Ergonomic Color Image Technology with High Visual and Material Efficiency based on Elementary (unique) Hues

Klaus Richter, Berlin University of Technology, Section Lighting Technology, Berlin, Germany

Abstract

An ergonomic color image technology produces visually equally spaced 16-step output colors produces for equally spaced 16-step rgb input data on printers and on displays even in the case of different ambient light reflections on the display surface. If the output is equally spaced for example in the CIELAB space then a high visual efficiency is reached. If additionally for printers with CMYN colorants the achromatic colors are only printed by the black colorant N instead by the overprint of three chromatic colorants CMY than additionally a high material efficiency is reached. For an efficient image reproduction it is highly important to produce a relative colorimetric reproduction which is linearly spaced as function of relative CIELAB data. Therefore the definition of meaningful relative CIELAB coordinates is necessary. For this any device is described by six chromatic colors OLV and CMY. The six device colors OYLCMV form a chroma hexagon in the (a, b*) CIELAB diagram. In the third dimension the achromatic color Black N is located at the top and White W is at the bottom.*

Introduction

An ergonomic color image technology leads to equally spaced outputs on printers and on displays for equally spaced input data. This image technology needs transformation equations between *standard* CIELAB data and *relative* CIELAB data in both directions. Naive users appreciate if at least the hue output is device *independent* and based on the elementary (unique) hues. For equally spaced *rgb* input data in any hue plane many users require equally spaced CIELAB data in this hue plane. In this paper the CIELAB color space and CIE standard illuminant D65 is used but any other CIE color space and any other CIE illuminant can be used instead. The visual output on printers and monitors with the relative colorimetry of this paper is highly independent of all the different parameters.

Standard and *relative* CIELAB space

For any CIELAB color within and outside the hexagon device space (defined by eight device colors in CIELAB) the definition and calculation of *relative* device (d) coordinates olv^*_d or $cmy0^*_d$ and *relative* elementary (e) (unique hue) coordinates rgb^*_e or $cmy0^*_e$ has been published [2] and [9]. Therefore simple colorimetric equations for the transfer between *standard* and *relative* CIELAB coordinates are available in both directions. The new *relative* device and elementary coordinates are in the range between 0 and 1, similar as the relative coordinates rgb'_{sRGB} of the sRGB color space according to IEC 61966-2-1 [3]. There is the cylindric *standard* CIELAB space with the coordinates $L^*C^*_{ab}\ h_{ab}$ (lightness, chroma, hue angle). Now two new cylindric *relative* color spaces are defined with the two coordinates *relative* chroma c^* and *relative* triangle lightness t^*. Both coordinates are in the range between 0 and 1. Both spaces are double cones and differ only in the hue angle spacing. One is similar to the double cone of the *Ostwald* [4] color space with complementary device hues *O–C, Y–V,* and *L–M* in the opposite directions. The other is similar to the double cone space of the *Natural Color System* [5] with the elementary hues *R–G* and *J–B* in the opposite directions.

High visual and material efficiency

A high visual efficiency on printers and displays is reached, if for example the 9 steps between device Black *N* and White *W* are equally spaced in CIELAB (compare Fig. 1). Additionally the 9 steps are equally spaced for any CIELAB hue between the two achromatic colors and the color *X* of maximum CIELAB chroma which a device can produce. Therefore at least a user can distinguish the 3 times 9 steps in the hue triangle *N–W–X–N* for any hue. For an output linearization method to reach this property for any device, see for example ISO/IEC TR 19797 [6].

A high material efficiency on printers is reached if all grey colors between Black and White are *only* printed by the black colorant. Example outputs by the standard offset printing process and by printers which use the four colorants CMYN have been produced as a digital – analog color atlas. For a continuous change between the achromatic colors and the chromatic colors a special colorimetric color separation technology has been developed (compare Fig. 8). The technological problem to produce a constant CIELAB hue angle for any color series on any device has been solved by a new three dimensional output linearization method which is an improvement of the method given in ISO/IEC TR 19797 [6].

Device independent elementary hue output

A device independent and elementary hue output is a main user wish. This output property has been realized recently by many printer devices, for example laser printers, inkjet printers, and the standard offset printing process. User prefer the elementary hue output of *RJGB* (Red, Yellow, Green and Blue) instead of the device hue output *OYLV* with three primary and the secondary color *Y* which all differ for any device. For the definition of the elementary hue angles the CIELAB hue angles of the CIE test colors no. 9 to 12 *(RJGB)* of CIE 13.3 [7] are used. The CIELAB hue angles h_{ab} are 25, 92, 162 and 272 degrees for *RJGB*, compare Fig. 5.

