forward and inverse transformations lead to a loss of information (for example with the software *Adobe Photoshop*). Either some calculated colour data larger than one or less the Zero are clipped and are lost for further transformations.

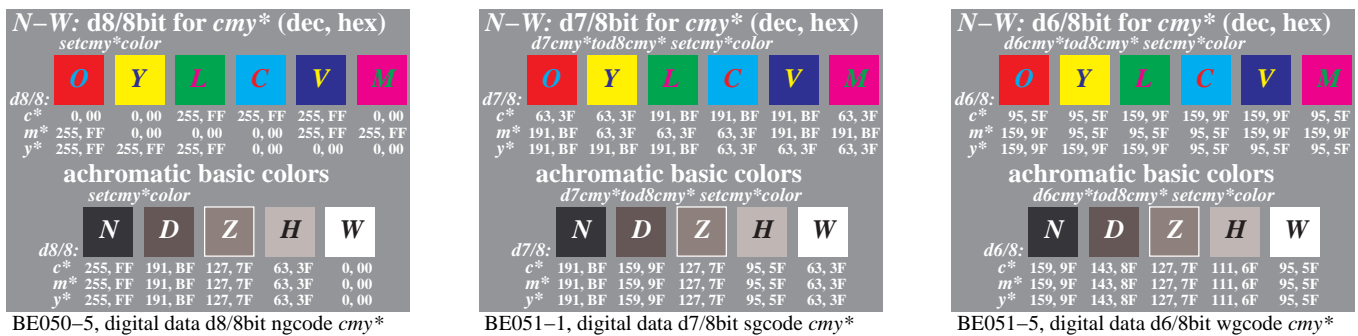


Figure 20: Colour encoding for basic colours and for a 5 step the grey scale by 7/8bit and 6/8 bit

Fig. 20 shows example the colour encoding for basic colours and for a 5 step the grey scale by 8/8bit, 7/8bit and 6/8 bit. The encodings may be called ngcode (narrow or normal gamut code), sgcode (standard or extended gamut code) and wgcode (wide gamut code). The standard gamut code allows to code 4 time more colours and the wgcode 16 times more colours compared to the ngcode.

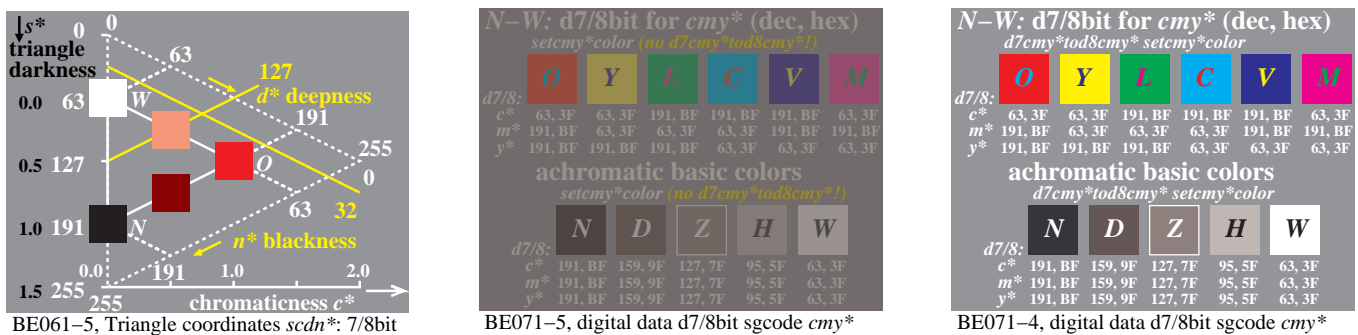


Figure 21: Colour encoding using deepness d^* for colours and 7/8bit without and with decoding

Fig. 21 shows the colour encoding using deepness d^* for the encoding and 7/8bit without and with decoding. Only colours between hex values 63 and 191 (between digital 0.25 and 0.75) are used in Fig. 21. The reproduction result is the same as in Fig. 20 (left figure). A naive user will not realize any encoded colour outside the 7/8bit boundary. This colours will be reproduced at the 7/8bit boundary. Experts can make use of these colour encodings if there is a wide gamut output device available and if for example an absolute reproduction in CIELAB is intended.

