Färgrapport

Colour Report F26

DA POS

THE FORSIUS SYMPOSIUM
on
COLOUR ORDER SYSTEMS

Papers
recieved in advance
as a basis for
discussions

Subtopics:

Why Colour Order Systems	a
Basic Concepts	b
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Colour Spaces and Models	d
Experimental evidence	e
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Applications	g
Other visual phenomenon	—
Colour Order Systems and Environmental Colour Design	—

AIC
Association Internationale de la Couleur
International Colour Association
Internationale Vereinigung für die Farbe

MIDTERM MEETING 1983

Färginstitutet

SKANDINAVISKA FÄRGINSTITUTET AB • SCANDINAVIAN COLOUR INSTITUTE

- THE FORSIUS SYMPOSIUM ON COLOUR ORDER SYSTEMS -

Papers and abstracts of posters given in advance.

This Colour Report contains the contributions delivered in advance as a background for discussions at the Symposium in Kungälv, Sweden, August 25- 29, 1983.
Between different "workers in colour", from scientists in physics, physiology and psychology to all kind of designers of environment, there seems to be a lack of understanding for the different objectives of colour order systems. The aim of the Symposium at this AIC Midterm Meeting is to diminish this gap.

The contributions are of two kinds, written papers and abstracts of poster papers intended to be exhibited. These papers are documents of their own value and they will not be orally presented at the Symposium. Instead a maximum of time will be devoted to clarifying talks at each sub-topic. It is therefore of paramount importance that they are read in beforehand by the participants. This will allow discuscussions to be held on a competent level.

On each paper is indicated the sub-topics- see cover- where it has been imagined to represent a relevant document.
They have also been given their numbers and index of pages and are listed in alphabetic order after authers on the following pages 2-5.

We thank all authors for their contributions to this first part of documentation of the Symposium for which it represents a working material. It is also a detached material of its own value.*)

The Symposium represents a Midterm Meeting of the AIC and is devoted to the memory of Sigfrid Aron Forsius, a Swedish scientist who already 1611 presented the three dimensional colour order space.

THE ORGANIZING COMMITTEE OF THE FORSIUS SYMPOSIUM ON
COLOR ORDER SYSTEM

Anders Hård   Lars Sivik   Åke Stenius   Gunnar Tonnquist

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*) This Colour Report can also be ordered separately from The Scandinavian Colour Institute, Box 14038, S-10440 Stockholm, Sweden.

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COLOUR CHART MEASURES IN THE "PLANETS - COLOUR - SYSTEM"

AUTHOR: Pr. Michel ALBERT-VANEL E.N.S.A.D. - C.F.C. PARIS FRANCE

The Planets -Colour-System is original as instead of studying colours separately, it studies them as different groups.
In classical colour research, the result is not so precise, as it has been reduced to three parameters so as to manipulate the colours more easily, this is fact has just widened the gap between scientific theory and its everyday use.
Especially when trying to talk of a picture or a landscape as a colour chart. Having then to describe the colours either too vaguely or choosin the predominant tones to give the general feeling. In both cases their action on each other is lost. A colour is never seen on its own, but always in reference to others, to its background, its light, etc...
It is this complete interaction that should be taken into consideration not only when creating colour charts, but also to change our general outlook on Art, textile, design, etc.

Colour Chart definition

A colour chart is what can be altogether seen by the observer at a given time in space. It is therefore relative and temporary, but it can be determined from different points of view.
Considering the visual field "a window" in which there are a given number of coloured dots, side by side. Thanks to graphic computer processing an image can be drawn from a mosaic of elementary dots, called "pixels", which can be reduced, if less dots are required (256 x 256, or 128 x 128, 64 x 64, 32 x 32, 16 x 16, 8 x 8, 4 x 4, 2 x 2).
On each pixel numbers give information: how much green, in relation to the red, medium light, etc. This information gives an idea of the colour chart.

Measure

To measure, certain number of references and fundamental laws must be known. It is the substractive pigments that are to considered in a picture for instance, or additive-ones on a television screen ?
Only when reproducing colours does one really have to known. Often when looking at a picture or a landscape as the colours blend at a distance in a "pointillist" effect, one remains between substractive and additive Rotating disks are a good example, except that these occur in time, not in space.

(ALBERT-VANEL 2)

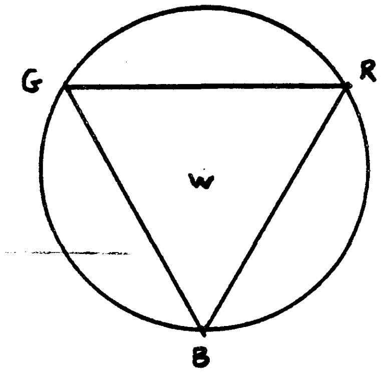
These disks have six colours: blue - cyan - green - yellow - red - magenta. Naturally since these are BETWEEN additive and substractive, and it has been proved that all the colours cannot be represented in three colour process. When optically they blend at a distance, it is possible to keep four colours only: blue - green - yellow - red.

Cyan and magenta getting too close to the other colours then and therefore no longer necessary. Just like Hering's theory, when black and white are added there are basically six colours.

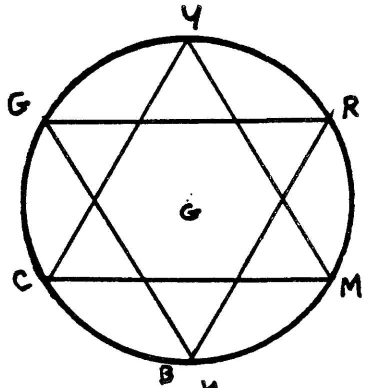
All colour charts therefore are balanced amongst those colours.

When optically blending they become additive when connected with light, substractive when with pigments.

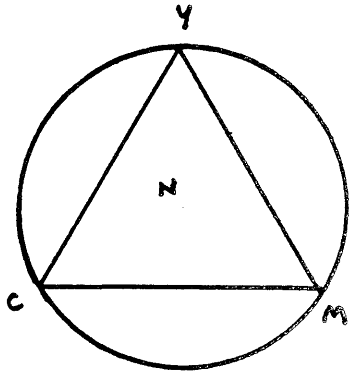
ADDITIVE

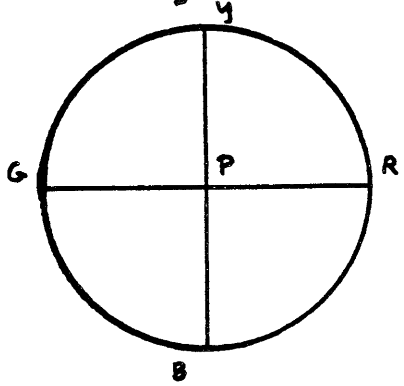


PROPORTIONAL



SUBSTRACTIVE





OPTICAL

Polychromy

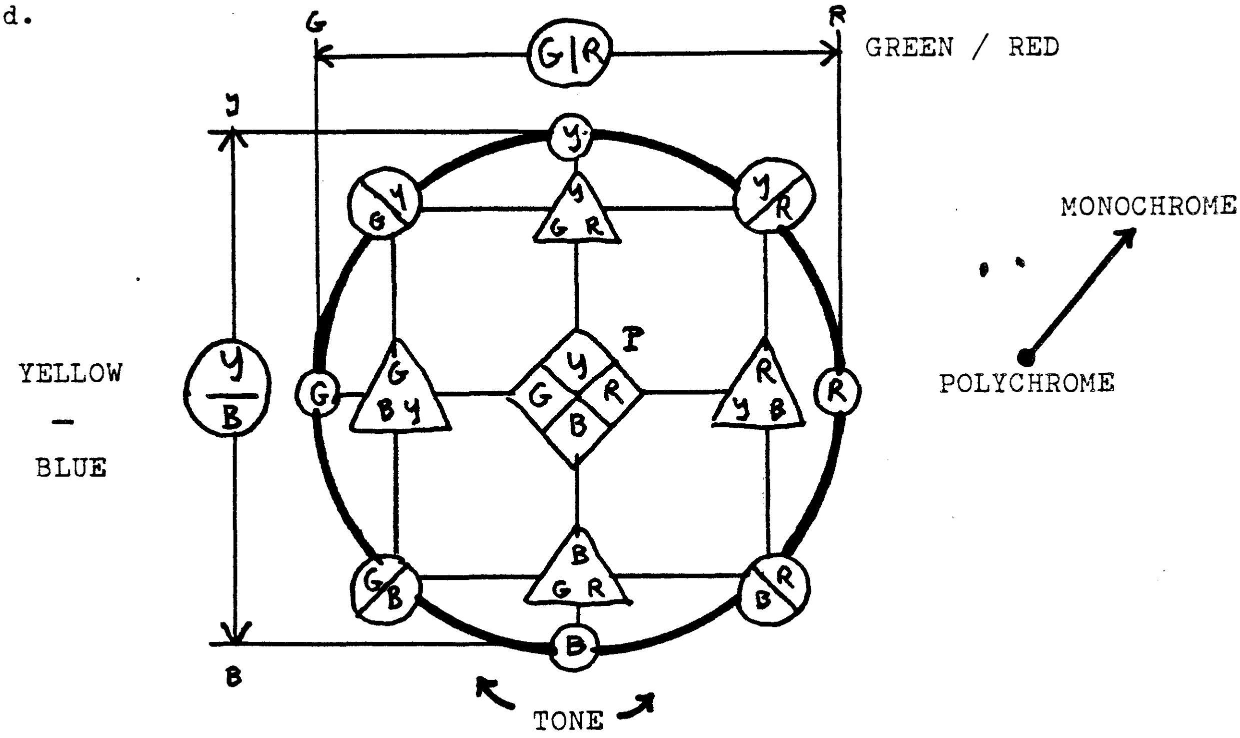
"Polychromy" this is the key to the chart. Looking a coloured chart with all its bright colours next to each other. If the colours are balanced then it is a polychrome chart. Imagine the polychromy in the middle of a surface (the four colours: bleu - green - yellow - red, balanced).

The predominant colour reaching the edge. A yellow colour chart getting yellower and yellower until it is completely yellow, then becoming monochrome.

Monochromy differs from polychromy in that its a chart where the colours are so close they cannot be seen separatly. This however is always relative.

An apparent monochromy may hide a spectral polychromy.

A monochrome chart tends to its unity. To analyse it, the yellow, blue, red, green are examined and measured.
This can be done from two antagonistic axes: yellow - blue and green - red.



Tone

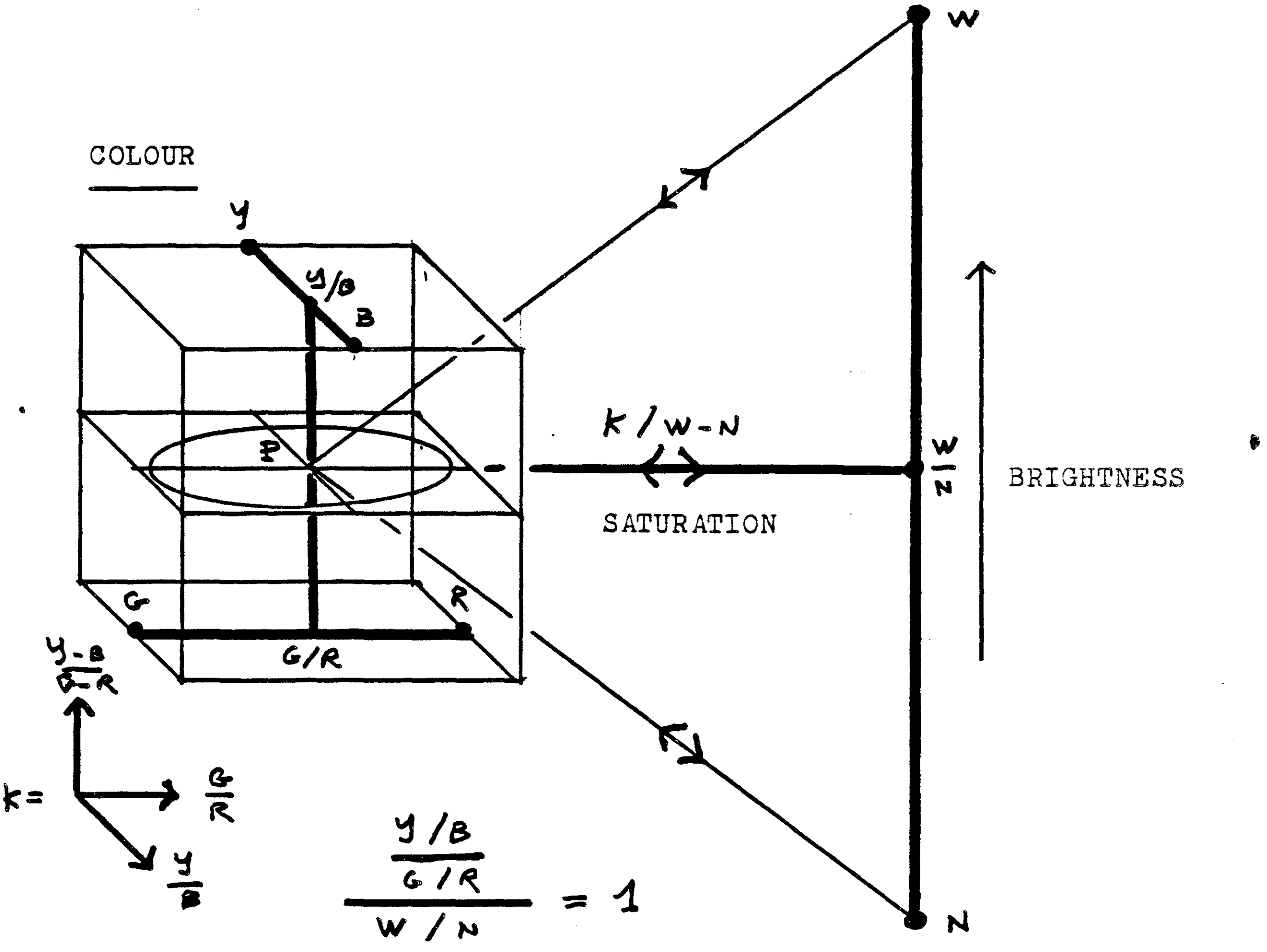
Like in classical chromatic circles tone is defined at an angular distance. This is referring to the four "cardinal points": blue - yellow - green - red. Tone becomes interesting especially when it describes the "entrhopy" point of the colour chart. According to the distance the colours may blend in just one point: grey when its a perfect polychromy; or otherwise in a tone completely predominant.

Saturation

Consider all of colour K (whatever its internal balance) in relation to the amount of black and of white introduced in the chart.

Brightness

After comparing the white in proportion to the black notice that the K colour chart has its own brightness. Its equivalence can be found in the grey grid.



Conclusion

A colour chart will therefore be specific through its:

- polychromy
- tone
- saturation
- brightness

Therefore all colour chart may be described as more or less polychrome or monochrome, hot or cold, satured or not, bright or dark.

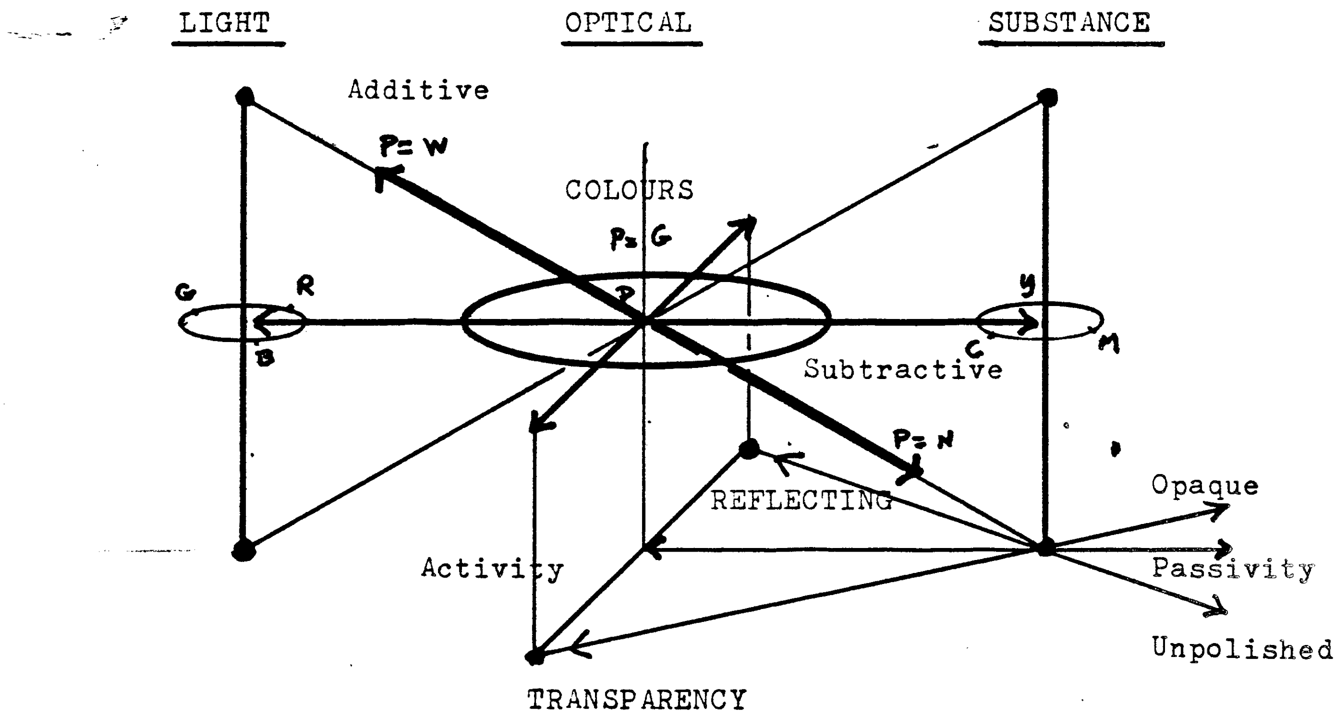
We have therefore a four dimensional space. To see it more cleary, we remove the black and the white axis from the saturated colour space.

This has a double interest:

With polychromy it is possible like to go from additive to substractive

The additive disappears in favour of white, where as with the substractive it does so in favour of black.

Instead of just converging towards black or white, it is also possible to aim at transparency or reflection. It is important not mix white and transparent or unpolished and reflecting, like metal surfaces for instance.

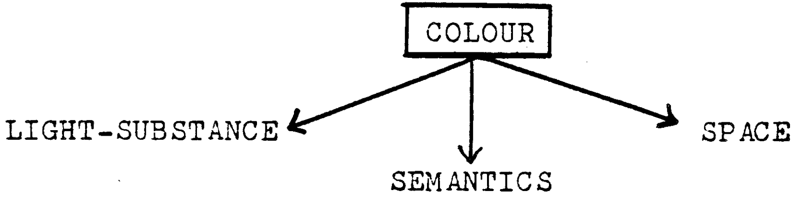


Space

Sixty three typical cases explain the colour chart, whether this or that colour is visible or not. Like the different positions of the planets whose magnetic field shorten as they get further away.
This may define a complete colour chart may it may not be enough. "Dispersion" therefore must be taken into account. Colours side by side will blend when spread. Bright colours can be reduced to minute spots on a white background. The coefficient of dispersion is found by observing how far the colours spread in relation to its surface. Of course background colours are inside or on the outside and how evently they spread. (They may do so differently, evenly, tone by tone or unevenly).

Semantics

With light, substance and space, semantics is the third possibility of change. What the picture contains influences how the colours are represented.
The same colour chart will be judged differently if it's in an abstract, figurative or a three dimensional picture. For instance it does not matte if a triangle is painted red or green, but a figure will resent being painted green.



2:1 (4)
e f

Color-Constant Extensions of the Munsell Book of Color

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Introduction

It is very important that material color standards, such as the Munsell Book of Color as an embodiment of the Munsell color-order system, exhibit color constancy. A page of colored standards should retain their hue and general relationships to one another irrespective of viewing and illuminating conditions. Otherwise, troublesome challenges must be expected as to the suitability of the collection.

Although the problem of lack of color constancy (also referred to as flare) is well known, how to prepare color-constant samples is not known. It is not that the use of some colorants always causes flare or that others never cause it. Flare can occur with any colorant, yet that same colorant can be used to make some colors that exhibit color constancy. The solution is expected to be that the spectral reflectance functions of the standards should satisfy some rather specific but not well understood criteria. The purpose of this study is to define these criteria based on theoretical approximately color-constant reflectance functions.