Affine transformation between CIELAB data

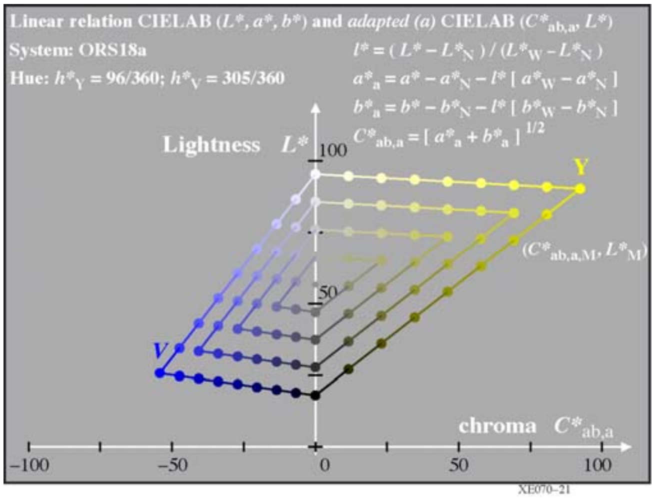


Fig. 1: Offset colors for hues Y – V in CIELAB diagram (L, C^*_{ab})*

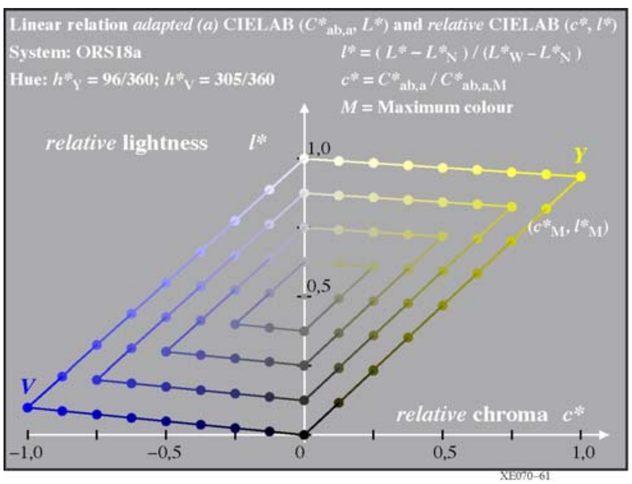


Fig. 2: Offset colors for hues Y – V in relative CIELAB diagram (l, c*)*