15. BAM-test chart files of 16x16x16 colours for output linearization

Main and important software products on *Windows*, *Unix* and *Mac* can produce the output of 16x16x16 colours of a BAM-test chart file which comes in different file formats (PS, PDF and others)

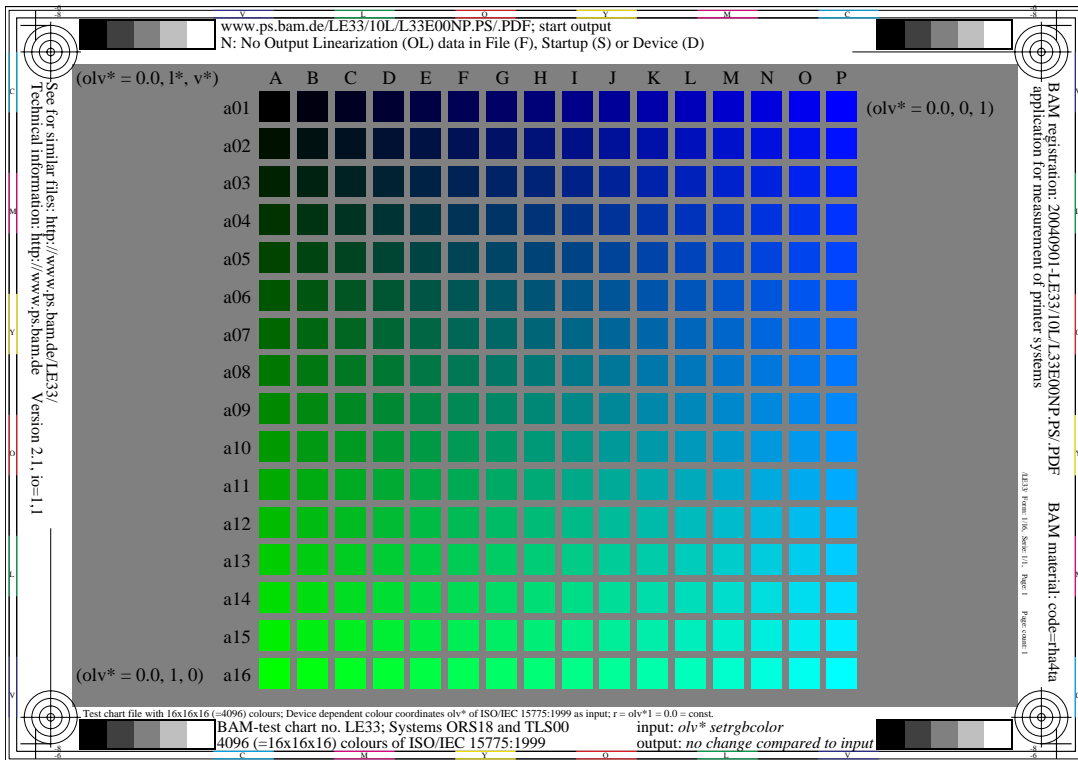


Figure 22: BAM-test chart file for 16x16x16 colours which are intended to be equally spaced
 Fig. 22 shows a BAM-test chart file with $\sigma^*=o/v^*_1=0.0$ for output. The file produces 16x16x16 colours on printer systems. It is intended that the output is equally spaced in relative CIELAB if the device is linearized.