Deriving these theoretical curves involved two steps. First, tristimulus values corresponding to equal appearance under a range of illuminants between 7600 K and 2300 K compared to that under CIE standard illuminant C were calculated using Nayatani nonlinear model of chromatic adaptation.

The second step was to generate spectral reflectance functions that gave exactly the Munsell renotation tristimulus values for illuminant C and as closely as possible the approximately color-constant tristimulus values over the illuminant range mentioned. A linear programming model was devised to generate these curves.

Deriving Approximately Color-Constant Tristimulus Values

Deriving tristimulus values corresponding to equal appearance for a range of illuminants necessitated a correction for chromatic adaptation. The method proposed by Nayatani et al.[1,2] was used. In the test field, a Munsell color chip with tristimulus values X, Y, and Z (based on renotation chromaticities[3]), is illuminated by CIE standard illuminant C with illuminance E = 1200 lux and viewed against a mat nonselective background with $\rho_o = 0.1977$ (Munsell Value 5/). In the reference field, the chip has tristimulus values X'^{j}, Y'^{j}, Z'^{j} represented by points m^{j} in tristimulus space that correspond to equivalent appearance under illuminants j when $E'^{j} = 1200$ *lux and* $\rho_o' = 0.1977$. The illuminants were CIE illuminant A and (Macbeth type) filtered incandescent with approximate color temperatures 3600, 4000, 4500, 5000, 5500, 6000, 6500, 7200, and 7600 K.

Nayatani's method derives the coordinates of a corresponding chip in the reference field which elicits the same perceptual response as the test-field chip irrespective of different states of adaptation in the two fields. In theory a color chip with a reflectance function that would integrate to tristimulus values X'^{j}, Y'^{j}, Z'^{j} for each illuminant j would be color constant for this series of illuminants.

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Generating Reflectance Functions With Properties Relating to Color Constancy

A linear approximation to tristimulus integrations for each j^{th} illuminant provided the basis for a linear programming model to determine the spectral reflectances R_i of the color chip. We let an unknown point t^j have tristimulus coordinates F^j, G^j, H^j, for example,

$$G^j = \frac{100}{k} \sum_i S_i^j R_i \bar{y}_i \qquad k = \sum_i S_i^j \bar{y}_i \ .$$

The wavelengths i vary from 390 to 700 nm; S_i^j represents the spectral reflectance of illuminant j; $\bar{x}_i, \bar{y}_i, \bar{z}_i$ are the CIE 1931 2° standard observer functions.

To achieve approximate color constancy, we imposed several constraints on the values R_i such that the resulting points t^j would be as close as possible to their corresponding m^j.

Preliminary observations of surface colors exhibiting a significant lack of color constancy suggested that hue shifts were the most objectionable appearance chang Accordingly, we introduced a hue vector joining the color-constant point m^j to a point s^j in tristimulus space corresponding to illuminant j. Points along the hue vector have approximately the same hue as the color chip having coordinates m^j. Movement along the vector from m^j to s^j corresponded to decreasing chroma and increasing lightness. The model constrained movement along the hue vector as well as off the vector by restricting the acceptable points t^j to lie within a linear approximation to a cylinder centered at m^j and having the hue vector as its axis. The diameter and length of the cylinder were controlled by the objective function of the linear program A parameter varied the relative importance of the length (which determined the chroma and lightness error) and the diameter (which determined the error in hue).

A second set of constraints, due to Ohta,[4] dealt with the spectral curve shape and were included to smooth potentially jagged curves that might result from the linear programming model.

Finally, we required that for illuminant C, the tristimulus coordinates t^C were identical to the Munsell renotation values.

Examples of color-constant reflectance functions are given in Table I and Figs. 1 and 2.

Estimating the Degree of Color Constancy

Precisely determining the degree of color constancy of a generated reflectance function would be a twofold task: (1) preparing a physical sample with exactly the predicted reflectance distribution, and (2) conducting visual experiments to judge the magnitude of color constancy in terms of perceptibility and acceptability criteri Unfortunately both tasks are beyond the scope of this initial research. However, indices were devised that estimated the accuracy of the optimization as a first approximation.

The linear program minimized the error between the color-constant tristimulus values, X'^{j}, Y'^{j}, Z'^{j} and the approximate tristimulus values F^{j}, G^{j}, H^{j}, respectively. Thus root mean squares could be used as simple indices of color constancy: the greater the index, the poorer the approximation and the poorer the degree of color constancy. However, given that the uniformity of any color space would not be retained when the adapting illuminant changes, the magnitudes of these differences would be difficult to compare among the illuminants. Instead, using Nayatani's transformation as above but with illuminant j in the test field and illuminant C in the reference field, the approximate tristimulus values F^{j}, G^{j}, H^{j} were transformed to F'^{j}, G'^{j}, H'^{j}, corresponding to the equivalent appearance under adaptation to illuminant C.

To be consistent with the premise that hue deviations were the major criterion for flare, a color-constancy index was devised that weighted CIELAB hue as McLaren[5] did in a study correlating acceptability data from industrial pass-fail judgements for color-difference equations with dimensions of lightness, chroma, and hue:

$$CCI^{j} = [(L^{*}-L^{*'j})^{2} + (C^{*}-C^{*'j})^{2} + (2H^{*}-2H^{*'j})^{2}]^{0.5}/(1+0.02\ C^{*})$$

where L^{*}, C^{*}, H^{*} were calculated from the renotation values and $L^{*'j}$, $C^{*'j}$, $H^{*'j}$ were calculated from F'^{j}, G'^{j}, H'^{j}.

Discussion

At the time of this writing, preliminary results indicate our linear programming model can indeed generate smooth reflectance functions with approximate color-constant properties. In some cases these curves have much lower color-constancy indices than their corresponding object-colors, in other cases they are approximately the same. We have found that for some colors, more conventional models (e.g. variations of Ohta's[6] minimax approximation) yielded better results.

When we analyzed the collection of reflectance functions having relatively low indices of color constancy, we found the following trends in curve shape: (1) curves were multimodal, often with zero reflectance at each end of the spectrum and always with at least one well-defined minimum between the ends; (2) primary peaks often corresponded in position to areas of maximum reflectance of the corresponding object-colors; (3) changes in the size and position of secondary peaks often had the greatest effect on overall color constancy. It is possible the position of these maxima and minima are related to the position of normal human-visual-system responses, but at present we have been unable to support this hypothesis.

Analyzing the collection of reflectance functions for any Munsell Hue indicated these trends: (1) with a decrease in Value, positions of maxima and minima remained constant while the overall size of the peaks diminished. Additionally, there was a slight systematic shift of each maximum, consistent with induction effects; (2) with a decrease in chroma, positions of maxima and minima remained constant with a systematic spreading of each maximum towards an equi-energy curve at the equivalent Value level (this may be true only for colors with Value equal to that of the background); and (3) with a decrease in Chroma, greater color constancy was achievable. These trends suggest that color chips from a page in a color-constant color-order system should be produced using the same colorants. This supports the original formulation techniques of the 1929 Munsell Book of Color.

Acknowledgment

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References

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Table I. Color-constancy indices and hue differences calculated from theoretical color-constant curves (T) and measured curves from a Munsell Book of Color (M). The spectral curves are shown in Figs. 1 and 2.

		CCI					ΔH^*_{ab}				
		7600	6000	5000	4000	2854K	7600	6000	5000	4000	2854K
5P 3/10	T	0.13	0.28	0.50	0.80	2.16	0.07	0.26	0.47	0.58	0.09
	M	1.96	1.04	1.39	3.02	6.74	1.74	0.40	0.88	2.68	6.30
5Y 7/10	T	0.69	0.93	1.76	3.09	5.90	0.78	0.71	0.58	0.38	0.57
	M	2.41	1.95	1.80	2.48	5.74	2.84	2.29	1.53	0.15	3.42

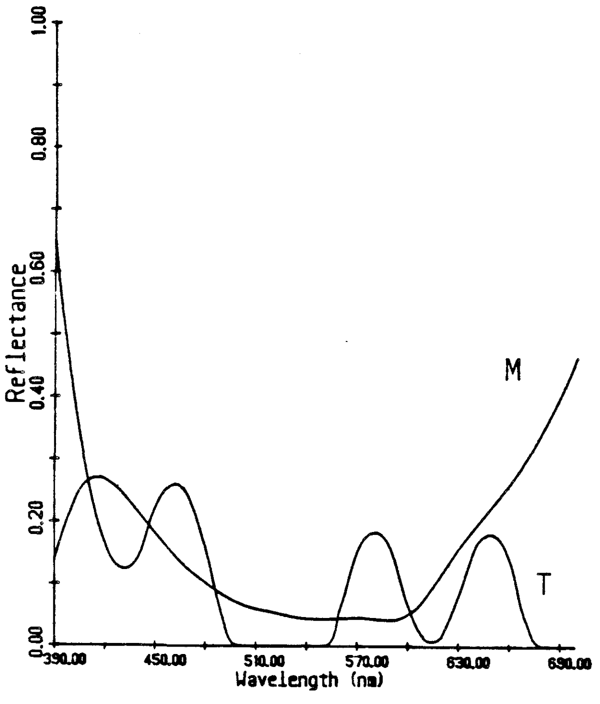

Figure 1. 5P 3/10

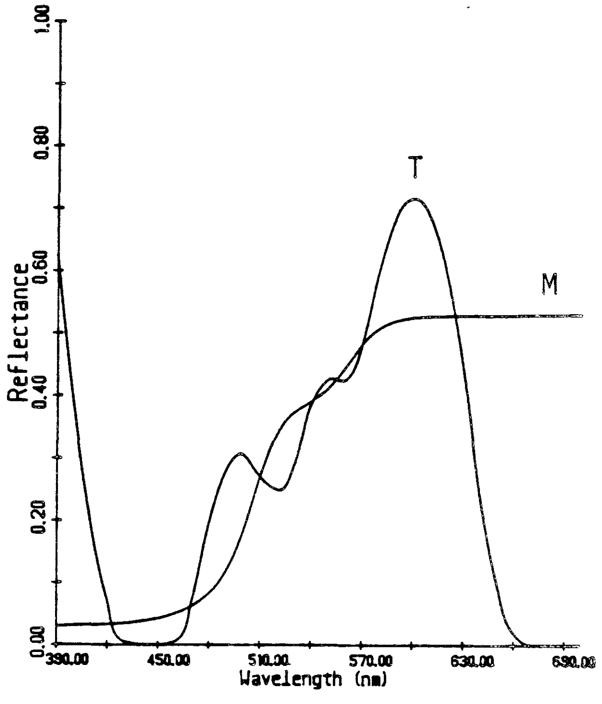

Figure 2. 5Y 7/10

Munsell Notations of the Natural Color System

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Introduction

In 1965, Hård[1,2] described the philosophy and the production of a color-order system based on the Hering-Johansson opponent-color system. In this color atlas, the spacing of the samples was based on their resemblances to the elementary color sensations whiteness, blackness, and two adjacent hue sensations out of the four redness, yellowness, greenness, blueness, corresponding to the so-called unique hues. The preliminary spacing of this Natural Color System (NCS) was revised, and in 1978 a new color atlas and set of aim points for the system were issued as Swedish National Standard SS 01 91 02 and SS 01 91 03, respectively. The new standard has been described,[3] although details of the visual scaling leading to the system have not been described in the literature.

Based on the original spacing and samples produced in 1969,[4] Judd and Nickerson[5] studied the relation between the Munsell and NCS scales. They concluded that simple relationships existed between the Munsell system and the NCS as then constituted, that the samples of the two systems represented different samplings and descriptions of the same color space, and that there was consequently little difference in the color spaces arrived at experimentally in terms of color-difference judgments (the basis of the Munsell system) or color resemblances (the basis of the NCS).

The 1978 Swedish Standard provides for the first time a complete set of aim points for 2211 colors and specifications of 1412 samples in the Color Atlas, in terms of CIE tristimulus values and chromaticity coordinates. It was of considerable interest to re-examine the relation between the Munsell System and the NCS, and between the Munsell Book of Color and the Swedish Standard Color Atlas with this revised and extended data base. This poster presentation provides preliminary results of this study in progress.

Experimental

CIE color coordinates for the aim points of Swedish National Standard SS 01 91 03 and for the samples of Swedish Standard Color Atlas SS 01 91 02 were kindly made available by Anders Hård and Åke S:son Stenius. The coordinates of the samples were derived from spectrophotometric measurements made on a Zeiss DMC 26 spectrophotometer. These data were converted to Munsell notations using a computer program based on that derived at the U.S. National Bureau of Standards (NBS) by Rheinboldt and Menard.[6] The program retains the NBS data base and therefore the accuracy of the original NBS program. The tables of NCS, CIE, and Munsell notations resulting from these conversions will be displayed, and arrangements can be made to provide the data to interested workers for research purposes.

Preliminary Analysis

Time has allowed only a brief first analysis of the Munsell notations of the NCS data. We present here the results of a preliminary examination of the NCS aim points for one hue, ϕ = -Y30R. Figure 1 shows a Munsell Value-Chroma plot for the aim points for that hue, and similar charts will be displayed for other hues. In the figure, the Munsell Hue for each NCS aim point has been listed; they range from approximately 6.4 YR to 1.0 Y. The locations of approximately vertical curves of constant NCS chromaticness c and approximately diagonal curves of constant NCS blackness s are also indicated as an aid in identifying each NCS aim point in terms of its notation s, c, ϕ.

From Fig. 1 it can be seen that constant NCS hue corresponds only approximately to constant Munsell Hue, though the differences appear to be systematic. This appears to be the case throughout the hue circle, and charts of Munsell Hue vs. Munsell Chroma showing NCS aim points over narrow ranges of Munsell Value will be displayed to illustrate this. It can also be seen from the figure that lines of constant NCS c and constant NCS s are not precisely straight, but show systematic slight curvature.

The NCS hue selected for analysis is close enough to one studied by Judd and Nickerson,[5] Y25R, that comparisons can be made. They found the 1969 point of c = 100 by extrapolation, to be at Munsell V/C = 7.8/17.5, whereas the new c = 100 point appears to be located at about V/C = 7.1/18. Judd and Nickerson also found that the line s = 0 extrapolated to the position of NCS white on the neutral axis at V = 10.3 and the line 100-s extrapolated to the position of NCS black on the neutral axis at V = 1.8. We estimate the corresponding points, from data at ϕ = -Y30R only, to be at approximately V = 10.0 and 0.0 respectively, corresponding closely to the locations of pure white and black on the Munsell Value scale.

Time has not permitted further analysis at this writing.

Acknowledgment

General support of The Rensselaer Color Measurement Laboratory from the Troy Laboratory of E. I. du Pont de Nemours and Co., the Ford Motor Foundation, the PPG Industries Foundation, and the Sherwin-Williams Foundation is gratefully acknowledged. This is Contribution No. 123 from The Rensselaer Color Measurement Laboratory.

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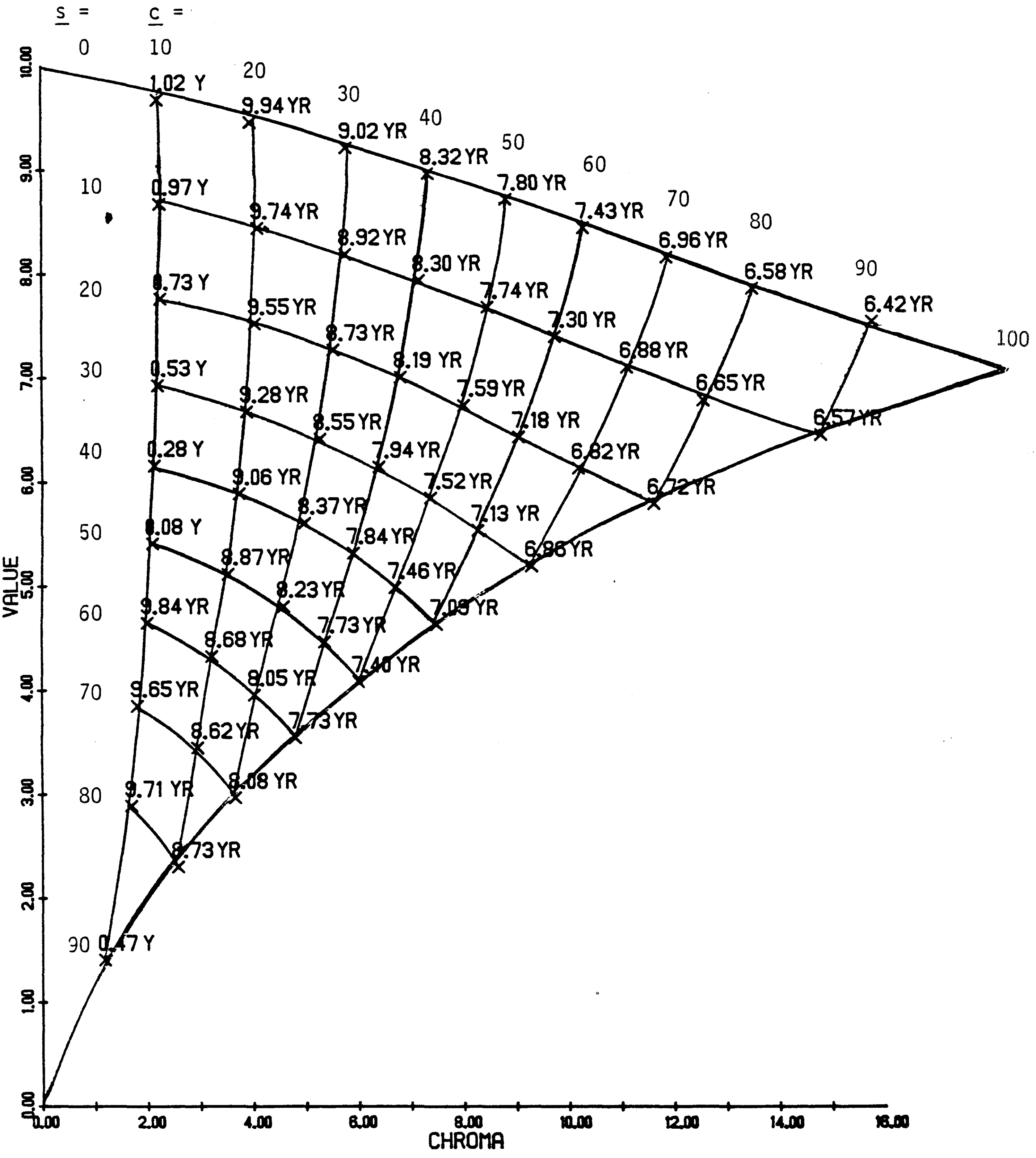

Figure 1. Munsell Value-Chroma plot showing the aim points for NCS hue -Y30R. See the text for discussion.

Illuminant Dependence of Object-Color Ordering

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ABSTRACT: Ordering of colors--e.g., by the dichotomous Farnsworth D-15 test--is modelled as a cyclic ordering (right/left handedness) of object reflected-light chromaticities. It is shown that the cyclic ordering of three such chromaticities is illuminant-invariant if, when the three reflectance spectra are taken as "tristimulus functions" in a formal sense, the spectrum locus of the resulting "chromaticity space" is convex and well-ordered in wavelength. The illuminant-invariance is also assured (irrespective of the reflectances) when the illuminant consists of three predetermined spectral lines whose relative powers are allowed to vary. Computer-simulated effects of illuminant change on ordering of the Color Rendering Index reflectances are presented as predictions of future experimental results.

1. Introduction.

Traditional color order systems specify how to tesselate a uniform color space with reflectances under a particular illuminant. In several directions within the space, adjacent reflectances map into equivalent perceived color differences. Particularly in the case of the Munsell and Natural Color Systems, this has resulted in the use of some rather elegant crystallographic concepts to specify object colors with errors impartial to the position in a uniform color space. However, change in the spectral power distribution (SPD) of the light source disturbs the uniformity of color spacing between reflectances. This is true even when the metric structure of color space compensates by chromatic adaptation (Pointer, 1974).

For this reason, we introduce a definition of color order that is less prone to illuminant disturbance than distance between two colors. Three reflectances with intrinsic labels (1,2,3) map to points in chromaticity space (under a particular illuminant) such that, if the points are not collinear, they are ordered either clockwise or counterclockwise as one proceeds from 1 to 3. We denote the cyclic ordering parameter of these colors as +1 if the ordering is counterclockwise, -1 if the ordering is clockwise, and 0 if the points are collinear. Conditions under which the cyclic ordering parameter of three reflectances is robust under illuminant change are discussed later in the present paper.