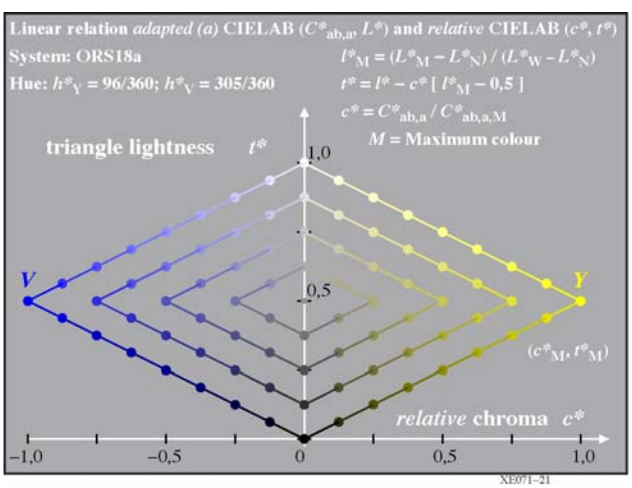


Fig. 3: Offset colors for hues Y – V in relative CIELAB diagram (t, c*)*

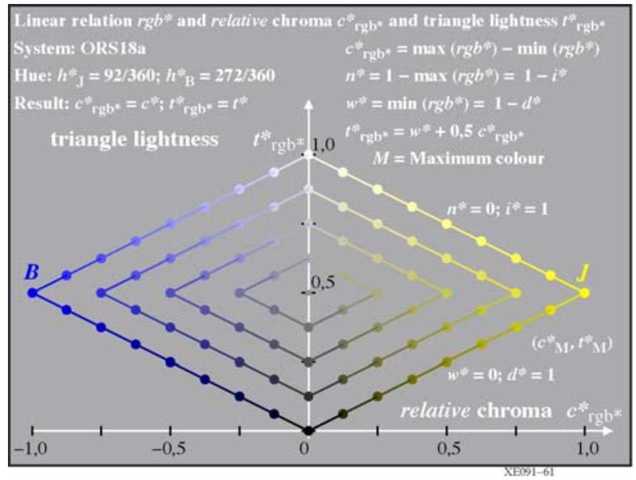
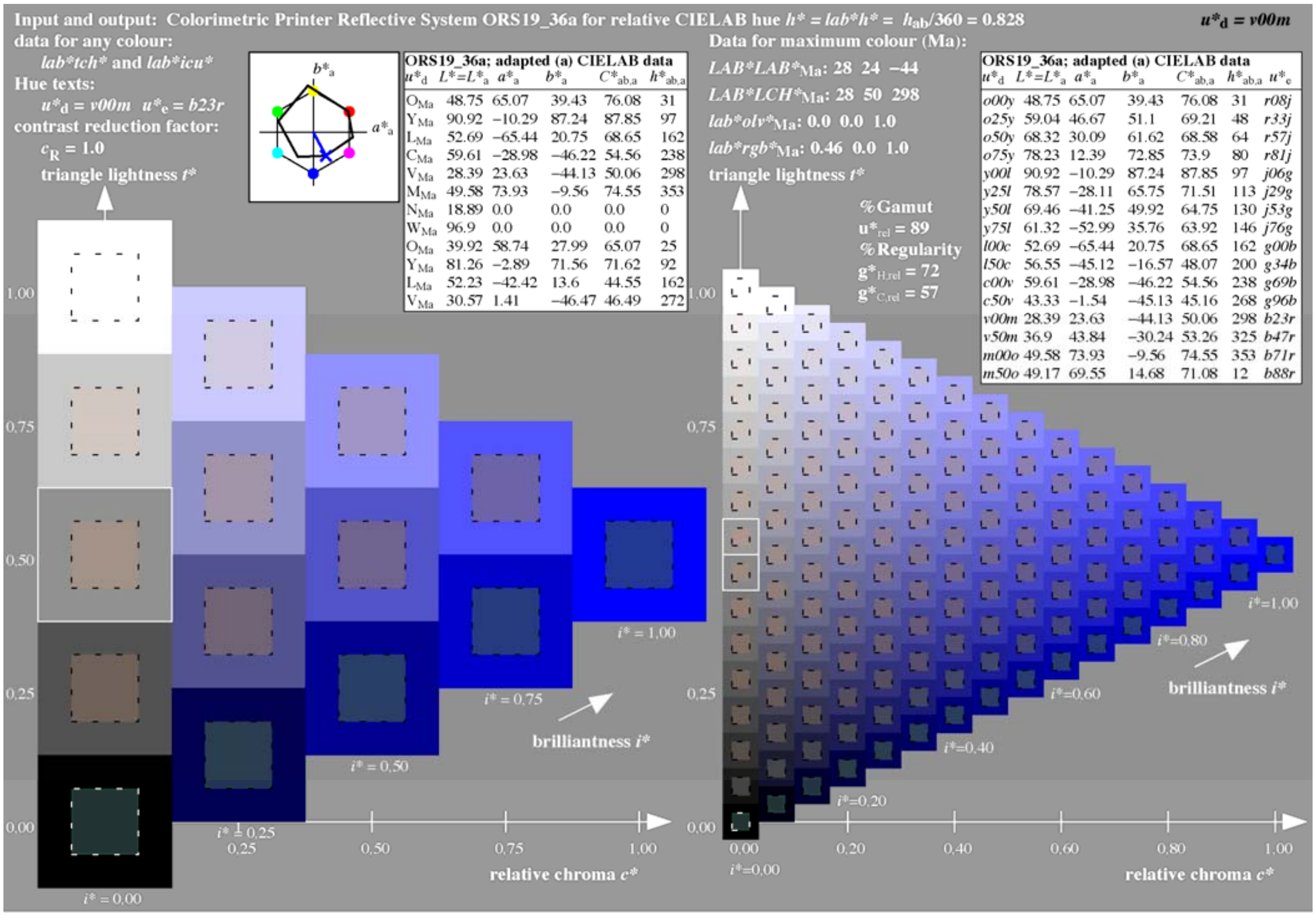


Fig. 4: Offset colors for hues J – B in relative rgb diagram (t^*_{rgb}*, c_{rgb}*)*