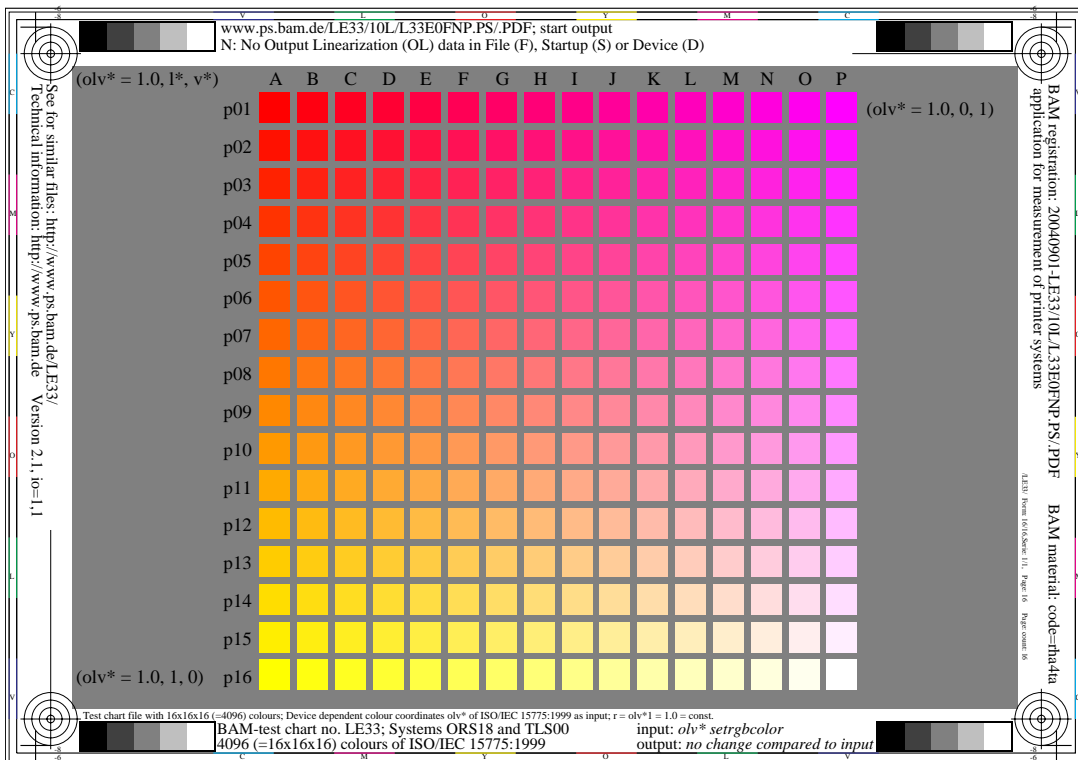


Figure 23: BAM-test chart file for 16x16x16 colours which are intended to be equally spaced
 Fig. 23 shows a BAM-test chart file with $\sigma^*=o/v^*_1=1.0$ for output. For the original file with 16 pages see the URL <http://www.ps.bam.de/LE33/10L/L33E00NP.PDF>

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16. Corresponding colorimetric data of device spaces and CIELAB