The perceptual usefulness of cyclic color ordering can be tested via a dichotomous color-blindness test (such as the Farnsworth D-15 test). If cyclic ordering has perceptual meaning, then a normal subject attempting to arrange a few colored chips in spectral order will reproduce the cyclic orderings in chromaticity space of the reflected lights from these chips. In this experiment, the reflectances of the chips should, under some nominal light, be fairly saturated, about equal in value, and dispersed appreciably in hue about the white point. This will tend to insure that, after chromatic adaptation, the perceived white will lie within the cluster of points generated by the reflectances under a new light. Hence hue ordering about the adapted neutral can be identified with cyclic ordering among the reflected-light chromaticity points. The appreciable hue differences will tend to keep the colors distinct under different lights, and hence reversals in color ordering will not be contaminated by the issue of just-noticeable differences and color confusion.

It should be emphasized that such effects as visual nonlinearities might make the experimental orderings different from the computed orderings in chromaticity space. Hence the connection of the visual task results with the simple cyclic ordering formalism is not trivial. If the connection can be made, it will provide a new descriptive framework for object-color ordering as perturbed by substantial changes in illumination.

2. Illuminant Dependence of the Cyclic Ordering Parameter.

The mathematics in this paper is aimed at showing one basic fact: Three reflectances can change cyclic order with change of illuminant only if, when the reflectances are treated formally as tristimulus functions, the "color space" that results has a spectrum locus that is not everywhere convex. Our computer simulations show that ordering changes may take place when at least one of the reflectances is multimodal in wavelength (e.g.,a purple). Having summarized the principal result, we proceed to the formalism.

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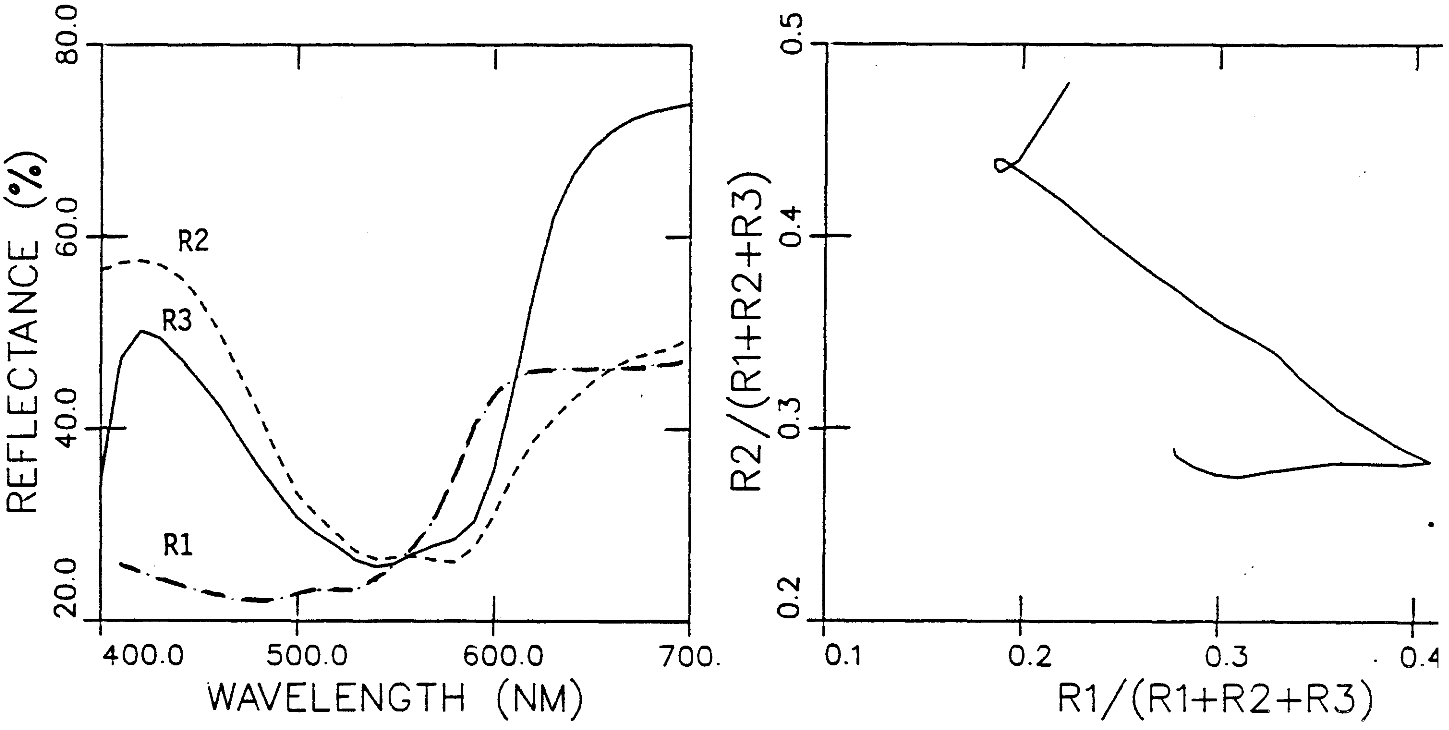

Figure 1. Formal analogue to spectrum locus, constructed from reflectances 7.5R 6/4, 2.5P 6/8, and 10P 6/8 (labelled R1, R2, and R3, respectively).

Table I. Munsell CRI reflectance triads and 3-line lights displaying significant color reversals relative to benchmark light.

Light wavelengths	Reflectances with det(r)≥.01	det(r)
405, 436, 578 nm	7.5R6/4, 2.5P6/8, 10P6/8	.0107
	5Y6/4, 2.5P6/8, 10P6/8	.0121
	5GY6/8, 2.5P6/8, 10P6/8	.0129
405, 436, 620 nm	7.5R6/4, 5PB6/8, 10P6/8	.0100
	7.5R6/4, 2.5P6/8, 10P6/8	.0151
	5Y6/4, 2.5P6/8, 10P6/8	.0104
405, 436, 660 nm	7.5R6/4, 10BG6/4, 10P6/8	.0106
	7.5R6/4, 5PB6/8, 10P6/8	.0143
	7.5R6/4, 2.5P6/8, 10P6/8	.0148
405, 436, 546 nm	5GY6/8, 2.5P6/8, 10P6/8	.0163
	2.5G6/6, 2.5P6/8, 10P6/8	.0124

significant positive values of det(r), the appearance under any light of a large value of det(r) is termed a significant reversal relative to this benchmark light. The purples 10P 6/8 and 2.5P 6/8 participated in 11 and 8 of these reversals, respectively, and 7.5R 6/4 participated in 6 of the 11 most significant reversals. All these spectra are bimodal in wavelength (have two maxima), and hence produce nonconvex "spectrum loci" of reflectance triads. An example of this behavior is shown in Fig. 1, for reflectances 7.5R 6/4, 2.5P 6/8, and 10P 6/8 (labelled $r_1(\lambda)$, $r_2(\lambda)$, and $r_3(\lambda)$, respectively). The lights and reflectances producing the 11 most significant reversals are summarized in Table I. Note that lights with predominantly short-wavelength lines (such as in ordinary fluorescent lights) produced the greatest number of these reversals.

4. Implications Regarding the Design of Atlases.

In the selection and formulation of colorants to produce a color-order atlas, compromises must be made to deal with a number of mutually contradictory requirements. Among these requirements are the following:

a.) Each color chip in the atlas should be minimally sensitive to illuminant or observer changes. This dictates avoiding any spectral selectivity greater than is needed to produce each desired color.

b.) The atlas should cover a substantial fraction of the volume of color space accessible with durable colorants; this dictates some use of high-chroma colorants.

c.) The use of high-chroma colorants to produce low-chroma colors would require mixtures of substantially more than three colorants in each color if condition (a) is to be met.

d.) For accuracy and economy of color control, each chip should be made with a minimum number of colorants, preferably three (or perhaps four), plus white.

The foregoing statements suffice to reveal the necessity of compromise in designing the colorant-mixture scheme to produce the atlas. The problem is made additionally difficult by the following requirement:

e.) The appearance of any sequence of colors selected by varying only one dimension of the color space should be minimally sensitive to changes in illuminant or in observer. To meet this condition, it is desirable that, at each wavelength of the visible spectrum, the reflectance of each member of any linear sequence should be a monotonic function of its sequential position, insofar as this can be achieved with available colorants.

In selecting colorant mixtures to exemplify any real sampling of an ordered color space, it is desirable that an algorithm be available to dictate the continuity of spectral changes. The simplicity of the concept of cyclic ordering may facilitate the devising of appropriate algorithms.

The cyclic ordering parameter of three reflectances under a given light is the algebraic sign on the triple scalar product of the reflected-light tristimulus vectors generated by these reflectances. Let the reflectances be $r_k(\lambda)$ (λ is wavelength and k=1,2,3), the illuminant SPD be $I(\lambda)$, and the tristimulus functions in a particular basis be $q_j(\lambda)$ (j=1,2,3). Then the cyclic ordering parameter P is given by

$$P = \mathrm{sgn}(\det Q) = \mathrm{sgn}(\det \langle I(\lambda) q_j(\lambda) r_k(\lambda) \rangle \ ) \qquad (1)$$

where $\langle\ \rangle$ denotes integration over the visible wavelength range, det Q is the determinant of the 3x3 matrix Q of the reflected-light tristimulus values, and $\mathrm{sgn}(x) = 1$ for $x > 0$, -1 for $x < 0$.

We first examine the effects of $I(\lambda)$ on P for illuminants consisting of spectral lines at three wavelengths. Thornton (1971) has discussed theoretical properties of these 3-line lights, and has also invented the "prime color" lamp as a useful approximation to a 3-line light with good color rendering properties. In view of the growing popularity of three-band lights, it is practical concern as well as mathematical expedience that motivates their discussion here.

A 3-line light's spectral power distribution has the form

$$I(\lambda) = \sum_{i=1}^{3} a_i \, \delta(\lambda - \lambda_i) \qquad (2)$$

where λ_i are the three emission wavelengths, a_i are the powers emitted at these wavelengths, and $\delta(\ )$ is the Dirac delta function (Butkov, 1968). This light causes the j-th tristimulus value of the k-th reflectance to have the form

$$Q_{jk} = \sum_{i=1}^{3} a_i \; q_j(\lambda\ ) \; r_k(\lambda\ ). \qquad (3)$$

Writing matrix $A_{ji} = a_i q_j(\lambda_i)$ and $B_{ik} = r_k(\lambda_i)$, it follows that matrix Q is the product of A and B, hence

$$\det Q = \det(a_i q_j(\lambda_i)) \det(r_k(\lambda_i)) = a_1 a_2 a_3 \det(q) \det(r) \qquad (4)$$

where q is the matrix with elements $q_j(\lambda_i)$, and r is the matrix $r_k(\lambda_i)$.

From Eq. 4 we can deduce three instructive theorems about the behavior of the cyclic ordering parameter with change of 3-line light:

a.) Since the powers a_i are nonnegative, they cannot influence the sign of det Q unless one or more a_i is zero (which renders the tristimulus vectors coplanar--an uninteresting case). In particular, this means that in the experiments of McCann, McKee and Taylor (1976), object-color orderings by our definition could not be disturbed by changing the gains on three narrowband lamps they used for illumination. (Of course, changing the wavelengths of these lights in their experiment might well have changed the ordering.) One test of our cyclic-ordering hypothesis would be to vary the relative powers of a 3-line light and observe whether there is an effect on an observer's spectral ordering of colored chips: Theory predicts no effect.

b.) The tristimulus functions can affect P only through the factor det(q). In order for this to occur, two triplets of λ_i must exist such that the chromaticity points generated by the monochromatic lights for one triplet have clockwise ordering in increasing λ_i, and the other choice has counterclockwise ordering. Since the spectrum locus is convex and well-ordered in wavelength, this reversal will never happen: indeed, in CIE x-y space, the ordering of monochromatic lights is always clockwise in increasing wavelength. Incidentally, the fact that the spectrum locus is convex and well ordered in wavelength is also necessary for the optimality of Schrödinger colors (West and Brill, 1983).*

c.) It follows from (a) and (b) above that, for CIE tristimulus space, changing a 3-line light changes P only if det(r) changes sign. When is that possible? By analogy with (b) above, construct a formal "chromaticity space" analogue with $r_k(\lambda)$ as "tristimulus functions", and observe the spectrum locus in this space. If it is convex and well-ordered in wavelength, then det(r) can never change sign by changing the λ_i.

It can be shown that the condition described in (c) insures the invariance of P under any change of illuminant SPD, not only for 3-line lights. We sketch the proof here for a light with N spectral lines, and then pass to the continuum by a simple argument.

If $I_\ell = I(\lambda_\ell)$, $r_{k\ell} = r_k(\lambda_\ell)$, $q_{j\ell} = q_j(\lambda_\ell)$, then

$$Q_{jk} = \sum_{\ell=1}^{N} I_\ell q_{j\ell} r_{k\ell} \qquad (j,k=1,2,3) \tag{5}$$

It is readily shown from Eq. 5 that

$$\det(Q) = \sum_{\substack{\ell_1,\ell_2,\ell_3=1\\ \ell_1<\ell_2<\ell_3}}^{N} I_{\ell_1} I_{\ell_2} I_{\ell_3} \det\begin{bmatrix} q_{1\ell_1} & q_{2\ell_1} & q_{3\ell_1} \\ q_{1\ell_2} & q_{2\ell_2} & q_{3\ell_2} \\ q_{1\ell_3} & q_{2\ell_3} & q_{3\ell_3} \end{bmatrix} \det\begin{bmatrix} r_{1\ell_1} & r_{2\ell_1} & r_{3\ell_1} \\ r_{1\ell_2} & r_{2\ell_2} & r_{3\ell_2} \\ r_{1\ell_3} & r_{2\ell_3} & r_{3\ell_3} \end{bmatrix} \tag{6}$$

From Eq. 4, this will be recognized as the sum over all wavelength-triplet combinations of the det(Q) due to reflectances $r_k(\lambda)$ under 3-line lights with powers I_{ℓ_1}, I_{ℓ_2}, I_{ℓ_3} at wavelengths λ_{ℓ_1}, λ_{ℓ_2}, λ_{ℓ_3}. Clearly the total det(Q) can change sign only when at least one term in Eq. 6 changes sign. This is precluded by precisely the condition in (c) above: So long as the "spectrum locus" generated by $r_k(\lambda)$ is convex and well-ordered in wavelength, det(r) cannot change sign for any of the 3-line combinations, and hence neither can the total det(Q).

To extend the above proof to continuous illuminant spectral power distributions, assign $I_\ell = I(\lambda_\ell)\Delta\lambda$, let $\Delta\lambda \to 0$, and let $N \to \infty$.

3. Computer-Simulated Dichotomous Tests.

To understand the susceptibility of realistic reflectances to reversal of color ordering, we computed predictions of the results of a dichotomous hue ordering test, using the eight Munsell reflectances that form the basis of the Color Rendering Index (in the order presented in CIE Publ. 13.2, 1974, Table 1) under various 3-line lights. The wavelengths of the spectral lines were chosen from six that were deemed easy to obtain via fluorescent lights: Four mercury lines (405, 436, 546, and 578 nm) were used, as well as two lines at 620 and 660 nm obtainable from rare-earth phosphors (W. Thornton, personal communication). The parameter P was computed from the sign on -det(r) (since $\det(q) \leq 0$) for all 3-reflectance combinations out of the eight CRI reflectances, and for all the 3-line combinations from the above menu of six wavelengths. Since the reflectances were tabulated only to third-decimal-place accuracy, values of det(r) were deemed significant only when greater in magnitude than .001.

Of a total of 1120 computations of P, only 130 had P=-1. Of these, only 90 had det(r) greater than .001, and only 11 of these had det(r) greater than or equal to .01. Since a light at wavelengths 436, 546, 620 nm produced no

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*In preparation.

THE DEGREE OF TRANSPARENCY ACCORDING TO DIFFERENT SYSTEMS MEASURES.

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It has been shown (Metelli 1967,1974,1982) that physical transparency is neither a necessary nor a sufficient condition for the perception of transparency and that the perception of transparency depends on two orders of conditions, figural and chromatic. We can abolish transparency in a figure by modifying either the form or the colour of its regions. Here we are dealing with the chromatic conditions of transparency, beginning with a short description of the mathematical model by Metelli. On the ground of previous researches (G.M.Heider 1933) Metelli considers transparency as a chromatic scission: a stimulation which normally determinates the perception of one colour, gives rise, under special conditions, to the vision of two colours, two coloured surfaces, one seen behind and through the other. Metelli mantains that the phenomenon of chromatic scission is the inverse of the phenomenon of chromatic fusion and consequently the same equation which describes colour fusion according to Talbot's law can be used to describe chromatic scission in phenomenal transparency. The theory was developed for achromatic colours only (an extension of the theory has been proposed by Da Pos 1976 ,1977 for chromatic colours) and in the case of complete and balanced transparency (Fig.1) when the front layer is evenly transparent against two differently coloured regions lying behind. We consider the simpler case of partial transparency in which a part only of the front figure is transparent against the background while the remaining part is opaque (Fig.2). In this case the colour of the region W where the two layers are superimposed, is determined

Fig. 1

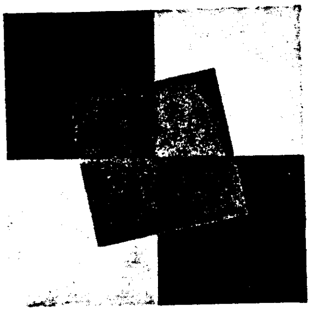
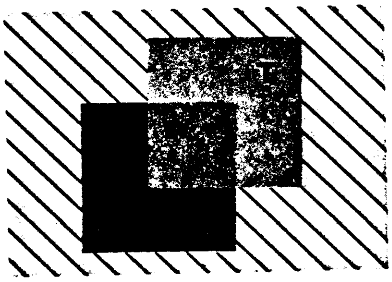


Fig. 2



by the Talbot's law:

$$w = \alpha g + (1-\alpha)\ t \qquad (1)$$

w = reflectance of the region W, g = reflectance of the region G, t = reflectance of the region T, α and $(1-\alpha)$ = proportions of the two colours g and t in a colour wheel which are mixed to produce the fusion colour w.

The same equation can be applied to transparency: when we have the perceptual scission of the transparency, the stimulus colour w splits into αg, the colour seen behind (the opaque surface colour), and $(1-\alpha)t$, the colour seen in front (the transparent surface colour). Given the three colours g w t, the unknown α means how much opaque colour g is visible through the transparent layer, i.e. how much transparent the front surface is.

$$\alpha = \frac{w - t}{g - t} \qquad (2)$$

This coefficient of transparency (α) has a physical meaning as it describes how much colour g is present in the mixture. The ascertainement that α parameter is physical measure gave rise to the requirement to obtain the correspondent perceptual measures. Metelli (1982) developed the assumptions underlying his mathematical model and deduced a formula of the same form as the former, but which involved psychological measures:

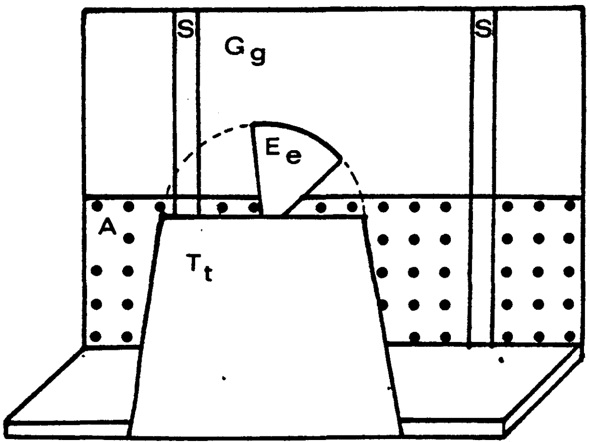
$$w^* = \alpha^* g^* + (1-\alpha^*)\ t^* \qquad (3)$$

w^*, g^*, t^* are perceptual measure of colours, α^* is the measure of transparency from a subjective point of view.

$$\alpha^* = \frac{w^* - t^*}{g^* - t^*} \qquad (4)$$

We tried therefore to look for what kind of colour measures in (3) and in (4) could allow to predict the subjective impression α^* of transparency. In the first experiment situations of transparency were realized by mean of an episcotister rotating in front of a background and subjects were asked to express a direct estimate of the perceived transparency by numbers from zero to 100. In the second experiment three situations of transparency were shown at a time to the subject and he had to adjust the w colour of the middle in order to obtain an intermediate impression of transparency between the two extremes. Experimental results were compared with theoretical predictions in which different colour systems measures were used.