Recently the affine transformation equations between *standard* CIELAB and *relative* CIELAB in both directions have been published in a CIE paper [2] and in DIN 33872 [9]. Fig. 1 to 4 show main equations and visually the affine transforms. Fig. 1 to 3 show the colorimetric equations for the data transfer between *standard* CIELAB, *adapted (a)* CIELAB and *relative (r)* CIELAB in diagrams for the complementary hues *Y–V*. The triangle lightness *t** and the *relative* chroma *c** of the *relative* CIELAB space look identical to the triangle lightness t^*_{olv*} and the *relative* chroma c^*_{olv*} which are calculated from the three *relative* coordinates *olv** (compare Fig. 3 and 4). The relative coordinates *olv** are defined in ISO/IEC 15775 for the device colors *OLV (Orange red O, Leaf green L, and Violet blue V).* The triangle lightness *t** is calculated from the CIELAB data and the triangle lightness t^*_{olv*} is calculated from the *olv** data. Both data are identical if the following two properties are valid:

- for the achromatic series *N–W* the three coordinates *olv** are linearly related to the relative CIELAB lightness $l^* = (L^* - L^*_N) / (L^*_W - L^*_N)$. The index *W* is used here for media White and the index *N* is used for media Black according to ISO/IEC 15775 [1].
- for the two chromatic color series of the Yellow hue *N–Y* and *W–Y* and the complementary Violet blue hue *N–V* and *W–V* the coordinates *olv** are linearly related to the CIELAB difference between both Black *N* and White *W* and the color *M* of maximum chroma (compare Fig. 7).

Between the input coordinates *rgb* which are interpreted (abbreviation ->) as elementary color data *rgb** and the *adapted* CIELAB data (L^*, a^*_a, b^*_a) or $(L^*, C^*_{ab,a}, h_{ab,a})$ the linear relations are automatically produced if a device is linearized in CIELAB. This is a basic requirement for any successful color management application according to ISO/IEC TR 19797 [6]. Many device manufacturers of printers and monitors have therefore at least some devices on the market which produce together with the operating system and the device driver this linear relationship. The linear relationship may be produced with either a conversion table or a color management system within the device. If applied a user will see visually equally spaced output colors for his device.



Ee680–7A, Page 14/198

Fig. 5: Offet colors for device hue Violet blue V with 5- and 16-step color series and may standard and relative CIELAB coordinates for the samples

Figure 5 shows an output of the device hue Violet blue V which is usually not equally spaced. For the outer squares the image file uses regular spaced *rgb* data which are interpreted as *olv** device data (compare Fig. 7). For the inner square *cmy0* data are used which are calculated by the "1 minus relation" of colorimetry, for example $c = 1–o$. Many devices show the same output colors for the center and the outer square and many not.

The CIELAB data and the affine calculations are given for a real offset printing process. Two CIELAB hue hexagons are shown: a regular hexagon with a hue angle difference of 60 degrees and the device hexagon defined by the CIELAB data of the real offset printing process on standard offset paper, see [1]. Additionally the CIELAB data of the CIE-test colors according to CIE 13.3 are given. The CIELAB hue angles (25, 92, 162 and 272) of these four CIE colors represent the hue angles of the elementary colors *RJGB*. The table on the top right shows the CIELAB values of 16 device hues. The hue angle of the device hue *V* is 298 degree and the hue angle of the elementary hue *B* is 272 degree. Therefore the device hue output looks very reddish blue. On other devices, for example on new *OLED* screens the hue angle may be near 240 degree and then the device color *V* appears very greenish blue. The hue angle differences of the two device hues *V* is therefore 58 degrees. This is in the range of the hue angle difference of Yellow *J* and Red *R* (92 – 25 = 67 degrees). It is very confusing for the users in offices if the hue output changes so much and therefore many user require the elementary hue output Blue *B* on any device.

The hue is the most critical attribute in color image reproduction. And any user has a very critical hue evaluation. For any user with normal color vision the standard deviation for the hue angle is about 3 degree in CIELAB for a highly chromatic hue circle. For a group of users the standard deviation is about twice. Therefore many users are disappointed if large hue differences are produced by different devices and require a device independent output with the elementary hue Blue *B*.

Fig. 5 shows the device hue text u^*_d and the elementary hue text u^*_e which plays the basic role in the next Fig. 6. The device hue text u^*_d uses the letters *oylcvm* for the six device colors and the elementary hue text u^*_e uses the letters *rjgb* for the four elementary colors. In both cases 100 steps are used between neighboring colors.