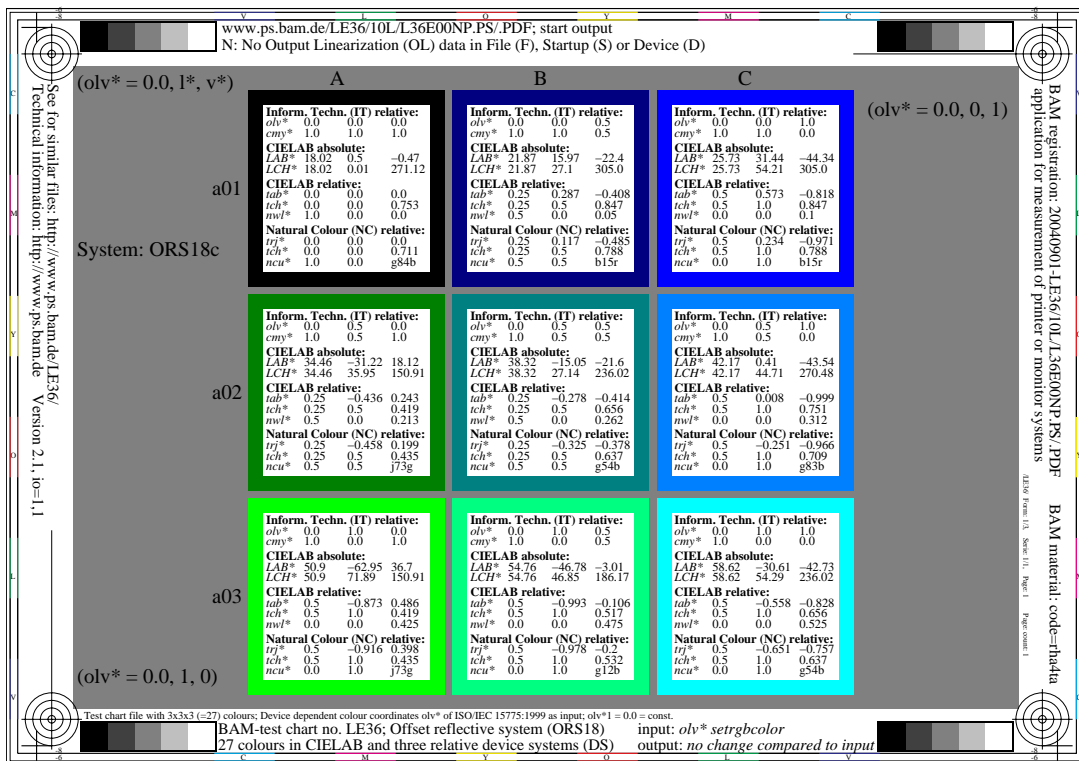


Figure 24: Corresponding colour coordinates in different colour spaces for a 3x3x3 colour output

Fig. 24 shows corresponding colour coordinates in different colour spaces for a 3x3x3 colour output in the plane $o^*_1 = olv^*_1 = 0.0$. The file produces the colour coordinates of 3x3x3 colours for the offset space ORS18c. It is intended that the output is equally spaced in relative CIELAB if the device is linearized. For the original file with 3 pages see <http://www.ps.bam.de/LE36/10L/L36E00NP.PDF>