EXPERIMENT 1.



T=homogeneously coloured part of the front figure. t=its colour measure.

E=visible part of the episcotister rotating at fusion speed; it lay at the same plane of the T surface and looked like a unique figure together with it. Through the episcotister the homogeneous background G was partially visible. e=episcotister colour measure (in this experiment e=t).

G=homogeneously coloured background; g=its colours measure (white when e was black, black when e was white).

A=Variegated part of the background against which the surface T looked clearly opaque.

S=stripes to strengthen depth perception.

Ten naive subjects took part in the experiment. Each subject was sitting at m 1.8 from the front figure and was adapted to the environment illumination of about 10 lux. When a curtain was raised to show the working and evenly illuminated apparatus, the subject had to fixate the background and judge with numbers from 0 to 100 how much transparent the front figure (in its upper part)appeared to him. 0 meant no transparency: it was impossible to see the background through the front figure and this appeared uniformly coloured and opaque; 100 meant absolute transparency: the background was fully visible in the upper part of the front figure which consequently disappeared. The size of the empty sector (D) of the episcotister was varied in twelve steps when the colour *e* was black, and in eleven steps when *e* was white (list in Tabs.1 and 2). The amplitude of the empty sector (D) corresponds, as Metelli pointed out, to the α value in (1) and naturally il can vary from 0 to 1 only. The result of the mixture $(\alpha g + (1-\alpha)e)$ is the colour w, which can be seen through a reduction screen (i.e. through a hole or a tube).

RESULTS

In Tabs. 1 and 2 two series of situations are reported. Colour measures of G & T are: g:R=.95, M=9.2, NCS=1.9 and t (e=t):R=.007, M=.58, NCS=98 (Tab.1) , and correspondingly the opposite in Tab.2. Colours were measured in three ways: by Reflectance (R), by Munsell value (M) and by NCS scale (NCS). M and NCS measures, put in (4), give the correspondent values $\alpha^*{}_M$, $\alpha^*{}_{NCS}$. St.= mean subjective direct estimates of transparency.

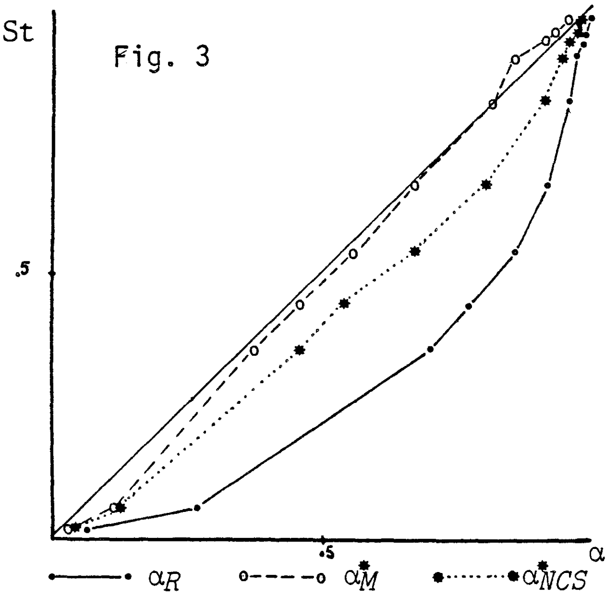
	w						
D	R	M	NCS	α_R	α^*_M	α^*_{NCS}	St
350°	.92	9.1	3.1	.97	.98	.98	.99
336°	.88	9	4.1	.93	.97	.97	.97
310°	.76	8.4	11	.80	.90	.91	.88
240°	.64	7.8	17	.67	.83	.84	.80
180°	.47	7.3	28	.50	.78	.72	.72
100°	.27	5.7	49	.28	.59	.51	.53
60°	.17	4.6	64	.17	.47	.35	.47
30°	.09	3.5	78	.09	.34	.20	.36
15°	.04	2.4	88	.04	.21	.09	.23
7°	.02	1.7	93	.02	.13	.05	.10
3°	.01	1.1	96	.008	.06	.02	.06
1°	.009	0.7	97	.003	.02	.01	.001

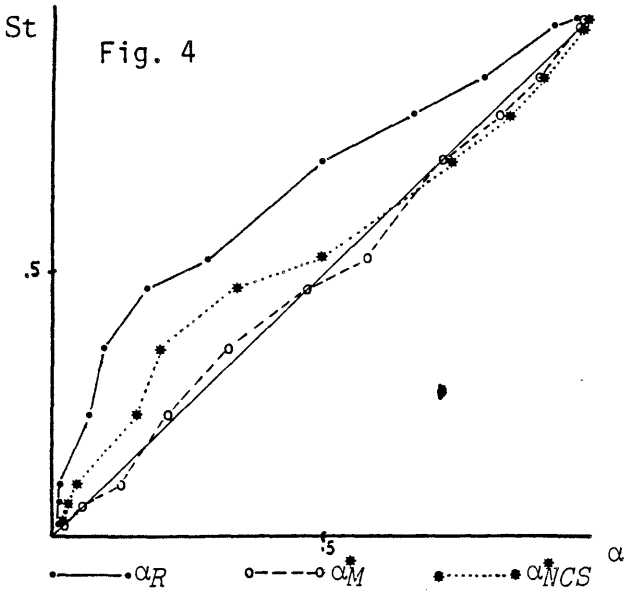
Tab. 1

	w						
D	R	M	NCS	α_R	α^*_M	α^*_{NCS}	St
358°	.011	.92	97	.99	.96	.99	.98
357°	.014	1.2	97	.99	.93	.98	.96
356°	.016	1.3	95	.99	.92	.97	.94
353°	.025	1.7	93	.98	.86	.95	.91
348°	.035	2.1	91	.97	.81	.92	.83
331°	.082	3.3	80	.92	.68	.81	.68
306°	.15	4.4	67	.85	.55	.68	.54
276°	.22	5.3	55	.77	.45	.56	.44
252°	.29	5.9	47	.70	.38	.47	.36
96°	.69	8.1	14	.27	.13	.12	.06
1°	.94	8.7	2	.01	.06	.01	.002

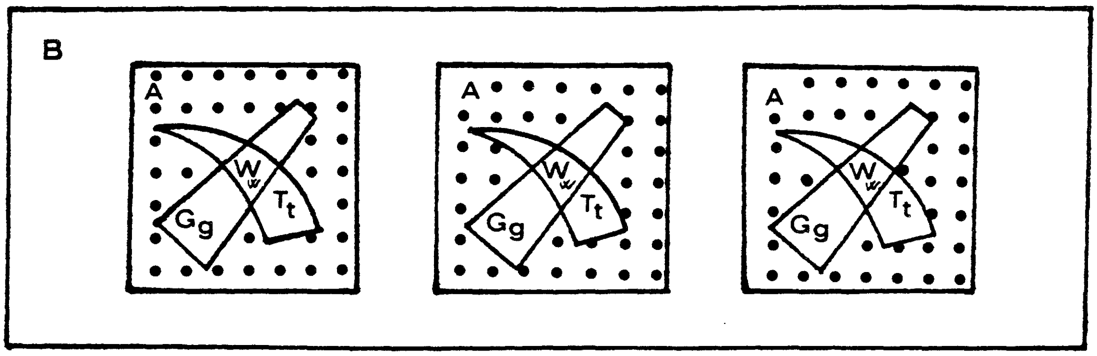
Tab. 2

In Fig. 3 and 4 mean subjective estimates (St) are plotted as function of the degree of transparency predicted by Metelli's model.





EXPERIMENT 2.



T=front and partially transparent figure (t=its colour). G=opaque figure (g=its colour); it lies on the same plane of T but, as consequence of figural conditions, it is generally seen behind. W=region where the two figures T and G are superimposed: it consists in a hole and its colour (w) is obtained by a colour wheel rotating behind; this colour is seen on the same plane of the front figures (Metelli, Da Pos, Cavedon 1978). In the middle situation, w can be varied at will by the observing subject. B= medium grey main background illuminated at 71 lux. A=variegated background.

Twenty naive subjects performed the first series of bisections with light transparent figure, and twenty subjects with dark transparent figure. Each subject made six bisections twice, once with the more transparent situation at right, the second time at left, alternatively. (Z = mean bisections)

RESULTS. Data are reported in Tabs. 3 and 4.

	R	M	NCS	α_R	α^*_M	α^*_{NCS}	Z_R	Z_M	Z_{NCS}
1	.09	3.6	77	.95	.92	.93			
2	.13	4.2	70	.75	.71	.72	.80	.71	.74
3	.16	4.5	66	.64	.60	.62	.71	.61	.64
4	.19	4.9	61	.53	.50	.52	.61	.50	.53
5	.20	5.1	58	.43	.40	.42	.54	.43	.46
6	.23	5.4	54	.33	.30	.31	.43	.33	.35
7	.32	6.1	44	.13	.08	.10			

w

Tab. 3

	R	M	NCS	α_R	α^*_M	α^*_{NCS}	Z_R	Z_M	Z_{NCS}
1	.09	3.6	77	.05	.08	.07			
2	.14	4.2	70	.25	.29	.28	.20	.29	.27
3	.16	4.6	65	.36	.39	.38	.30	.40	.38
4	.19	4.9	60	.46	.49	.49	.40	.50	.48
5	.21	5.2	57	.56	.60	.59	.49	.60	.57
6	.24	5.5	52	.67	.70	.70	.60	.70	.68
7	.32	6.1	44	.87	.91	.91			

w

Tab. 4

Colours (w) were measured by Reflectance (R), by Munsell value (M) and by NCS scale (NCS). The mean bisections (Z) and the corresponding stimulus values (α,α^*) derived from (2) and (4) are reported for the different colour systems. The same results are plotted in Fig. 5 (light transparent figure) and in Fig. 6 (dark transparent figure). Measures of g:R=.35,M=6.4,NCS=40; and of t:R=.08, M=3.4,NCS=80.

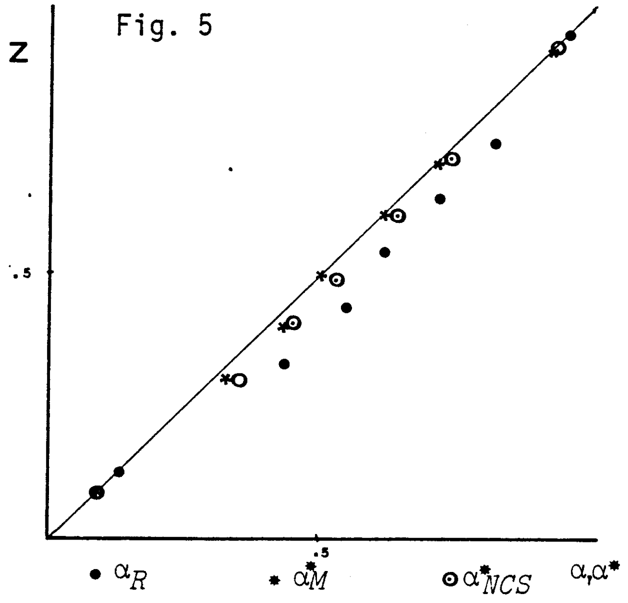


Fig. 5

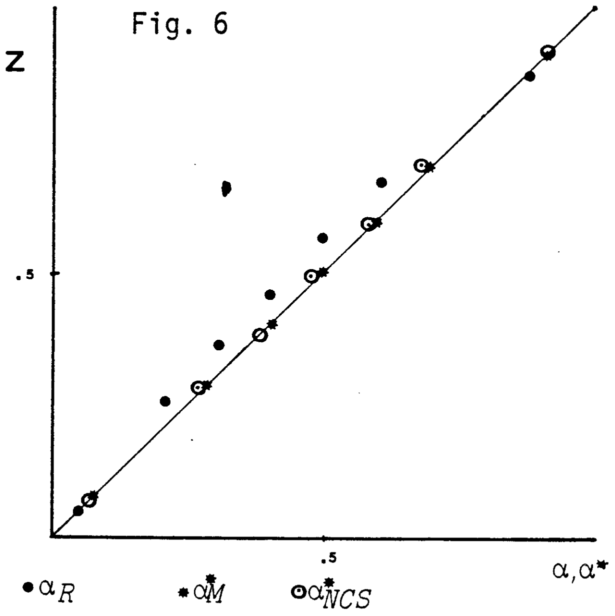


Fig. 6

DISCUSSION.

Our results indirectly confirm the algebraic model which was formerly proposed by Metelli at physical level. Moreover they strongly justify the deduction of the perceptual model, which show that in transparency situations it is possible to make good predictions of subjective degree of transparency from perceptual measures of colours. According to this model, especially if Munsell values are used, colours of the transparent figures do not modify the degree of subjective transparency, as usually happens when reflectance measures are used. Nontheless our results do not allow to decide which colour system fits better Metelli's model. It seems to us that the Munsell system, for the case of achromatic colours, is more adequate to our situations, even if an experiment on complete transparency, which is being conducted at present, favours the use of NCS system. We agree with Beck (1983) who made perceptual measures each time he needed: obviously this procedure is not always possible, especially if we are using chromatic colours, with which Metelli's model will be tested in the future.

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TRANSFORMATION OF NCS DATA INTO CIELAB COLOUR SPACE

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In order to use the NCS Colour System (Hård and Sivik, 1981) for computer graphics the CIE-tristimulus values of 1760 NCS notations (the nominal NCS notations given in Svensk Standard SS 01 91 03) were transformed into CIE 1976 (L*,a*,b*) space according to the formulae (CIE, 1978):

$$L^* = 116\ (Y/Y_N)^{1/3} - 16$$

$$a^* = 500\ [(X/X_N)^{1/3} - (Y/Y_N)^{1/3}]$$

$$b^* = 200\ [(Y/Y_N)^{1/3} - (Z/Z_N)^{1/3}]$$

where X, Y, Z are the tristimulus values given in SS 01 91 03 and X_N, Y_N, Z_N are the tristimulus values for CIE standard illuminant C.

$$X_N = 98.041$$

$$Y_N = 100.000$$

$$Z_N = 118.103$$

The CIELAB correlates of lightness (=L*) chroma and hue were for each NCS notation calculated according to the definitions (CIE, 1978):

CIELAB 1976 a, b, chroma; $C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$

CIELAB 1976 a, b, hue-angle; $h_{ab} = \arctan (b^*/a^*)$

Our major concern has been colours of large perceptive distances. To a comparison between NCS and CIELAB colour - difference formulae we refer to Tonnquist (1975).

The NCS data were plotted on CIELAB psychometric chroma diagram (a*, b*) for values of NCS blackness of 00, 10, 20, 40, 50, and 60. These plots are shown in Figure 1.

The data points for each of the NCS hue-triangles Y, Y50R, R, R50B, B, B50G, G, and G50Y were plotted on CIELAB chroma-lightness diagram. These plots are shown in Figure 2.

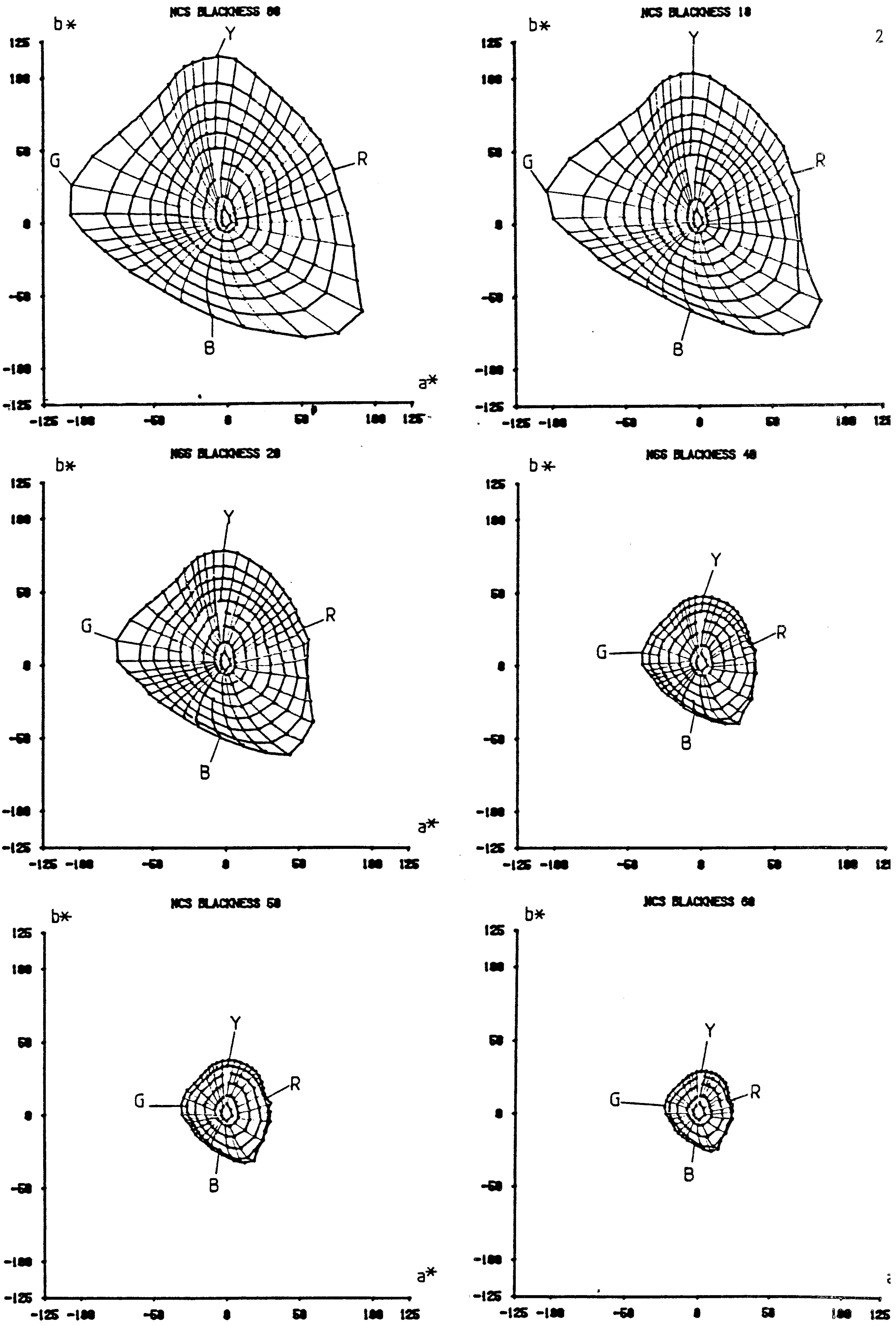
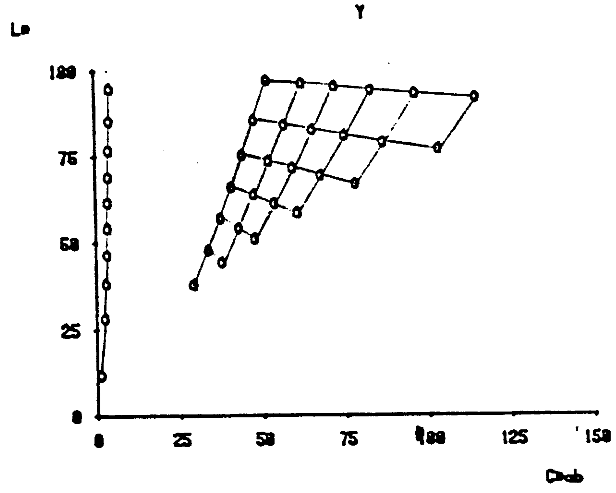
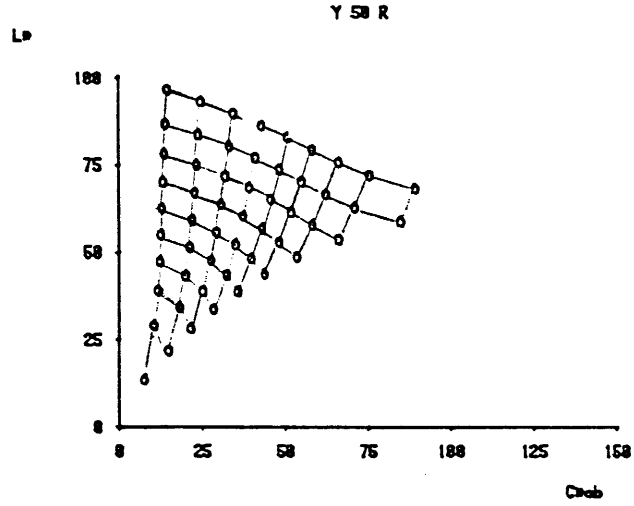
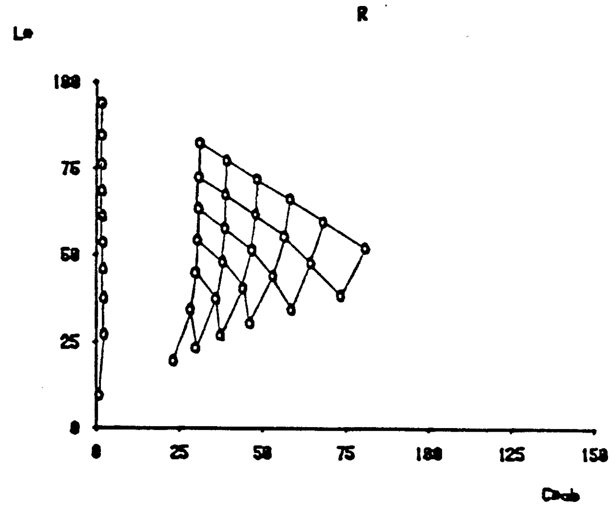
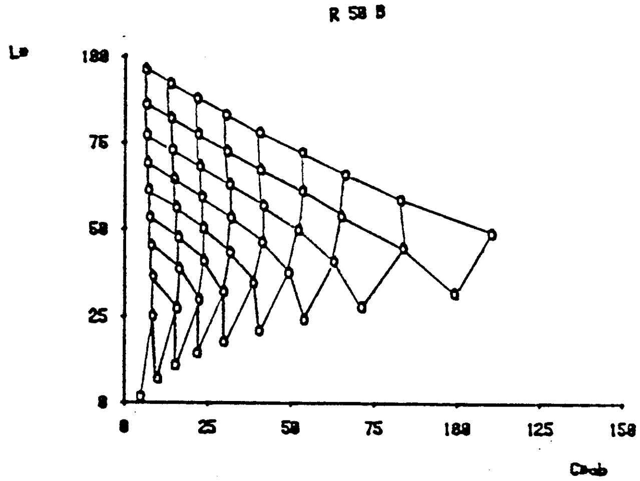


Figure 1: NCS data plotted in the CIE 1976 (a*,b*) diagram for NCS blackness of 00,10,20,40,50 and 60. The approximately straight radial lines are loci of constant NCS hue. The approximately concentric contours are loci of constant NCS chromaticness from 05 up to maximum 30 as for blackness 00 and 10.