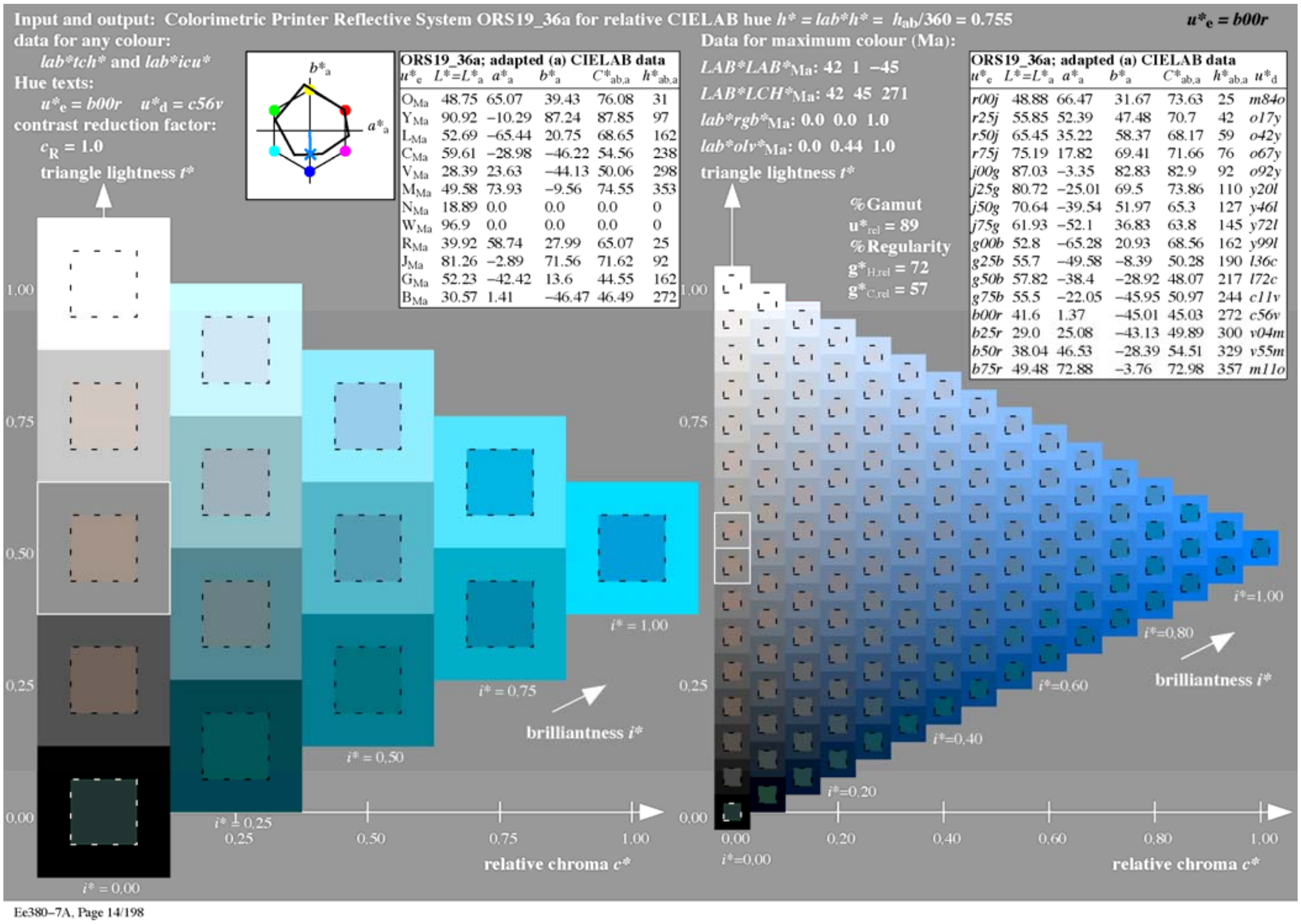


Fig. 6: Offset colors for the elementary hue Blue B with 5- and 16-step color series and may standard and relative CIELAB coordinates for the color samples

Fig 6 is designed for the elementary hue output Blue *B* instead of the device hue output Violet blue *V* in Fig. 5. Now the 16-step hue circle is based on the elementary hue text u^*_e and the device hue text u^*_d is calculated (top right). Now **the hue spacing is device independent** and visually more regular.