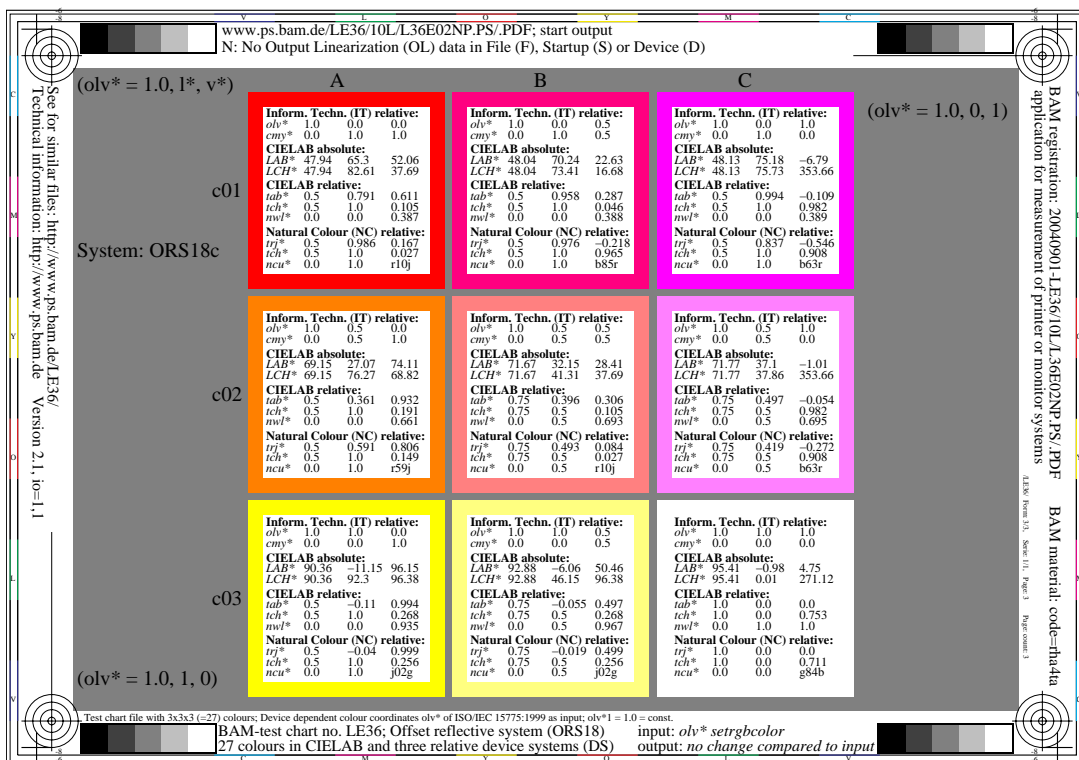


Figure 25: Corresponding colour coordinates in different colour spaces for a 3x3x3 colour output

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Fig. 25 shows corresponding colour coordinates in different colour spaces for a 3x3x3 colour output in the plane $o^*=o/v^*_1=1.0$. The file produces the colour coordinates of 3x3x3 colours for the offset space ORS18c.

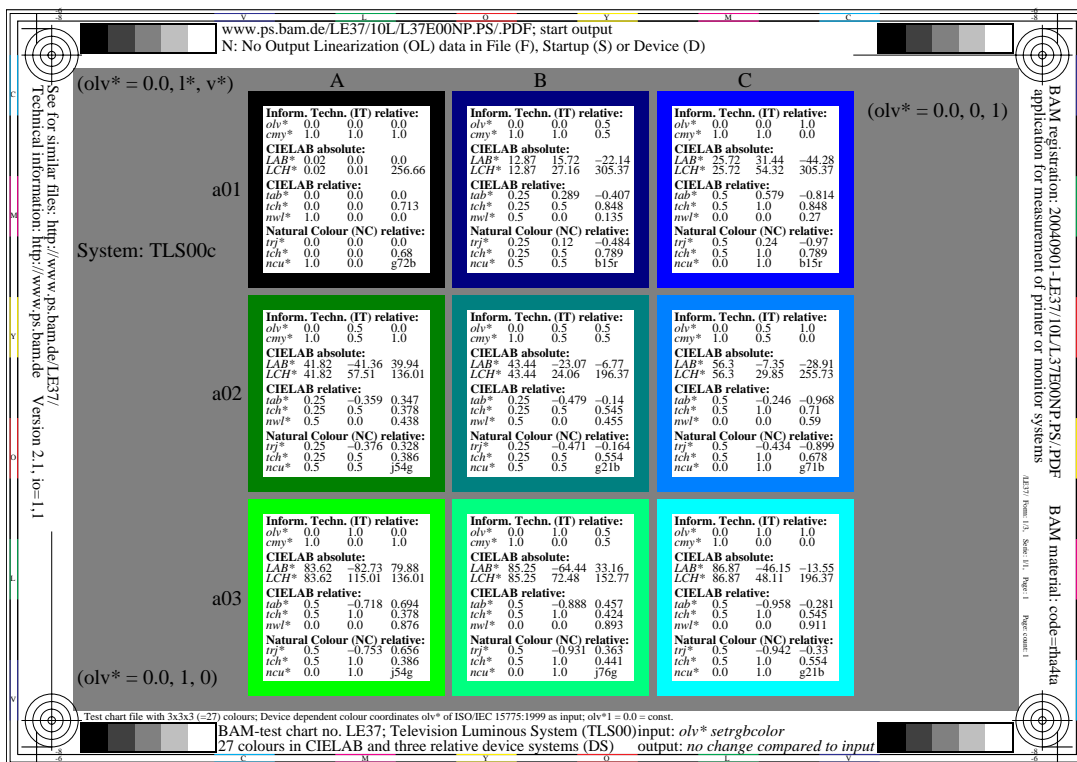


Figure 26: Corresponding colour coordinates in different colour spaces for a 3x3x3 colour output