Y
L*
100
75
50
25
0
0
25
50
75
100
125
150
C*ab


Y 50 R
L*
100
75
50
25
0
0
25
50
75
100
125
150
C*ab


R
L*
100
75
50
25
0
0
25
50
75
100
125
150
C*ab


R 50 B
L*
100
75
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0
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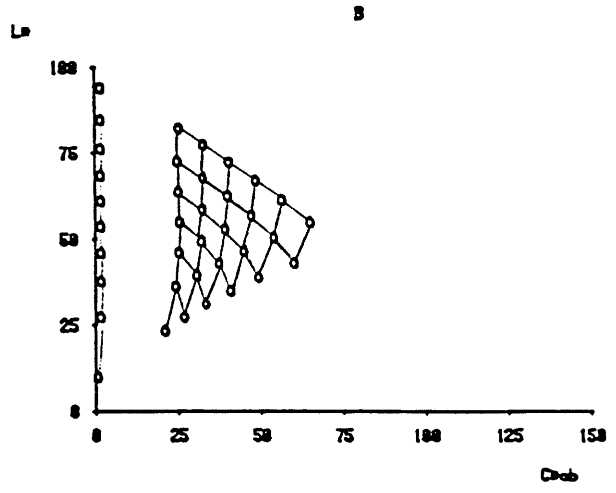
50
75
100
125
150
C*ab


B
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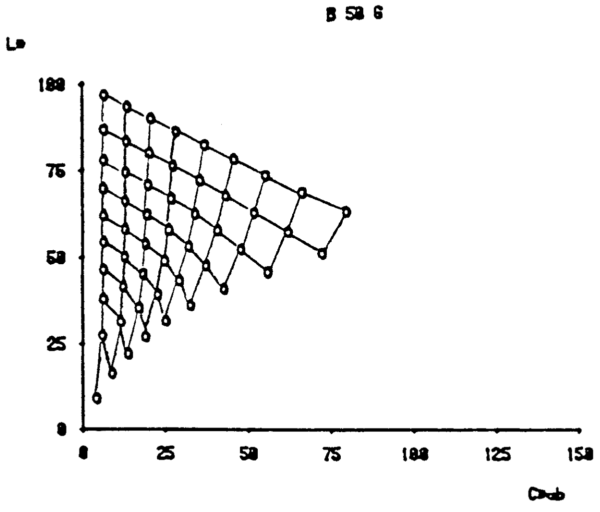
C*ab


B 50 G
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C*ab

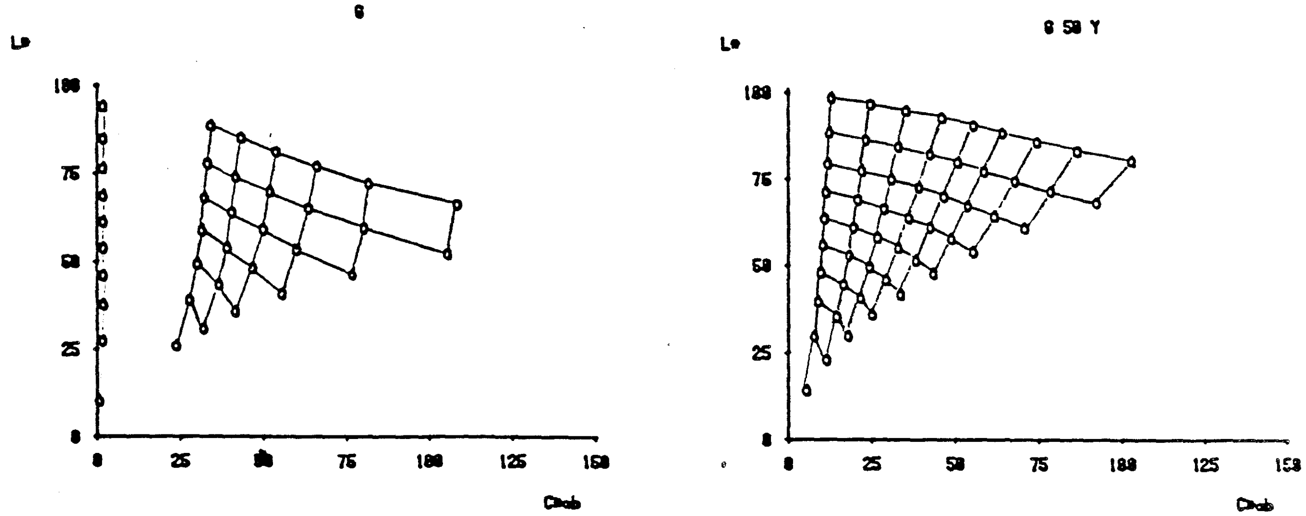

Figure 2: NCS data points for each of the NCS hues Y, Y50R, R, R50B, B, B50G, G and G50Y plotted on CIELAB chroma-lightness diagram. The approximately horisontal lines are loci of constant NCS blackness. The approximately vertical lines are loci of constant NCS chromaticness.

Analysis of data:

In the NCS system, each hue-triangle is equilateral, and lines of constant blackness and constant chromaticness are parallel. As shown from Figure 2, when transformed to CIELAB lines become slightly curved.

The mean CIELAB hue-angle was calculated for each NCS hue-triangle, by calculating the mean h_{ab} of the datapoints of each triangle. The transformation of NCS hue to CIELAB hue is shown in Figure 3. As shown from Figure 3 the hue segmentation becomes more irregular, when transformed to CIELAB.

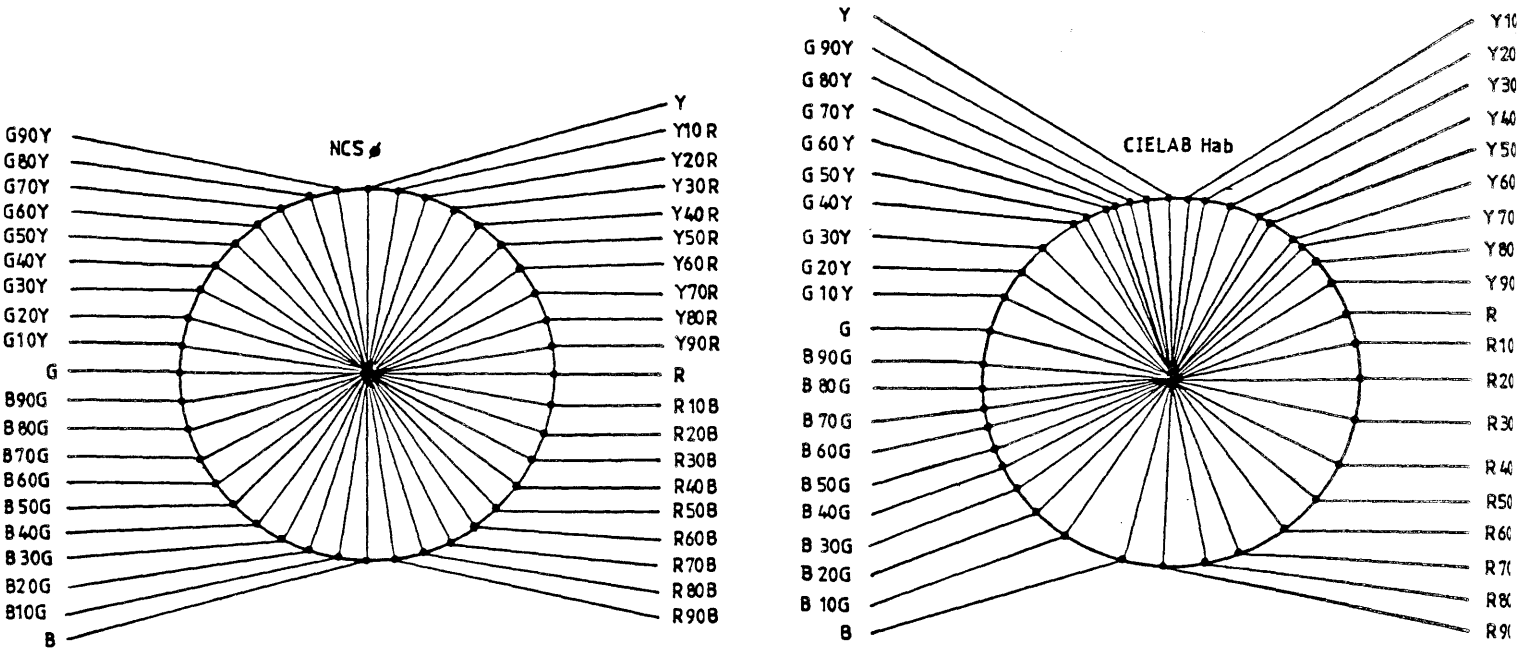

Figure 3: Transformation of NCS hue to CIELAB hue.

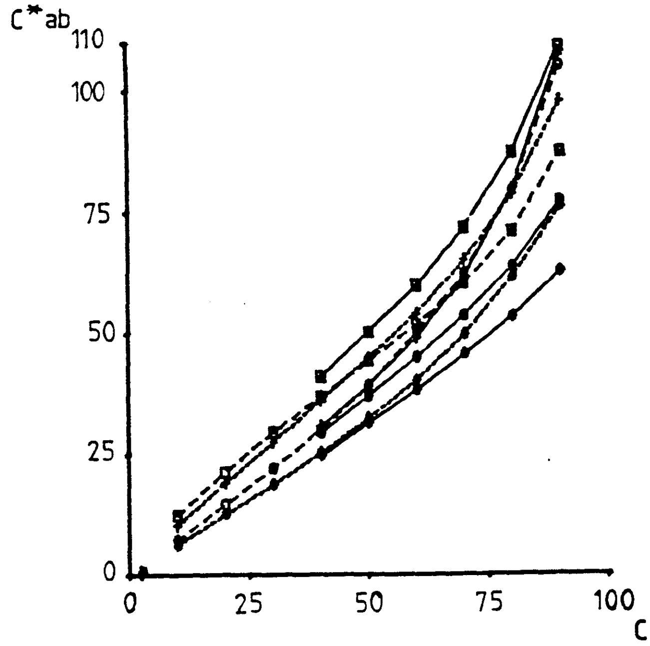

Figure 4: CIELAB chroma (C^*_{ab}) plotted against NCS chromaticness (C) for the NCS hues Y (□——□——□), Y50R (□---□---□), R (0——0——0), R50B (0---0---0), B (*——*——*), B50G (*---*---*), G (+——+——+), and G50Y (+---+---+).

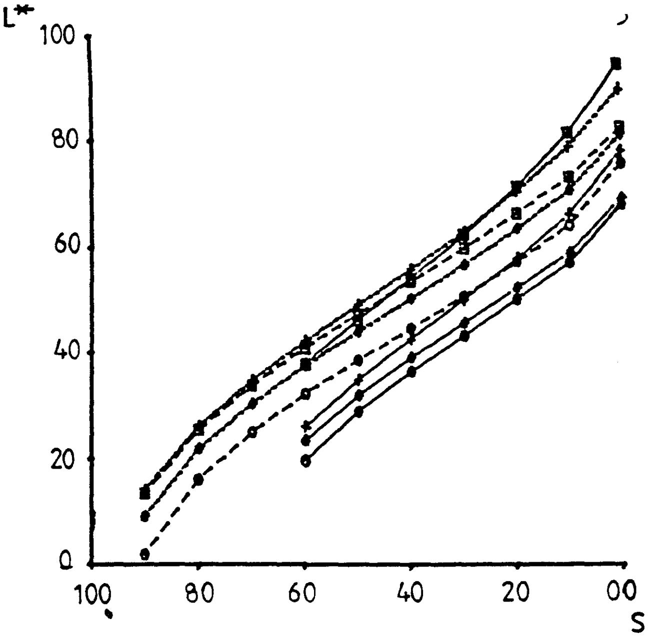

Figure 5: CIELAB lightness (L*) plotted against NCS blackness (S) for the NCS hues Y (□——□——□), Y50R (□---□---□), R (0——0——
R50B (0---0---0), B (*——*——
B50G (*---*---*), G (+——+——
and G50Y (+---+---+).

The mean CIELAB chroma was calculated for each level of chromaticness for each NCS hue. In Figure 4 chroma is plotted against chromaticness for the hues Y, Y50R, R, R50B, B, B50G, G, and G50Y.

The mean CIELAB lightness was calculated for each level of blackness for each NCS hue. In Figure 5 lightness is plotted against blackness for the hues Y, Y50R, R, R50B, B, B50G, G, and G50Y.

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SOME EXPERIENCES IN CALIBRATION OF COLORANTS FOR COMPUTER COLOUR MATCHING IN AUTOMOTIVE INDUSTRY

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In the Yugoslav comercial production of the colorant compositions, any desired colour is as yet normally produced by the trial-and-error mixing, based on experience, itself being derived purely empirically from the results of experiments in which the different colorants are mixed and the produced colours are visually observed. In recent years, due to increasing requirements of quality at the export market, such procedure have become unsatisfactory. So, the problem of the colour definition of a sample as well as the calculation of the colorant recipe on the basis of the measured spectrophotometric curves of a sample and its colorants, through the satisfactory digital computer procedure, is of a great economic importance.

We based our colorant formulation programme on the Kubelka-Munk two-flux theory (1), on the assumption that there is no interaction between the various constituents of a colorant layer. Consequently, both the absorption coefficient (K) and the scattering coefficient (S) of the film are supposed to be separately linear functions of the concentrations of the colorants.

In the next section we define our computer matching (CCM) algorithm, which is essentially based on the idea of E. Allen (2). We neglect the influence of the substrat in which the colorants were dispersed on the scattering and the absorption characteristics of the mixture. This gave good results.

Afterwards we describe the calibration of the colorants, a task which have shown to be of a great and decisive importance for the successful CCM.

Finally, we discuss our experience, based on the calibration of the ten colorants, comercially used in automotive industry, and on the CCM of the twenty comercial samples, made of three and four colorants.

Spectrophotometric measurements of the spectral reflectances of samples and colorants have been performed by SuperScan 3 (Varian) UV-Visible Spectrophotometer, in the 10 nm steps (2 nm bandwidth), in range from 400-710 nm (32 points). The integrating sphere of the 0/d illuminating and viewing conditions was used. The illuminant used was CIE Standard Illuminant D 65, and the calculations were done on Digital computer Decsystem 20.

Computer colour matching algorithm. Similarly as in mentioned paper of E. Allen, we define the matrices

$$t = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \; ; \quad u = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \; ; \quad T = [\bar{X}_{i,j}] \; , \; i = \overline{1,3} \; , \; j = \overline{1,32} \; ;$$

$$E = [E_{i,j}] \; , \; E_{i,j} = 0 \;\; \text{if} \;\; i \neq j \; , \; i = \overline{1,32} \; , \; j = \overline{1,32} \; ;$$

$$DK = [DK_{i,j}] \; , \; DK_{i,j} = (dR/dK)_{i,j\;i,j} \; , \; i = \overline{1,32} \; ;$$

$$DS = [DS_{i,j}] \; , \; DS_{i,j} = (dR/dS)_{i,j\;i,j} \; , \; i = \overline{1,32} \; ;$$

$$K = [K_{i,j}] \; , \; i = \overline{1,32} \; , \; j = \overline{1,3} \; ; \; K_4 = K_{4,i} \; , \; i = \overline{1,32} \; ;$$

$$S = [S_{i,j}] \; , \; i = \overline{1,32} \; , \; j = \overline{1,3} \; ; \; S_4 = S_{4,i} \; , \; i = \overline{1,32} \; ;$$

$$C = [C_i] \; , \; i = \overline{1,3} \; ; \; \Delta C = [\Delta C_i] , \; i = \overline{1,3}$$

where X, Y, Z are the tristimulus values of the sample to be matched, $\bar{X}_{i,j}$'s are the tristimulus coefficients for the specified condition of wieving, $E_{i,j}$'s is the relative spectral energy distribution of the illuminant; R is the spectral reflectance of the sample, so $dR/dK = -2R^2/S(1-R^2)$ and $dR/dK = R(1-R)/S(1+R)$ represent the derivatives of $R(\lambda)$ with respect to K and S respectively ; $K_{i,j}$ and $S_{i,j}$ are K's and S's values of the colorants and $K_{4,i}$ and $S_{4,i}$ are the coresponding values of the fourth colorant (the third colorant, in the alternative algorithm for the three-colorant mixtures), arbitrarily chosen between four; finally, C_i's are the colorants concentrations in the mixture, that satisfy the condition $C_1 + C_2 + C_3 + C_4 = 1$. Linearization of the functions $R(K,S,\lambda)$ with respect to S and K, the linear relations of S(C) and K(C) of C, as well as the choice of the Kubelka-Munk function $F = K/S = (1-R)^2/2R$ resulted in the matrix formula for the calculation of unknown concentrations of the colorants in the mixture

$$C = -\{T \cdot E \cdot [DK \cdot (K - K_4 \cdot u^T) + DS \cdot (S - S_4 \cdot u^T)]\}^{-1} \cdot T \cdot E \cdot (DK \cdot K_4 + DS \cdot S_4) \qquad (1)$$

Although in both DK and DS appears the unknown factor 1/S, it is cancelled out of the expression, since it is present as a linear factor in both the numerator and the denominator. The sample sharacteristics appear in this expression only through its spectral reflectance, a measured quantity. This removes the ambiguity of the rough match concentration in the original Allen´s algorithm, due to the presence of the S in his formula. If we define the tristimulus values of a sample and the match as (X_s, Y_s, Z_s) and (X_m, Y_m, Z_m) than the corections for C´s, ΔC´s, are found in next iteration as

$$\Delta C = \left\{ T \cdot E \cdot \left[DK \cdot (K - K_4 \cdot u^T) + DS \cdot (S - S_4 \cdot u^T) \right] \right\}^{-1} \Delta t \qquad (2)$$

S_s that appears in (2) are calculated from the known concentrations of the rough match.