CIE action on elementary hues

In Stockholm 2008, at the last meeting of CIE Division 1 "Color and Vision" a reporter ship was created to look at the "Elementary hue angles for image technology applications". For any CIE illuminant four points in a colorimetric space define the elementary colors by the following visual criteria:

R	Red	neither bluish nor yellowish and neither blackish nor whitish
J	Yellow	neither reddish nor greenish and neither blackish nor whitish
G	Green	neither bluish nor yellowish and neither blackish nor whitish
B	Blue	neither reddish nor greenish and neither blackish nor whitish

Brilliantness *i** and blackness *n**, whiteness *w** and deepness *d** are opposite coordinates similar as redness *r** and greenness *g**, or yellowness *j** and blueness *b**. For example for CIE standard illuminant D65 visual criteria can evaluate four fixed CIELAB data of the four elementary colors *RJGB*. Most people seem to evaluate all colors *in relation* to these four colors which they have in mind. The *relative* image technology of this paper is based only on the device independent hue angles of the four CIE-test colors *RJGB* and not on their lightness and chroma.

One source for the CIELAB values of the visual elementary colors $RJGB_{vis}$ is the *Natural Color System* [5]. At present the use of the elementary hue angles is a useful step on the way to a complete device independent image technology based on visual criteria. The developed *relative* colorimetric system based on the elementary hue angles RJGB may play an important role to define colors according to naive user wishes. The relative coordinates may be stored in documents together with the eight device CIELAB data and then for any triple of *rgb* data the *LAB** data can be calculated at any time. For input and output of documents the complete gamut of the output device can be used without any loss of information. Basic applications of such a *relative* colorimetry for scanners, printers and displays are described in ISO/IEC TR 24705 [8].