Fig. 26 shows corresponding colour coordinates in different colour spaces for a 3x3x3 colour output in the plane $o^*=o/v^*_1=0.0$. The file produces the colour coordinates of 3x3x3 colours for the television space TLS00. It is intended that the output is equally spaced in relative CIELAB if the device is linearized. For the original file with 3 pages see <http://www.ps.bam.de/LE37/10/L37E00NP.PDF>

Conclusion

This paper proposes new colorimetric coordinates which are similar compared to the coordinates used in color order systems. The new coordinates are device dependent and have a linear relationship to CIELAB. There are different linear relationships for input and output devices depending on the eight CIELAB data of the colours $CMYOLVNW_{\text{input}}$ and $CMYOLVNW_{\text{output}}$. The paper gives a new starting point for many different New Work Item Proposals which seem to be of interest for many different technical committees of ISO/IEC and ISO. The proposals are of interest in the field of image technology.

This paper uses the 8 device colours $CMYOLVNW$ defined in ISO/IEC 15775 for the colours of printing (PR) and television (TV). There is a method to transfer from any triple of coordinates to any other triple by colorimetric equations. If new application programs use the equations then there is a new link between image technology and colour order systems. If additionally the input or output device (scanner, printer or monitor) is linearized according to ISO/IEC TR 19797 then there is a linear relationship between any triple of input and output device coordinates and the device independent CIELAB coordinates.

The linear relationship allows to calculate the output for any input and vice versa. The linearization of the device is necessary as a setup_stage for any colour management method. There are files which support the input and output of 3x3x3, 5x5x5 and 16x16x16 colours. The file output and the output of test charts according to ISO/IEC 15775 may be used for the linearization of the device (by improved device drivers).

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DIN 33866-2, Edition:2000-10; Part 2: Method for specifying image reproduction of colour devices by analog input and analog output for colour image reproduction devices: analog ‹ analog (copiers) - Realisation and application
DIN 33866-3, Edition:2000-07; Part 3: Method for specifying image reproduction of colour devices by digital input and analog output as hardcopy for colour image reproduction devices: digital - analog (printers) - Realisation and application
DIN 33866-4, Edition:2000-10; Part 4: Method for specifying image reproduction of colour devices by analog input and digital output for colour image reproduction devices: analog - digital (scanners) - Realisation and application
DIN 33866-5, Edition:2000-10; Part 5: Method for specifying image reproduction of colour devices by digital input and analog output as softcopy for colour image reproduction devices: digital - analog (monitors) - Realisation and application
- [2] **DIS ISO/IEC 19839-X**; Information technology - Office machines - Colour image reproduction equipment, see www.ps.bam.de/IEDIS/IEDIS.HTM
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- [4] **ISO/IEC TR 19797**, Edition 2004-09, Device output of 16-step colour scales, output linearization method (LM) and specification of the reproduction properties, ISO/IEC JTC1/SC28 (21pages, 400 kByte), see <http://www.iso.ch>
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- [6a] **ISO/DIS 22028-2:2004** (under Ballot), Photography and graphic technology Ñ Extended colour encodings for digital image storage, manipulation and interchange Ñ Part 2: Reference Output Medium Metric RGB colour image encoding (ROMM RGB)
- [6b] **ISO/DIS 22028-3:2004** (under Ballot), Photography and graphic technology Ñ Extended colour encodings for digital image storage, manipulation and interchange Ñ Part 3: Reference Input Medium Metric RGB colour image encoding (RIMM RGB)
- [7] **ISO/CD 15076:2004**, Image Technology - ICC Colour Management - Architecture, profile format, and data structure to be expected soon as ISO/DIS
- [8] **ISO/CD 19005:2003**, Document management ‹ Electronic document file format for long-term preservation ‹ Part 1: Use of PDF (PDF/A)

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There are technical publication and technical reports in the internet, see the following URL under Publications
<http://www.ps.bam.de>

[11] Richter, Klaus, Relative CIELAB output for display systems of ISO TC 159 at daylight work places, see the URL (1.4 MByte, 27 pages)