The application of the iterative procedure, defined by (2) was twofold: a) After the rough match concentrations had been found, the CCM programme went on automatically to the calculation of the reflectances of the match, as well as the K´s and S´s values of the match ($\approx$ to the sample), and than to the numerical evaluation of ΔC, in as many steps as is enough to satisfy the condition $|\Delta C_i| < \varepsilon$ (it was mostly enough up to three steps with $\varepsilon = 10^{-4}$). Corections ΔC_i in such a way were up to 5% of the values in the rough match, and gave the better agreement with the sample, than uncorected rough match did. But the primar task of such a procedure was our experience that the iterative procedure never stops (ΔC_i´s go larger and larger) if the composition (isomeric) of the colorants was a bed gess. That resulted in a method for detecting the colorants composition in a mixture (isomeric) not only quantitatively but also qualitatively; b) After the corrected rough match concentrations were found, the colour layre was made out of them, and its spectral reflectance curve measured. With such "real" values, we entered the iterative algorithm (2). Such a procedure was repeted until we get satisfactory visual agreement of the match and the sample. This occured at the colour difference values from 0,7 to 2 MacAdams, depending on the sample composition. The number of iterations to reach such a goal was from 0 to 3, but in most cases it was two. We mached 20 comercial colour samples, 14 of these were of 4 colorants and

6 of 3 colorants, not necessarily with the white.

In the case of the four colorants in a composition, the problem is well defined: there are the three independent conditions in tristimulus values and the fourth was $\sum C_i = 1$. In the case of the three colorants compositions, the problem is overdefined. In such a situation, at each step of algorithm, the three groups of the three independent equations were made, the unlogical results discarded and the rest averaged. That gave not worse results than those we got in the case of four components mixtures.

Calibration of the colorants. The ten colorants, comercially used in the automotive industry were calibrated (in the sence of determination of the S and K coefficients (3),(4)). These are: black, blue, green,yellow, orange, violet blue, oxid red, oxid yellow, red and violet. This was done by mixing the colorants with the white (and/or with black, for the high reflectance colorants, as are yellow and orange), in the different concentrations (7 to 12 points). In that way the surfaces $K(C,\lambda)$ and $S(C,\lambda)$ were obtained. The intersections of such surfaces with the planes λ= const. were not the stright lines but rather the curves, which we fitted to the analytical curves (the correlation better than 0,98)

$$S(C,\lambda) = S_0(\lambda) + A(\lambda)\cdot(C - G)^{B(\lambda)} \qquad (3)$$

One could expect that if one enter with such S's and K = S•F into the algorithm, the results of the matching would be better and the convergence faster. But, our experience showed that this was not the case. We couldn't have any acceptable recipe result with such "correct" K's and S's. This is esentially a consequence of the conceptual nonlinearity in the mixing of the various constituents in the colour, in contrast with the linear theory used. Fortunately this inconvenience was surpassed by appropriate averaging of $S(C,\lambda)$ and $K(C,\lambda)$ over the ranges of their concentrations in white. So, by trial-and-eror method we made the choices of the ranges of averaging of K's and S's over a range of concentrations in white, which gave the positive rough matches concentrations and satisfactory fast convergence in each of the 20 matched samples. The general rule was that for the dark pigments (black, green,...)

everaging of $S(C,\lambda)$ and $K(C,\lambda)$ over C should be performed in the range $C \leq 3\%$, for the medium dark (oxid red, blue, ...) in the range $C \leq 20\%$, for the medium light (oxid yellow,...) $C \leq 100\%$ and for the colorants with high reflectivity (yellow, orange) in the range $C > 50\%$.

Conclusion. We conclude with the empirical results: The interaction between the different constituents of the colour layer causes the nonlinear dependence of the mixture coefficients K_s and S_s on the concentrations of the colorants. Still we can use the linear two-flux Kubelka-Munk theory, but the effect of nonlinearities hav to be cancelled by the appropriate averaging of the K and S coefficients of the colorants. With such a choice of the coeficients, the numerical procedure mentioned earlier could be used not only for the quantitative but also for qualitative determination of the isomeric colorants mixtures compositions.

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BRIGHTNESS, WHITENESS AND LIGHTNESS

Paul Green-Armytage, 1983.

DIMENSIONS OF A COLOUR SOLID

It is widely accepted that a 3-D "colour solid" can be constructed to illustrate the different dimensions of colour appearance. It is also generally agreed that one of these dimensions, a colour's hue or chromatic type, can be indicated on a continuous scale in the form of some kind of ring - circular, square, hexagonal or otherwise.

Every colour has a place on this ring but each place is shared. For example a vivid reddish orange would have the same place as other colours that are lighter, darker, duller, weaker, etc., but which are all 30% yellowish and 70% reddish. Although they share the same position on the ring each of these colours can have its own place in the solid. To establish this place two other scales are needed which must be chosen to correspond with two other dimensions of appearance.

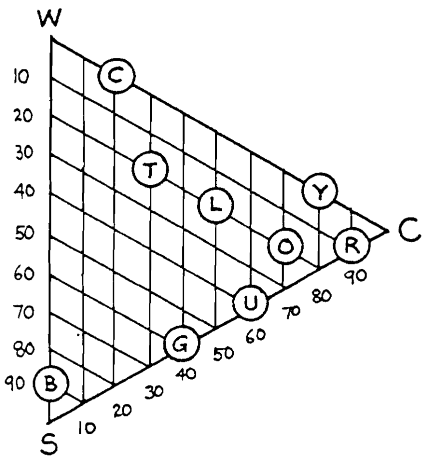
There are many possible scales - dark to light, dull to vivid, dim to bright etc. - but two sets of scales have become established as the most useful and from these the colour solids of many systems have been constructed. Representative systems and their scales are:

NCS		MUNSELL
- hue	(chromatic type)	- hue
- chromaticness	(chromatic amount)	- chroma
- blackness		- value (light reflectance)
- whiteness		

The work behind this paper was aimed at comparing the structures of these systems, understanding the differences and resolving certain confusions. The hope was that some conclusions might be reached about the relative merits of the two structures.

CONFLICT OF TERMINOLOGY

Confusions arise from the way in which such terms as brightness, whiteness and lightness are applied to colour scales. To investigate this problem nine colour chips were selected from the NCS colour album for which there were close equivalents in the Munsell System. The colours are shown in their various positions on cross-sections of the two systems in fig. 1.



NCS			MUNSELL
G50Y	Ⓒ	v.pale chartreuse	5 GY
B70G	Ⓣ	pale turquoise	7·5 BG
Y10R	Ⓨ	yellow	2·5 Y
R60B	Ⓛ	lilac	2·5 P
Y30R	Ⓞ	ochre (dk.,yellow)	7·5 YR
Y90R	Ⓡ	red	7·5 R
R70B	Ⓤ	ultramarine blue	7·5 PB
G10Y	Ⓖ	dark green	2·5 G
	Ⓑ	black	N

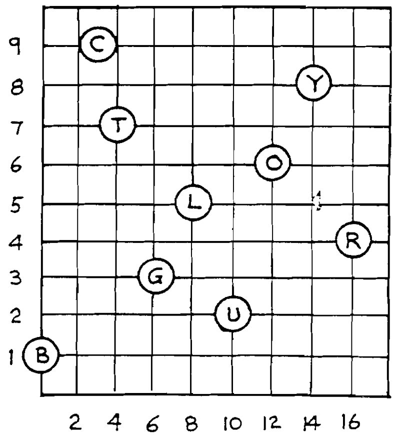
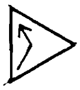
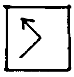
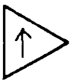
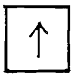
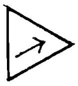
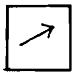
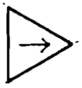
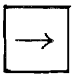


FIG. 1

Directions can be established within each cross-section which determine orders for the colours. Such orders can be compared with other orders established by asking people to arrange the colours according to, for example, lightness. The comparison can reveal the extent to which the construction of the systems reflects the ordering of everyday language.

INVESTIGATION - COLOUR ORDERING

Several people were asked to order the colour chips according to the various terms. The table shows some of these orders together with relevant orders extracted from the systems.

ORDER No.		SCALE											ORDER BY
1	a		B	G	U	O	R	Y	L	T	C		NCS
	b	BLACKEST	B	G	U	O	R	Y	L	T	C	WHITEST	Howard
2	a		B	G	U	R	O		Y/L	T	C		Munsell
	b	BLACKEST/ DARKEST	B	G	U	R	O	Y	L	T	C	WHITEST/ LIGHTEST	Clare
3	a	BLACKEST	B		U/G	R	Y	O	L	T	C	WHITEST	Sarah
	b	DARKEST	B	U	G	R	Y	O	L	T	C	LIGHTEST	Sarah
	c	BLACKEST	B	U	G	R	Y	O	L	T	C	WHITEST	Ben
4	a		B	G	U		R/O	L	Y	T	C		NCS
	b	DARKEST	B	U	G	R	O	L	Y	T	C	LIGHTEST	Michael
	c	BLACKEST	B	U	G	R		O/L	Y	T	C	WHITEST	Peter
5	a		B	U	G	R	L	O	T	Y	C		Munsell
	b	DARKEST	B	U	G	R	L	O	T	Y	C	LIGHTEST	Ben / Selga
	c	LEAST BRIGHT	B	U	G	R	L	O	T	Y	C	BRIGHTEST	Selga (black background)
6		LEAST BRIGHT	B	C	G	U	R	T	O	Y	L	BRIGHTEST	Selga (white background)
7	a		B	G	T		U/C	L	O		R/Y		NCS
	b		B	G	T		U/C	L	O	R	Y		Munsell
	c	LEAST BRIGHT	B	G	T	U	C	L	O	R	Y	BRIGHTEST	Penny
8	a		B	C	T	G	L	U	O	Y	R		NCS
	b		B	C	T	G	L	U	O	Y	R		Munsell
	c	LEAST VIVID	B	C	T	G	L	U	O	Y	R	MOST VIVID	Ben
9		LEAST BRIGHT	C	T	B	G	U	L	O	R	Y	BRIGHTEST	Rosie
10		LEAST BRIGHT	B	T	C	O	G	L	U	R	Y	BRIGHTEST	Catherine
11		LEAST VIVID	R	B	C	Y	O	G	T	U	L	MOST VIVID	Lauris
12		LEAST PURE	T	C	G	O	L	U	Y		B/R	PUREST	Michael

Such results expose certain factors and point to certain conclusions.

1. Different people can mean different things by the same term (orders 3b, 5b).
2. Some people can mean the same thing by different terms (order 2b).
3. The meaning of more than one term can be confused in a single situation (order 6).
4. Context can play a critical role, especially the contrast between a colour chip and the colours of the background and neighbouring chips (orders 5c and 6).
5. Terms might be referring more to the effect of a colour in its context than to the inherent properties of the colour itself. (Black on white is comparatively "bright" - order 9.)
6. Objective judgements can get mixed up with subjective response. A "crude" red is not "vivid", a "subtle" lilac is. (order 11)
7. For colour scales to be useful there must be an agreed objective basis which can operate reliably in different contexts.
8. The terms of everyday language, with the possible exception of whiteness and blackness, are understood in too many different ways. Unequivocal terms are needed for each scale.
9. When the concept of colour scales is first introduced each scale needs to be illustrated with colour samples and understood in perception before it is linked with language by the application of a term.

CHOICE OF SCALES

The horizontal scale indicating chromatic amount (chromaticness or chroma) is common to both structures. This scale can be accepted when it is associated with those terms and when some other confusions have been cleared up. The issues involved in a choice of scale or scales for the third dimension become clear in the different interpretations of the terms brightness, whiteness and lightness.

HORIZONTAL SCALES

The terms of everyday language which are most readily associated with the horizontal scales apply more to colour effect than colour fact. Different orderings reflect different individual reactions to colour, hence the confusion.

At the bottom of this scale are the achromatic colours including black, but black can be placed near to the top in scales of "purity" (order 12) "intensity", "saturation" and even "brightness". The most reliable everyday term is probably "vividness".

Even when the scale is understood there is another source of confusion which is also due to use of language. This appears in the yellow to red section of the chromatic sequence. As a result of language evolution the colours in this section are only called "yellow", "orange" or "red" when they are highly chromatic. As the chromatic amount decreases the colours get called "brown". Pale reds and purples also get called "pink", but between blue and yellow, colours can be light, dark, vivid, dull and almost grey but still be called "blue" or "green". This means that when judgements are made about the chromaticness of colours there can be a single scale operating in the blue sector and a double scale in the organge sector (fig. 2).

This can lead to a moderate blue chip being judged to be more chromatic than dull yellow-orange like the ochre(o) chip. (This chip, with 70% NCS chromaticness and Munsell chroma 12 is well down the scale in orders 10, 11 and 12.)

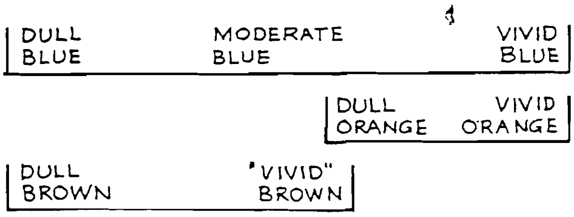


FIG. 2

BRIGHTNESS

The term "brightness" is used particularly loosely and is applied to scales in all directions. It seems to imply a combination of light reflectance (vertical scale - order 5c) and chromatic amount (horizontal scale - order 9).*

Since people clearly confused ideas in some orders it is reasonable to conclude that a compromise diagonal direction is best associated with brightness (order 7c). This may represent a genuine perceptual scale with a physiological basis.

*NOTE: As with some other comparisons, order 9 is not a perfect match for order 8 but it is sufficiently close to suggest that the orderer meant essentially the same thing.

WHITENESS

Whiteness and blackness seem to be the best understood and most reliable terms fo describing colour appearance. Order 1a is, strictly, two scales which intersect. These are the scales of the NCS and refer to the whiteness and blackness in a colour's appearance. There was some confusion between "whiteness of appearance" and "closeness to white" and difficulties with colours having no clear dominance of whiteness or blackness. Such difficulties largely disappear when a colour can be placed within the NCS triangle and the relative influence of the three perceptual extremes - white, black and most chromatic - can be weighed.

LIGHTNESS

The investigations reveal two distinct meanings for "lightness". For some people lightness is the same as light reflectance which is essentially what is meant by Munsell "value" (order 5a, 5b). For others a light colour seems to be the result of a mixture involving a white colourant. Pale turquoise and lilac are "whiter" and therefore "lighter" than vivid yellow (orders 2b, 3b). With this interpretation of lightness the mid point between lightest and darkest for each chromatic type occurs where the colour is at its most chromatic.

These points might be established through experience and stored in the brain for reference. The points are at different light reflectance levels which serve as base lines for judging the lightness and darkness of colours. This means that "light" (whitish) colours like lilac (L), which are above their base line can actually be "darker" (of lowerlight reflectance) than "dark" (blackish) colours like ochre (O) which are below their base line (fig. 3).

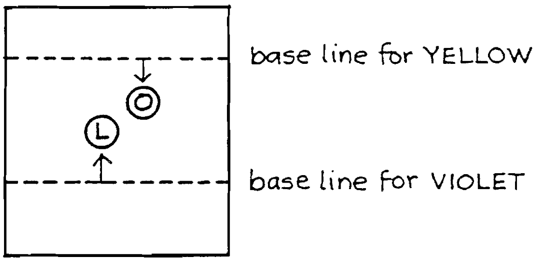


FIG 3

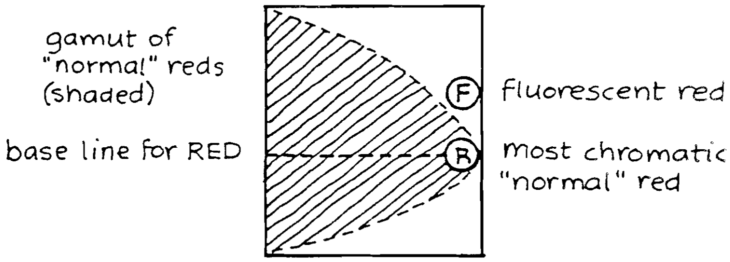


FIG 4

The base line concept can also account for the distinctive appearance of the rarely encountered fluorescent colours. Such colours are at maximum chromatic amount for their chromatic type but appear to be reflecting more light than would be expected; they are above their base line and so outside "normal" experience (fig. 4)

LIGHTNESS, WHITENESS, LIGHT REFLECTANCE AND VALUE

To resolve the confusion over the meaning of "lightness" separate terms like "whiteness" and "light reflectance" or "value" should be adopted. "Lightness" itself should be abandoned.

The meaning of whiteness is reasonably clear.

Light reflectance and value are best understood in terms of a corresponding scale of greys from white to black. The minimally distinct border technique of relating colours to a scale of greys is embodied in the NCS Lightness Meter and is particularly helpful. The scale needs to be illustrated and the distinction made between steps that are visually equal and those that are equal in terms of increasing percentage reflectance of incident light.

The distinction also needs to be made between what we see and what we know. The two surfaces of a piece of folded pink paper may be judged to be equally light reflectant because we are aware of the direction of the light and know that one surface is receiving direct illumination while the other is not. Similarly we may judge both surfaces to be physically the same and, therefore, equally "whiteish". Nevertheless they do not look the same. One is clearly "closer to white". This does not present problems in the NCS which is independant of physical samples. It is based on perceptio and a change in appearance means a different notation and a correspondingly different position in the solid for each surface.

If a system based on perception were to be constructed with a light reflectance or value scale it would be necessary to make a distinction and establish that, for example, light reflectance refers to the physical properties of a surface and value refers to its apparent position relative to a grey scale. The total context of the perception would supply the reference points for such a scale. Therefore both surfaces of the pink paper would have the same light reflectance but the directly illuminated surface would have a higher value.

CONCLUSIONS

At present the conflicting interpretations of "lightness" make the vertical scale of the Munsell type structure confusing and, therefore, unreliable. However the rectilinear co-ordinates are simple and the vertical scale directly indicates light reflectance or value which is crucial in applied design.

NCS type whiteness and blackness are more reliable but the triangular co-ordinates are difficult to grasp and the structure does not clearly illustrate light reflectance.

Assuming clarification of lightness, and if I had to choose, I would prefer the Munsell structure. But once the issues are clarified it can be seen that the two structures are not incompatible and that both can contribute to a clearer appreciation of the phenomena.

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AN INTRODUCTORY COLOUR SYSTEM

Paul Green-Armytage, 1983

My objective has been the development of a colour system which is scientifically acceptable and which can help ordinary people to a better understanding of colour as they experience and use it.

THE VISUAL CODE

The system is based on a model of what might be called the 'visual code' at the threshold of consciousness. The visual code is the pattern of nervous activity in its final form, just before that point where we become conscious of a particular colour.

Recent research suggests that this code might have three components or signals which can be called Y/B, R/G and 0/100. Each of the Y/B and R/G signals can be positive or negative, and give information about chromatic type (hue) and chromatic amount (saturation).

Positive signals indicate yellowness (Y/B+) or redness (R/G+). Negative signals indicate blueness (Y/B-) or greenness (R/G-). Chromatic type is indicated by the particular combination of positive and negative and the relative strength of each. E.g., Y/B+ with R/G- at equal strength would be a yellowish or 'lime' green. Chromatic amount is indicated by the total strength of the two signals combined. (In this situation a negative signal of blueness or greenness counts as a positive contribution to chromatic amount).

0/100 can only be positive and gives information about the percentage of light being reflected or transmitted in the particular situation, the situation being a guide to the possible limits. (Percentage light reflectance is independent of light energy. This independence and its significance in the process of colour vision, has been convincingly demonstrated by Edwin Land (1977)).

Before finally entering consciousness as a colour sensation, the three signals would be subject to modification because of past experience and present expectations. The model is illustrated in Fig.1.