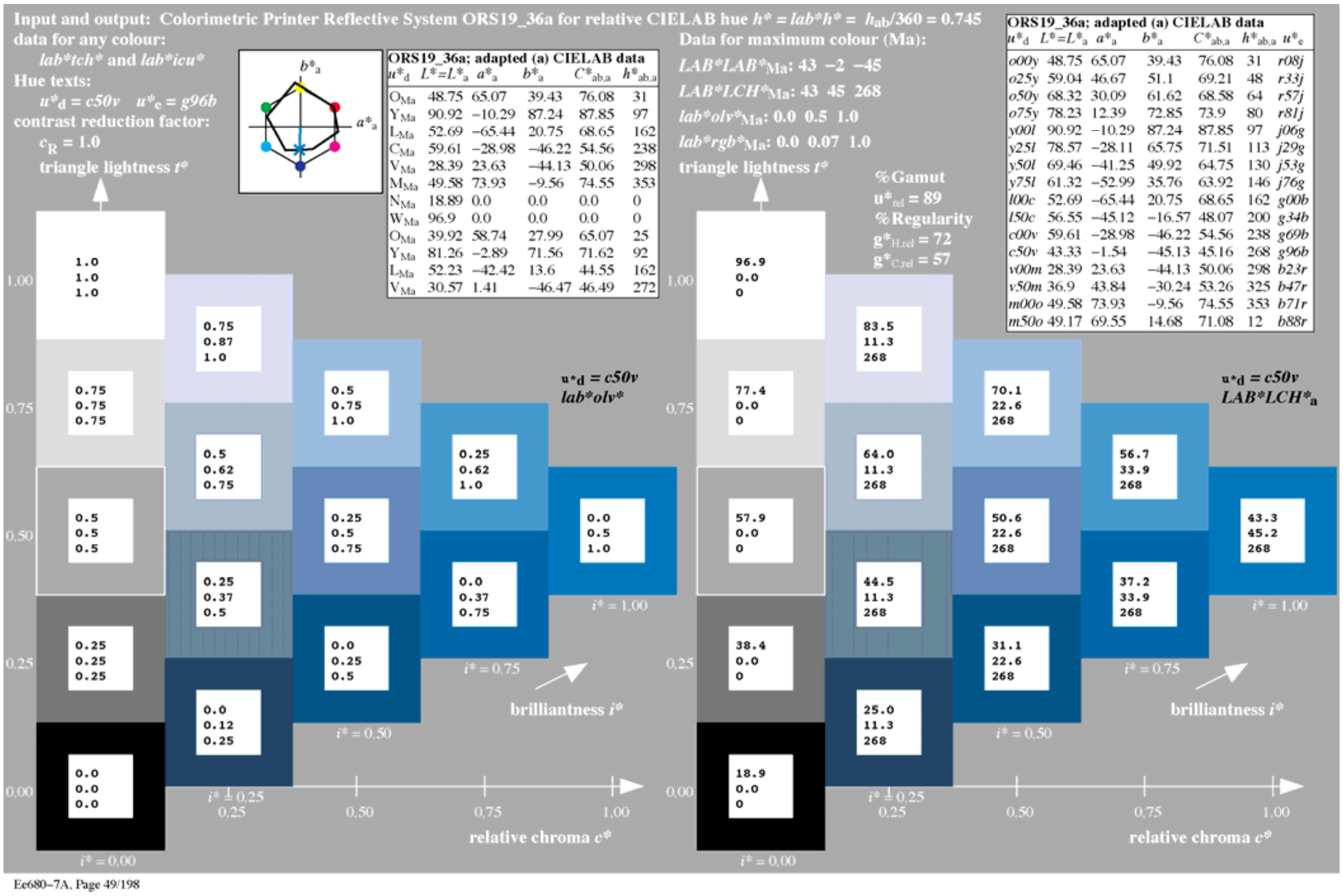


*Fig. 7: 5-step color series with relative CIELAB color data lab*olv* (left) and standard CIELAB color data LAB*LCH*$_a$ (= L*, C*$_{ab,a}$, $h_{ab,a}$) (right)*

For the device hue u^*_d = *c50v* and for all samples of the 5-step colour series Fig. 7 shows both the *relative* CIELAB data *lab*olv** (left) and the *adapted (a)* CIELAB data *LAB*LAB*$_a$ (= L*, C*$_{ab,a}$, $h_{ab,a}$) (right)*. A study of the data shows the regular spacing of both data sets and the affine connection. So if any of both data sets is given the other set can be calculated.

For the solution of application problem to produce the equally spaced output data for equally spaced *rgb* input data ISO/IEC 15775 has defined three kinds of images:

1. *image (star image)
2. *'image (star prime image)
3. '*image (prime star image)

For the *rgb* input data the output data are usually different from *LCH**$_a$ and are called *LCH*'*$_a$ (compare star prime image). A 9x9x9 grid of equally spaced *rgb* input data produces therefore usually a 9x9x9 grid of *LCH*'*$_a$ output data. Usually they fill the whole CIELAB space of *LCH**$_a$ data (compare star image) defined by the six chromatic device colors OYLCVM and the device Black *N* and White *W*. Therefore an interpolation method produces for any given color of the 9x9x9 grid of *LCH**$_a$ data the corresponding *olv'** data (compare prime star image) which produce the intended *LCH**$_a$ data. This has to be done only once for any device. The result is a:

9x9x9 transformation table *rgb –> olv'**

This *rgb –> olv'** table is device specific and may be used by the device manufacturer to linearize his device, for example within the device. According to ISO/IEC TR 19797 [6] a linearizing method is necessary as a starting point for any useful color management application. A linearizing method is usually applied for devices in the professional area.

With the above 9x9x9 transformation table *rgb –> olv'** the implementation is simple. The method is effective and it is expected that manufacturers of office devices will use it in future within the device and at least for some of their office devices. This allows a more effective color management in all application area. In the office area in many cases an additional colour management method may be obsolete, especially if the device independent elementary hue output is realized. In application many users may appreciate a choice "Device or elementary hue output" in the device driver.

Offset printing and printers use usually four colorants *CMYN*. Then the grey colors can be printed by approximately equal amounts of *CMY* or *only* by the black colorant *N*. The material efficiency is higher (and the cost for toner and ink lower), if the 9 grey steps are only printed with the achromatic colorant *N*.