<http://www.ps.bam.de/info04/RIC04.PDF>

[12] Richter, Klaus, Linearized printer output of corresponding colours by the MTL code, see (92 kByte, 2 pages)

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

[13] Richter, Klaus, Analog and digital ISO/IEC-colour charts for different reproduction tests and for the efficient use of colour in design, see (1000 kByte, 6 pages)

<http://www.ps.bam.de/AICMAR.PDF>

[14] Richter, Klaus, Images in ISO/IEC-test chart files which show basic problems of colour reproduction and produce equal output for corresponding colours defined in CIELAB related device spaces, see (760 kByte, 14 pages)

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[16] Richter, Klaus, CIELAB 16 step grey scales on printers and monitors by daylight illumination based on ISO/IEC 15775 and DIS ISO/IEC 19839-1 to 4, see (2300 kByte, 16 pages)

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<http://www.ps.bam.de/DFZBAM.PDF>

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Annex A: New Work Item Proposals for Colour Office Systems

There are first drafts of several New Work Item Proposals which are proposed to be discussed within ISO/IEC JTC1 SC28 (Office equipment), and in other international and national standard groups, for example

1. Equations for colorimetric coordinates

Method and equations for the transformation between device independent LAB^* (CIELAB) colorimetric coordinates and device dependent olv^* and cmY^* colorimetric coordinates in both directions based on eight device colours CMYOLVNW

<http://www.ps.bam.de/NWIP/NWI04DC.HTM>

2. Encoding and decoding

Method for encoding and decoding of device dependent colorimetric coordinates olv^* and cmY^* using 4, 6, 7 and 8 bits for the grey scale out of 4, 8, 12 or 16 bits for the three colorimetric coordinates olv^* or cmY^* .

<http://www.ps.bam.de/NWIP/NWI04EC.HTM>

3. Linearization of scanner systems

Linearization method for scanning systems which scan the analog ISO/IEC-test charts according to ISO/IEC 15775 with 16 step equally spaced colour scales

<http://www.ps.bam.de/NWIP/NWI04SC.HTM>

4. Device colour management

Definition of a double cone natural colour connection space (NCCS) and the connection between the input and the output device colour space (compare Fig. 9 to 12)

5. Test method for the compatibility class of a workflow

PDF/PS-test files for the test of the compatibility class of the workflow (compare Fig. 3)

6. Test method for the colour output specification (accuracy)

PDF/PS-test files for the colour output specification according to ISO/IEC 15775, Annex G.

7. Test files for 16x16x16 colour output, LookupTable and Output Linearization

PDF/PS-test files for the measurement of a grid of 16x16x16 output colours. The output colours are measured and used to define the inverse input colorimetric data $cmY\tilde{O}^*$ for the intended output. A mapping of cmY^* (star) to $cmY\tilde{O}^*$ will produce the intended linearized output (compare Fig. 21 to 25)

8. Colour management of display output

PDF/PS-test files produce 16 step equally spaced colour scales on the display surface. For the eight different display reflections between 0 and 40% compared to white large changes for the cmY^* (star) to $cmY\tilde{O}^*$ mapping are necessary (compare Fig. 14).

9 Test of the elementary hue output by 16 step colour scales

The colour series between white **W**, the four elementary colours **RJGB** and black **N** will be produced. This test will show if the appropriate colours CMYOLVNW are used in the workflow (compare Fig. 13)

10. Area coverage

The colorimetric coordinate **deepness** is the basis for a visual coverage on the paper. The deepness of the colour separations will be used to calculate the visual separation coverage which is a colorimetric basis to study yield.

Remark on Terminology: An improved terminology is needed for the colorimetric colour coordinates used in office standards and the workflow via the double cone NCCS. This terminology may be based on terms of CIE Division 8 Ómage TechnologyÓ ISO 22028-1:2004: Extended colour encodings for digital image storage, manipulation and interchange, Part 1 to 3, ISO/IEC 15775:1999, ISO/IEC TR 19797:2004 and ISO/IEC DTR 24705:2004.