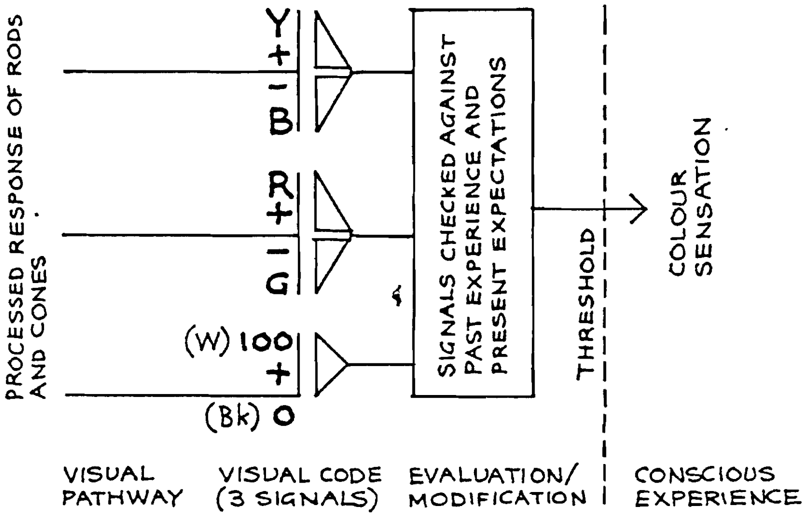


FIG. 1

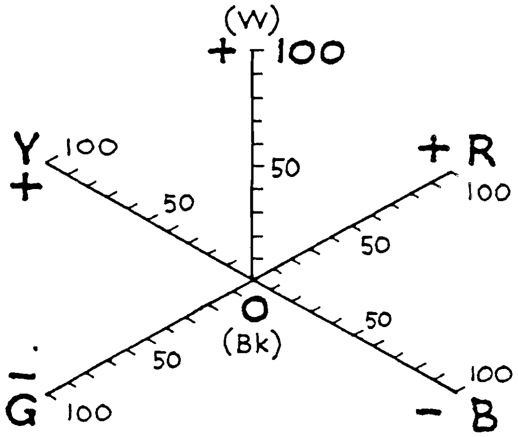


FIG. 2

THE VISUAL CODE COLOUR SPACE

The three signals of the visual code can be represented in a 3-D diagram (Fig. 2). From point '0' the lines to points Y,B,R,G and 100, can each be divided into 100.

Signals can range in strength from 0-100% positive or negative. In a particular example the strength of each signal can be marked on the corresponding lines which can then be used as co-ordinates to locate a point in space. E.g., 'Mauve' could be located in the space from its visual code which might be Y/B-20, R/G+30, 0/100+50. (Fig.3).

It is easier to read the location of a point in a 3-D space if it is presented in two projections. (Fig. 4). Projection 1 indicates chromatic type and chromatic amount, while projection 2 indicates light reflectance.

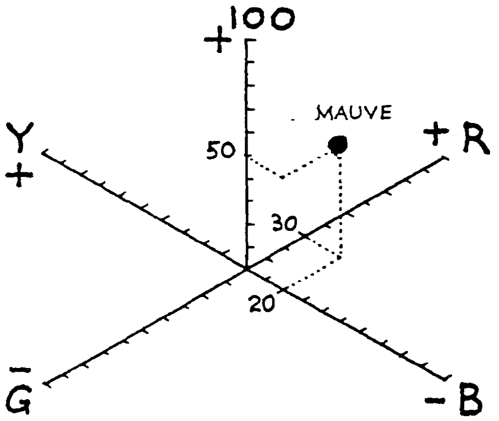
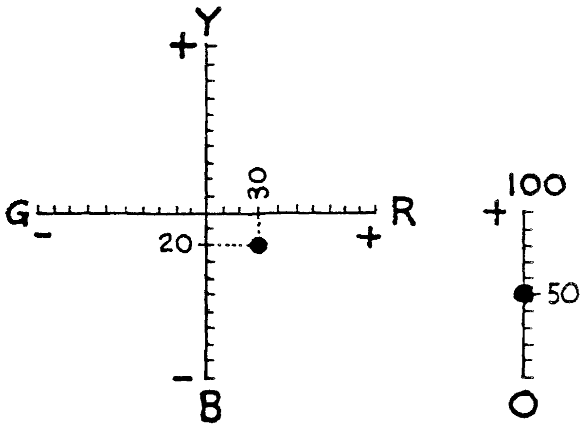


FIG. 3



PROJECTION 1

PROJECTION 2

FIG. 4

PROOF OF CORRECTNESS OF A MODEL

A model such as this can be shown to be sound in two ways; it can be approached from either side of the threshold of consciousness.

Direct measurement of the physiological responses immediately before the threshold of consciousness might establish the nature of the visual code. To my knowledge this has not been achieved.

Alternatively we can analyse our conscious experience of colour sensations and see if we can judge colours accurately in terms of the three hypothetical signals.

The research behind the Swedish Natural Colour System (NCS) has revealed that observers can be in impressive agreement about such judgements.

ELEMENTARY COLOURS

There are six special situations in the working of the visual code, of which we might be aware and which can be equated with six 'elementary colours' - yellow, blue, red, green, black and white.

If there is no positive or negative signal from one of Y/B or R/G, the experience might be, e.g., a green that is neither yellowish nor bluish, a pure or 'unique' green. This gives us four chromatic reference colours:

Y/B+	Reference	Y/B-	Reference	Y/B0	Reference	Y/B0	Reference
R/G0	Yellow	R/G0	Blue	R/G+	Red	Y/G-	Green

If 0/100 is at or near its limits, (0 or 100), there could be no significant signal from Y/B or R/G. Near 0 the experience would be 'black'. Near 100 the experience would be 'white' for opaque materials and 'clear' for transparent ones.

JUDGING COLOURS

A judgement about a colour's appearance can be made by recording a position on three scales which correspond to the three attributes or dimensions of colour:

1 Chromatic type (hue) A colour's chromatic type can be judged as its relative similarity to two chromatic reference colours. This is most easily done on a percentage scale. E.g., Lime Green might be 50% yellowish and 50% greenish.

2 Chromatic amount (saturation) this can also be judged on a percentage scale where 0% is grey and 100% is the most chromatic appearance imaginable for that chromatic type. A vivid lime green might be 80% chromatic and a dull one 40%.

Several colours can appear different but be of the same chromatic typ and chromatic amount, e.g., a pale lime green and an olive green. A third judgement is needed to separate such colours.

3 Light reflectance (value) It is possible to estimate what percentage of the incident light is being reflected (or transmitted) by the coloured material. This gives us a third percentage scale with black at 0 and white at 100. A lime green surface might have 70% light reflectance and an olive 40%.

THE COLOUR JUDGEMENT COLOUR SPACE

The three scales can be combined in a 3-D diagram which can be read as a colour space. (Fig. 5). Judgements about a colour's appearance can be marked on each scale, which can then be used to locate a point in the space. E.g., the 'Mauve' might be judged to be 40% bluish, and 60% reddish with 50% chromatic amount and 50% light reflectance. (Fig.6).

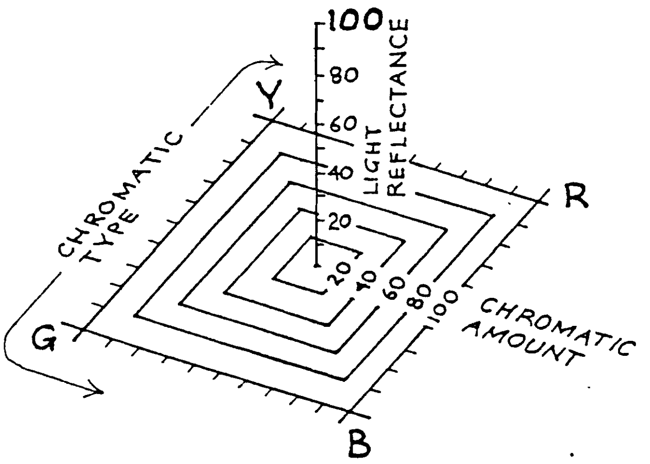


FIG. 5

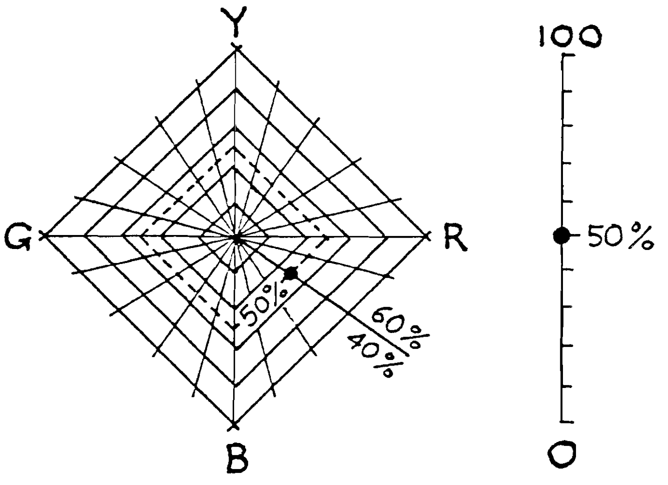


FIG. 6

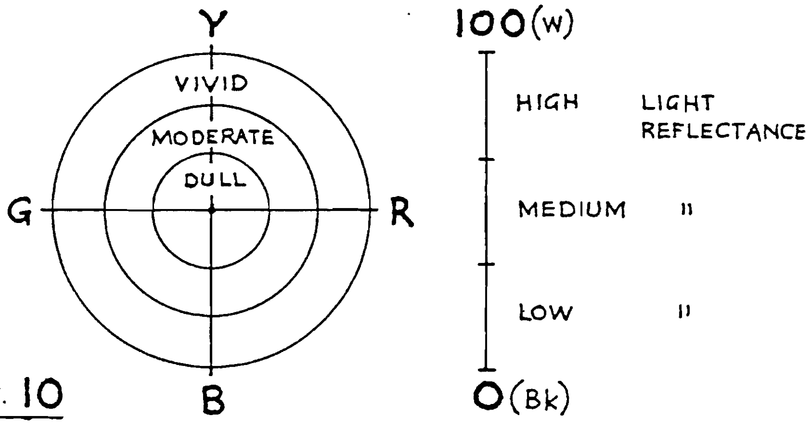
COLOUR JUDGEMENT AND THE VISUAL CODE

The colour judgement space and the visual code space have essentially the same structure. This makes it possible to relate the two if the scales from both are combined on projection 1. (Projection 2 is the same for each space).

We can now make a judgement about a colour's appearance and see what visual code signals might have been responsible for such a sensation, and we can say what colour sensation we might expect from a particular set of visual code signals.

SYMBOLS FOR DESCRIBING COLOURS

The colour space can be divided into zones which can be shown on the two projections of the space. These projections can be used as symbols for everyday descriptions of colours. (Fig. 10).



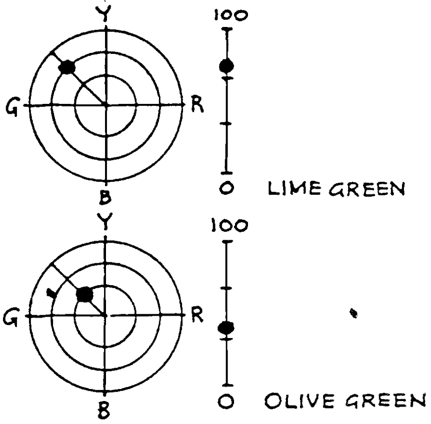


FIG. 10

RELATION TO OTHER SYSTEMS

The system can serve as an introduction to other systems. It is a simple matter to add to the other symbols the NCS triangle for indicating the colour's nuance, thereby linking the two systems. (Fig. 11)

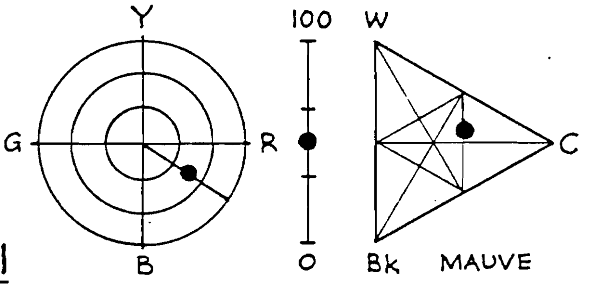


FIG. 11

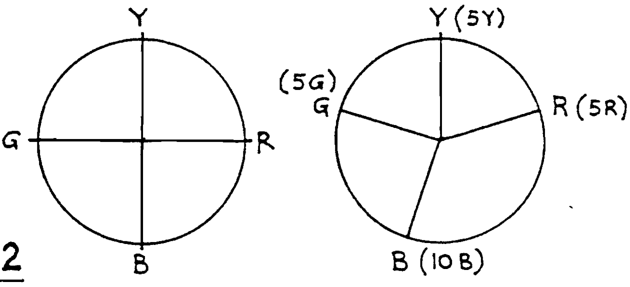


FIG. 12

The main point of difference between this and the Munsell system comes from the different conceptual starting points. The difference is most apparent in the relationship between chromatic types as they occur opposite to each other on the circle. (Fig. 12).

The CIE chromaticity diagram can easily be related to the projection 1 in this system which shows chromatic type and chromatic amount. Similarly the estimation of light reflectance in this sytem can be equated with the measurement which determines the CIE luminance factor Y.

The visual code space can be used to approach the problem of uniform colour scales.

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COLOR ORDER SYSTEMS - WHO NEEDS THEM?

W. N. Hale

Recent improvements in color measuring instruments, both in accuracy and precision of measurement and with respect to the variety of specimens they can measure, leads one to ask how useful are the various color order systems and to question the value of illustrating such systems with books of color chips. Why do we need them? If certain groups need them, what do they need?

Instrumental measurement data tells us what the color is, but a color order system is needed to appreciate how a number of colors are interrelated. Visually spaced color order systems permit one to understand the magnitude of a set of related colors in three dimensional space, which leads to optimum methods of fractionating that space, or of sampling it with actual colors. Until we put sets of color data into an organized system we find it difficult to understand, and therefore to work with in any fashion.

Color tolerance work demands a systematic approach to specification of desired tolerances on a visual attribute-by-attribute basis. In such work it is the usual thing for the magnitude of tolerance to differ for each visual parameter. A series of colors, representing the appropriate part of the color order system of interest, permits one to have a visual appreciation of this region in color space, and is a useful preliminary to fine-tuning the individual tolerances.

Systematic collections of color chips, on charts, have been available since the beginning of this century, and these have covered the greater part of the accessible color space, to differentiate them from abridged collections designed to sample the color range of specific colored materials or specimens (soils, rocks, bird plumage, etc.). In most cases it has been that by viewing the complete collection, users have decided that an abridgement, for their specific purpose, would be feasible. The specific has thus been derived from the general.

Visually-spaced color chip collections can be divided into two categories. Some are derived empirically, such as Munsell, Ostwald and the Natural Colour System. Others are mathematical transformations from CIE measurement data, such as Hunter and CIELAB. The former would seem to enjoy a great advantage in providing optimal visual spacing, inasmuch as they are limited only by their creator's ability to improve upon existing visually-spaced system. Thus the early Munsell System was importantly improved by the 1943 respacing, which also produced the graphical relation to CIE space. A further improvement in this system seems called for now, and with the wealth of data from the recently specified OSA colors this would not be terribly difficult. However, such empirical systems are not readily related to instrument results in the same easy way as are those with a direct mathematical link.

For many years color measuring instruments have augmented their CIE data readouts with mathematical transformations to such color spaces as Hunter L, a and b. Now such instruments provide CIE and transform it into Hunter, CIELAB and other instrument-related color order systems and the color difference formulations derived from them. The ability of such systems to approach perfect visual color space (should we ever agree upon what it is) is a function of how well one can formulate the mathematical transform. Given the number of improvements that have been made, and the fundamental limitations inherent in such transformations, further improvement in visual spacing by this approach is likely to be quite modest.

The numerous variables involved in viewing colors and color differences -- light sources, illuminating and viewing conditions, adaptation and other psychological factors -- certainly limit the perfection we can reasonably expect to achieve. Perhaps further improvements in color spacing are not really practical.

What is desired by way of an improved color space? The 1976 CIE recommendation of CIELAB seems quite a good one. While it has room for improvement in certain color regions, whose spacing is importantly different from that in other regions, is this terribly important? Most industrial color work involves extensive treatment of small regions in color space, as with establishing and maintaining tolerances in the manufacture of consumer products.

Transformation equations from CIE to CIELAB require modest amounts of computer capacity and can even be handled with programmable calculators of the small hand-held variety. This can be a tremendous advantage.

With all the excellent instruments and improved color order systems, we might well ask, do we still need collections of color chips? I believe that we do. Who needs them? First they are needed in the aesthetic areas. Architects, designers in all fields, those who select colors for any purpose, need extensive collections from which to choose. The color in the mind's eye must be located and specified before it is lost from imagination. These practitioners need visually ordered color sets which permit them to not only select specific colors found in the sets, but also to specify by visual interpolation the many intermediate colors. A set of 1,000 colors may allow one to visualize, and specify, 100,000 colors.

Who else needs color charts? Many scientists regularly work with specimens that are not suitable for instrumental measurement due to size, shape, surface conditions or physical location. Some colors must be measured in the field. Some plants change color quickly when harvested, some acquatic creatures change color quickly out of water.

In the United States two professional societies in the biology field have recently emphasized their members' needs for suitable collections of color standards. They plan to propose a new set of color charts for biology and hope someone will produce it to their requirements.

Biologists require color charts of a size convenient for use under the comparison microscope because many of their specimens are quite small. They need accurate color measurements of chart colors because they must assign color specification by visual interpolation. And they need materials at a cost which is sufficiently low so that all those who need this tool can afford to buy it. Because most postage stamp colors are quite small, the philatelists have much the same requirements as the biologists.

Many other scientific disciplines involve specimens which need to be classified and specified, but which are not amenable to instrumental treatment. All of these groups, however, are more concerned with the adequacy of the color gamut, and the appropriateness with which it is sampled, than with the niceties of equal visual spacing.

What are the characteristics of an ideal set of physical color standards? How would such a set be an improvement over those now in use? An ideal set should represent some form of visual spacing, and should preferably be a mathematical transformation from CIE, so that it could be available as instrument readout. It should be in high gloss finish for maximum gamut, and should encompass the entire color space accessible in the colorant medium employed. Some transparence should be permitted, as with some currently available materials, although this is not generally known.

The optimum set of color standards might sample the color space on a constant lightness basis, with the colors on each chart showing equal steps in chromaticity. Both natural and manufactured materials vary more in lightness than in other color dimensions. In color tolerance work the lightness tolerance is almost always the largest one. Such charts would permit maximum accuracy in specifying chromaticity, which is what most users desire. Such charts could be sampled in equal increments in CIELAB a and b, with the spacing of colors modified to provide more colors where desired, such as the neutral region and the gamut limit positions.

While it is tempting to suggest the colors be made with permanent, non-fading materials, few of these exist, and those are very expensive. The charts should be made with pigmented lacquer films on paper, either by mounting chips or by direct deposition upon the paper stock. Printing, using current techniques, would result in too much variability throughout the print run, although it would provide a low cost product. Color photographic technology does not provide sufficient accuracy and reproducibility, and the colors may be less permanent than pigmented films.

Colors made with pigmented films do change with time, in both light and dark storage. This is caused by both pigment and vehicle ageing, resulting in some colors changing more than others. Storage at sub-freezing temperatures, while improving permanence, is usually not feasible.

One approach to color change problems is to produce charts in large quantity, and publish suitable measurement data. This permits the user to make more accurate interpolations than when only aimpoints and tolerances are available. Subsequent measurements could be made and published at five year intervals. While it is recognized that charts will age differentially as a function of use and storage, such periodic remeasurements are a great deal better than none at all.

Improvements in instruments are very welcome, but we still need color order systemsand sets of color samples to visually represent them. We already have a suitable color order system, mathematically related to CIE. Who will then undertake the production of the needed color standards so that everyone can document the colors of interest to them?

FORSIUS SYMPOSIUM ON COLOUR ORDER SYSTEMS

AUTHOR: ARCHITEKT EMIL HANISCH,
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THE FRIELING-SYSTEM

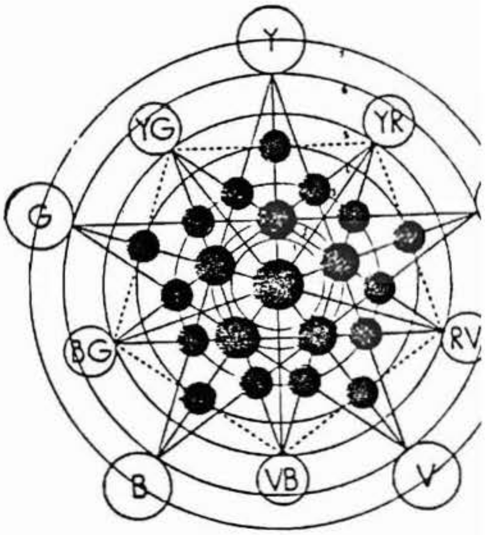
BY DR. HEINRICH FRIELING, MARQUARTSTEIN

Das FRIELING-System

nach Dr. Heinrich Frieling, Marquartstein

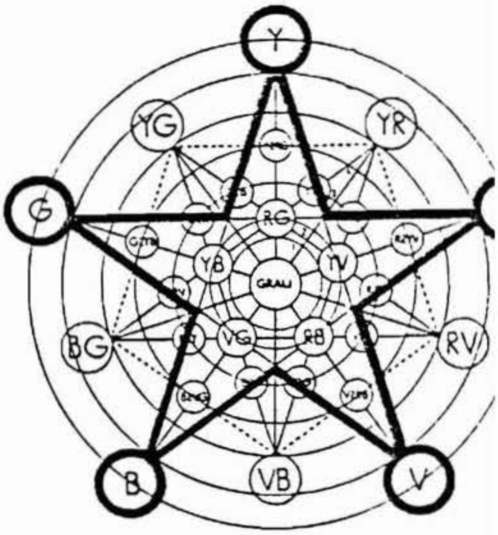
A SYSTEM THAT HAS A LOT TO IT - "IN ITSELF".