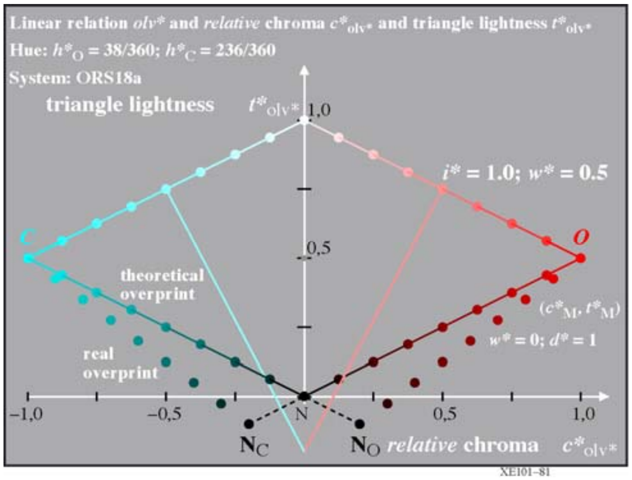


Fig. 8: Mixture colors in a hue plane O–C with different amounts of black

Print output with high material efficiency

Many simple colorimetric models assume that in the CIELAB space the overprint of for example Orange red *O* and Black *N* produces colors on a line between *O* and *N*, see Fig. 8. For the offset printing process the real colors are on a line between *O* and N_o. The color N_o has a lightness lower than the lightness of black *N* and is highly chromatic with a CIELAB chroma of up to 15. This is similar for *C* (Cyan blue) and *N*. If a light whitish orange red color (i^*=1, w^*=0.5) is overprinted by black *N* then the darkest color is on the dashed line between *N* and N_o. Using these properties a model defines a colorimetric transformation between *olv** and *cmyn** in both directions. It is not necessary for the following that the model is exact.

In real printing processes this model has been applied for the *rgb* input data as described before with a fixed relation *rgb–>cmyn*. Instead of the *rgb* data the *cmyn* data (four instead of three numbers for any color) have been used. This again produces an $LCH^{*\prime}_a$ output which deviates from the expected LCH^*_a output. Again the corresponding *olv'** input data can be calculated by a three-dimensional interpolation method. A transform of the *olv'** prime-star-data by the fixed relation produces *cmyn'** data. Again a print output with the *cmyn'** data produces the intended *LCH*a* data. Therefore the intended output is produced using a:

9x9x9 transformation table *rgb –> cmyn'**.

Then the amounts of the four colorants CYMN can be calculated for any CIELAB color in any hue triangle N–W–X–N which a device can produce. The outputs have the advantages of using at least less than 200% of the four colorants, for example 50% C, 50% M and 90% N which sums up to 190%. This reduces the printing costs and stabilizes the printing process. Up to now often up to 340% of the four colorants are used by many printing technologies. Another large advantage is that the scales between the complementary device hues *O– C, Y–V*, and *L–M* via a central grey Z (lightness $L^*_Z = 0.5\ [L^*_N + L^*_W]$) are continuous. The disadvantage that some deep dark colors below the line *N–X* cannot be printed is of minor importance for most office applications.

Summary

A high visual and material efficiency is reached if colorimetric methods are used in image technology. A model describes all the available colors of a device in the CIELAB color space by eight colors OYLCVM and NW. These colors are defined for example in ISO/IEC 15775 for standard offset printing and the standard CRT monitor. There are DIN-test charts according to DIN 33872-1 to -6 which allow to evaluate visually if a device produces the intended equally spaced colors by Yes/No-criteria. The DIN-test charts are freely available [9].

Remark: If the first four small alphanumeric characters under any picture of this and other paper of the author are used, for example in the sequence http://www.ps.bam.de/Ee68 then similar images may be seen via an internet connection.

References

[1] ISO/IEC 15775:1999 and Adm1 2005, Color reproduction properties of color copiers
[2] Klaus Richter, Colorimetric Model of logarithmic Color Spaces LMSLAB, CIE-Session, Volume 3: extended papers, Beijing 2007, 40 pages on CD
[3] IEC 61966-2-1: 2005, Multimedia systems and devices - color measurement and management - part 2.1: color management, RGB default color space - sRGB
[4] Ostwald, W, (1930), Die Farbenfibel, Leipzig, Unesma.
[5] Svensk Standard SS 01 91 00 to 04:1982, Color notation system NCS
[6] ISO/IEC TR 19797:2004, Device output of 16-step color scales, output linearization method (LM) and specification of the reproduction properties, see (20 pages, 280 k Byte), see http://www.jbmia.or.jp/sc28/sc28docs/j28n656.zip
[7] CIE13.3:1995: Method of measuring and specifying color rendering of light sources
[8] ISO/IEC TR 24705:2005, Method of specifying image reproduction of color devices by digital and analog test charts, see (80 pages, 1 M Byte), see the last public draft http://www.jbmia.or.jp/sc28/sc28docs/j28n689.zip
[9] DIN 33872-1 to -6:2008 (in print), Method of specifying relative color reproduction with YES/NO criteria, see http://www.ps.bam.de/33872E

Author Biography

Klaus Richter received his BS in physics from the University of Giessen, Germany (1966) and his PhD in physics and colorimetry from the University of Basel, Switzerland (1969). Since then he has worked at the Federal Institute for Material Research and Testing (BAM). Since 1972 he teaches computer graphics and colorimetry at the Berlin University of Technology. He is editor of many ISO/IEC and DIN standards in the field of color image technology and in chair of CIE TC1-63 "Validity of the range of CIEDE2000.