- Ein System, das es "in sich" hat.



FIVE PRIMARY COLOURS FORM THE NUCLEUS AS STARTING POINTS OF THE MIXTURES, WHICH ARE ARRANGED AFTER THE PRINCIPLE OF THE PENTAGON.

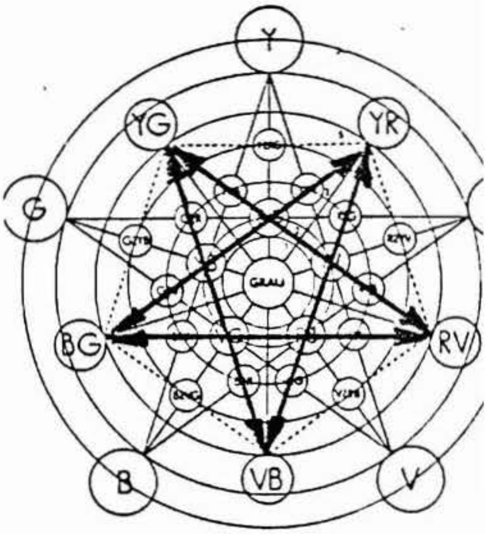
Den Kern bilden fünf Grundfarben als Ausgangspunkte der Ausmischungen, die nach dem Prinzip des Pentagons angeordnet sind.



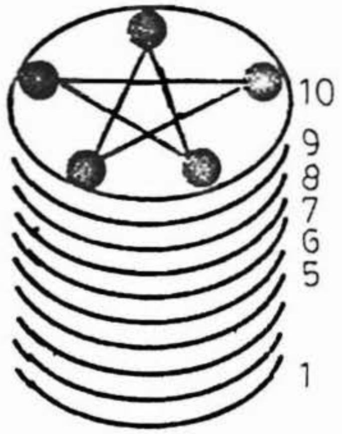
THIS PRINCIPLE OF MIXING IN ITS GEOMETRICAL FORM HAS GOT THE MIXING POINTS SITUATED CLEARLY OPPOSITE TO ONE ANOTHER.

E. G.

Dieses Mischprinzip hat in seiner geometrischen Form die Mischpunkte eindeutig gegenüberliegend.
z. B.



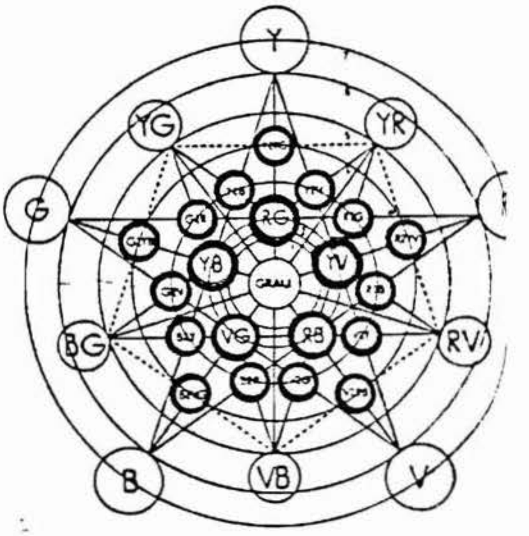
THE COLOUR SPACE IS SEEN IN AN ABSTRACT WAY AS CYLINDER THAT IS DIVIDED UP INTO TEN PLANES ACCORDING TO GRADES OF LIGHTNESS. IN THE BRIGHT ZONE FURTHER IN-BETWEEN PLANES EXIST.



Der Farbraum wird abstrakt als Zylinder gesehen, der in zehn Ebenen nach Helligkeit aufgeteilt ist. Im hellen Bereich sind weitere Zwischenebenen.

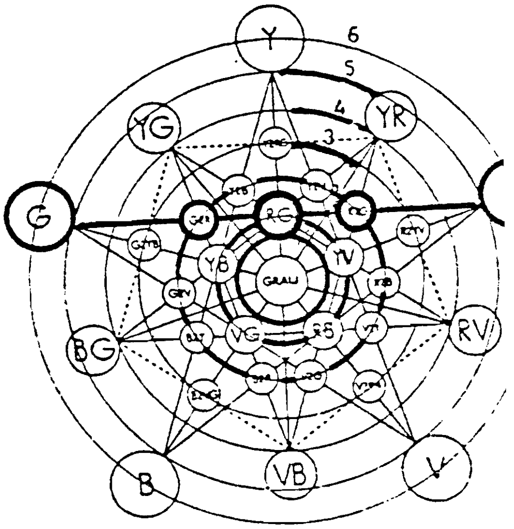
THE MIXING SYSTEM IS PLANNED IN AN ARTISTIC AESTHETIC WAY. THE STEPS OF MIXING ARE GRADED BY PERCEPTION. WE HAVE TO DO WITH ADDITIVE MIXTURE OF COLOURS SITUATED OPPOSITE TO ONE ANOTHER. DEPENDING ON THE CASE OF APPLICATION THE MATERIAL CHOSEN IS DYED FOLLOWING THE MIXED COLOURS OF THE SYSTEM.

Das Mischsystem ist künstlerisch, ästhetisch angelegt. Die Mischschritte sind visuell gestuft. Es handelt sich um additive Mischung gegenüberliegender Farben.
Je nach Anwendungsfall werden die ermischten Farben mit dem zur Anwendung vorgesehenen Material farblich nachgestellt.



THE OTHER MIXING SYSTEMS HAVE GOT A SCREEN, CONSISTING OF LINES OF THE SAME HUES GOING FROM THE GREY AXIS TO A HUE OF THE EXTERIOR CIRCLE, THAT ARE GRADED IN EQUAL STEPS IN SHADES OF INCREASING SATURATION WITH THIS SYSTEM THE POINTS OF THE SCREEN RESULT FROM THE CROSSING OF THE CONNECTINGLINES OF THE POINTS OF THE PENTAGON.
THE MIXING OF THESE IN-BETWEEN SHADES IS REACHED BY ROTATING OR GRAPHICALLY IN THE CIE CHART OF NORMS.

Andere Mischsysteme haben ein Raster aus Linien gleichen Bunttones von der Grauachse zu einem Buntton des äußeren Bunttonkreises, die in Stufen steigender Sättigung aufgeteilt sind.
Bei diesem System entstehen die Rasterpunkte an den Kreuzungen der Verbindungslinien der Pentagonpunkte.
Die Ermischung dieser Zwischentöne erzielt man durch Kreiseln oder graphisch in der CIE-Normtafel.



THE CLASSIFICATION OF COLOURS IS DONE IN SIX CIRCLES OF DECRASING SATURATION BETWEEN THE CENTRE AND THE CHROMATIC CIRCLE OF OPTIMAL COLOURS.

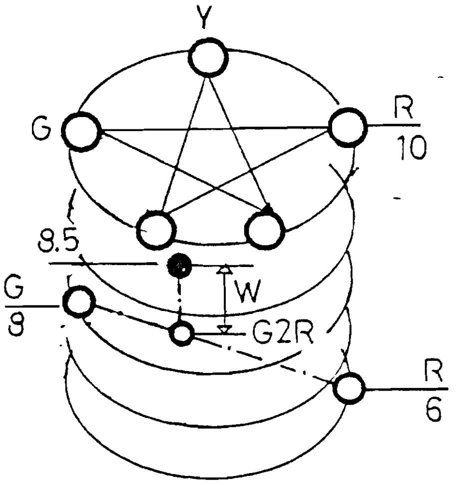
Die Stufung erfolgt in sechs Kreisen abnehmender Sättigung zwischen dem Mittelpunkt und dem Optimalfarbenkreis.

THE MIXING OF A CERTAIN COLOUR TAKES PLACE BY COLOUR ROTATION.

Die Ermischung einer Farbe erfolgt durch Farbkreiseln.

PLANE OF LIGHTNESS

Hellebene



INHERENT LIGHTNESS OF THE OPTIMAL COLOUR "G"

Eigenhelligkeit der Optimalfarbe (G)

PLANE 6

Ebene 6

INHERENT LIGHTNESS OF THE OPTIMAL COLOUR "R"

Eigenhelligkeit der Optimalfarbe (R)

EXAMPLE:	CHOSEN SHADE:	G 2 R, PLANE OF LIGHTNESS 8,5
	1ST STEP:	MIXING G & R AT APPROPRIATE PARTS
	2ND STEP:	BRIGHTENING UP UNTIL LIGHTNESS VALUE OF PLANE 8,5 HAS BEEN REACHED

Beispiel:	Ausgewählter Ton:	G 2 R, Hellebene 8,5
	1. Schritt:	Mischen von G und R zu entsprechenden Teilen
	2. Schritt:	Aufhellung bis Hellwert der Ebene 8,5 erreicht

ADHERING TO AN ABSOULTE GREY AXIS IS THOUGTH TO BE UNNECESSARY FOR THIS SYSTEM.

Die Einhaltung einer absoluten Grauachse wird bei diesem System für entbehrlich gehalten.

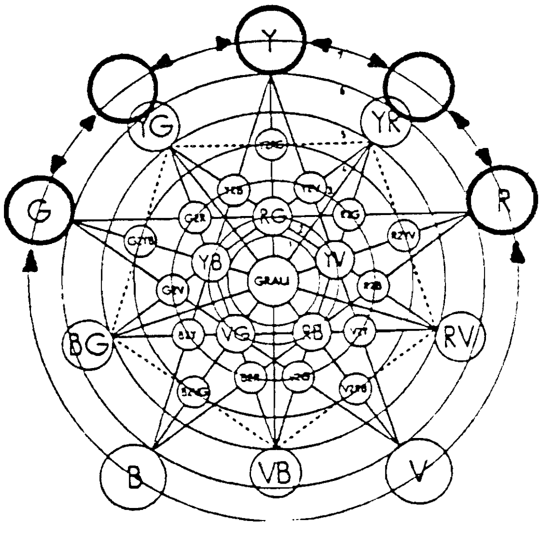
THE COLOURS SITUATED IN THE INTERIOR OF THE CIRCLE ARE THE COLOURS REQUIRED FOR DESIGNING ELEGANT ROOMS AND FOR PRETENTIOUS FASHION.

Die inneren Farben sind die Bedarfsfarben für Gestaltung eleganter Räume und anspruchsvoller Mode.

FOR ADVERTISING AND GRAPHIC PURPOSES THE EXTERIOR CHROMATIC CIRCLE IS PROPOSED. IT IS ARRIVED AT ALSO BY MIXING OF THE FIVE PRIMARY COLOURS, HOWEVER, BY MIXING OF THE COLOURS SITUATED NEXT TO EACH OTHER (RIGHT OR LEFT) IN THE CHROMATIC CIRCLE OF OPTIMAL COLOURS.

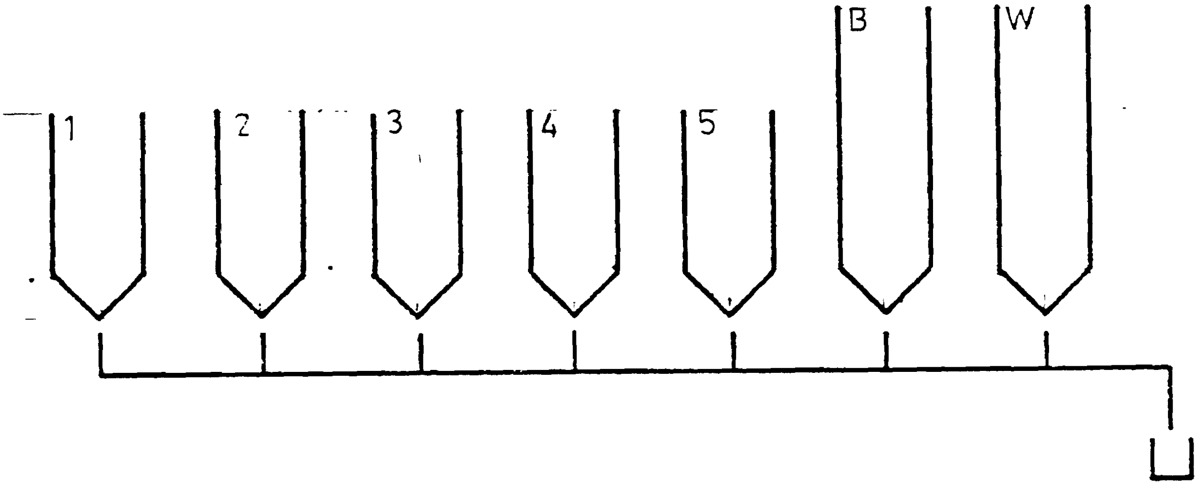
Für Werbe- und Graphikzwecke ist der äußere Farbkreis, der sich ebenfalls durch Ausmischungen der fünf Grundfarben, jedoch durch Mischung der im Optimalfarbenkreis als nächste (rechts oder links) liegenden Farbe ergibt.

EXAMPLE:
Beispiel:



WHEN USING HIGHT QUALITY AND POSSIBLY PURE COLOUR RAW MATERIAL, CONTRARY TO OTHER MIXING SYSTEMS ONLY FIVE SILOS OF PRIMARY COLOURS AND ONE EACH FOR BLACK AND WHITE ARE NECESSARY, WHEREAS MANY MIXING SYSTEMS USW EIGHTEEN AND MORE PRIMARY COLOURS.

Bei Verwendung hochwertiger, möglichst reiner Farbgrundstoffe sind im Gegensatz zu anderen Mischsystemen nur fünf Silos + Schwarz und Weiß nötig, während viele Mischsysteme achtzehn und mehr Grundfarben benutzen.



FOR COLOUR NOTATION CIE-COORDINATES, AS WELL AS SHADE : SATURATION : DEPTH OF SHADE - VALUES ACCORDING TO DIN 6164, WHICH ARE THE NEW GERMAN NORMS OF COLOUR DESCRIPTION, ARE AT DISPOSAL.

Für die Farbkennzeichnung stehen CIE-Koordinaten sowie T : S : D-Werte nach DIN 6164, den neuen deutschen Farbbeschreibungsnormen, zur Verfügung.

THESE CAN BE TAKEN AS BASIS FOR THE CALCULATION OF THE FORMULA WITH USUAL MATERIAL BY WAY OF COMMON DATA PROCESSING.

Die für die Rezepturberechnung mit herkömmlichen Materialien über gebräuchliche Datenverarbeitung zugrunde gelegt werden können.

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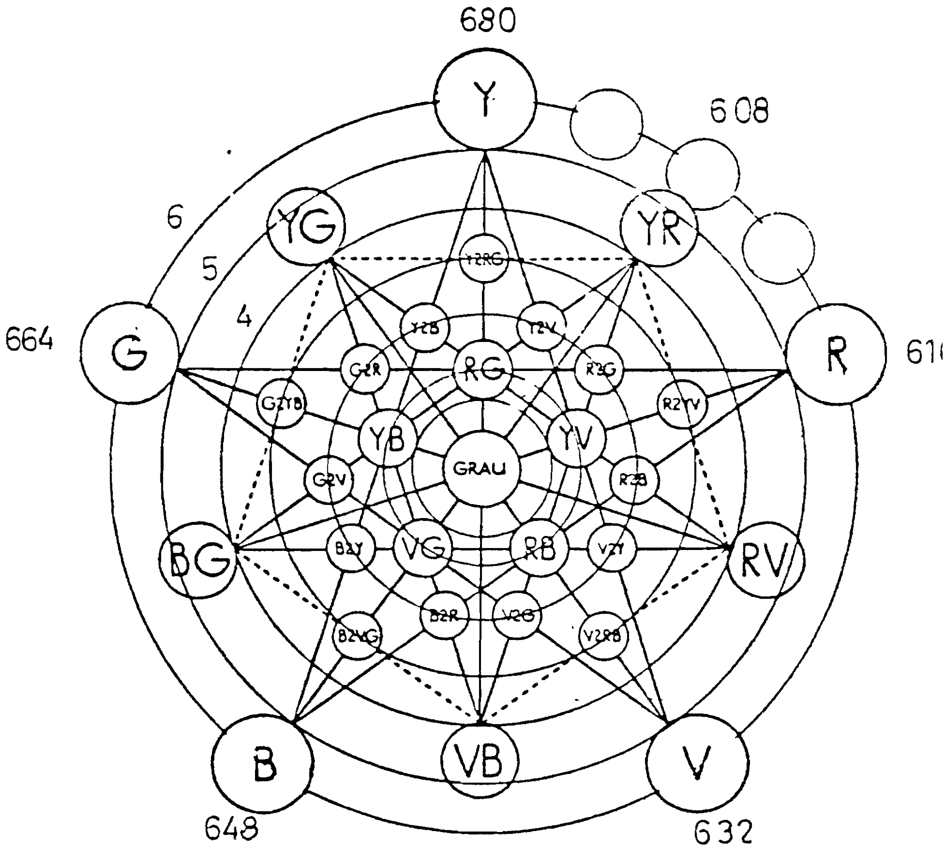
CHARACTERISATION OF THE COLOUR SHADES IS EFFECTED THROUGH A COMBINATION OF FIGURES CONSISTING OF COLOUR SHADE - SATURATION - PLANE OF LIGHTNESS.

Die Kennzeichnung der Bunttöne erfolgt in einer Zahlenkombination aus
Buntton / Sättigung / Hellebene.

E. G. 664 - 6 - 4
z. B.



LITERATUR: FRIELING, GESETZ DER FARBE,
MUSTERSCHMID-VERLAG, GÖTTINGEN.

A COMPARISON OF THE CIELAB AND JPC 79 COLOUR DIFFERENCE FORMULAE.

C. J. Hawkyard- UMIST

ABSTRACT.

Recent work at UMIST has produced a computer program enabling ΔE and ΔE_t, the colour differences between sample and standard according to the CIELAB and JPC 79 formulae, to be calculated. The input can be direct measurements from a spectrophotometer, or numbers keyed in by the operator.

The first study using this progam involved the visual assessment of 4 sets of samples round 4 standards supplied by a commercial dyehouse, and the measurement of their colour. The results indicated no significant difference in the performance of the 2 formulae.

A set of 78 colour cards ranging from low to high chroma and lightness were then used as standards, and numbers keyed in to the computer to obtain small differences ($\Delta E_t = 1$). Grahps of hue angle, chroma and lightness against the$\Delta E/\Delta E_t$ ration showed that only chroma had a significant effect.

Introduction.

The CIELAB (1) and ANLAB (2) modifications of XYZ colour space to produce more visually uniform colour spaces for the assessment of small colour differences are well known, and widely used. It is also common practice to convert the A and B values into chroma and hue so that the results are expressed in similar terms to the Munsell Colour Atlas. Hence -

$$\text{Colour difference} = \Delta E = \left[\Delta L^2 + \Delta A^2 + \Delta B^2\right]^{\frac{1}{2}} \quad \text{....(1)}$$

ΔL = L sample - L standard,
A and B similarly

$$\text{Chroma} = C = \left[A^2 + B^2\right]^{\frac{1}{2}} \quad \text{....(2)}$$

$$\text{Hue angle} = \theta = \arctan\left(\frac{A}{B}\right) \quad \text{....(3)}$$

$$\Delta E = \left[\Delta L^2 + \Delta C^2 + \Delta H^2\right]^{\frac{1}{2}} \quad \text{....(4)}$$

where ΔC = C sample - C standard

$$\text{and} \quad \Delta H^2 = \Delta E^2 - \Delta L^2 - \Delta C^2 \quad \text{....(5)}$$

Where ΔH is the metric hue difference expressed in colour difference units.

The tolerence level for acceptability of the colour of a sample to match a particular standard can then be expressed in terms of a sphere of radius ΔE as defined by equation (4). Unfortunately, it has not generally been found that a single number, say $\Delta E = 2$, gives a useful pass/fail tolerance level over a range of shades, and quite often limits for ΔL, ΔC and ΔH are set in practice.

Two British companies, Marks and Spencer and J and P Coats have further modified LAB colour space, and using microspaces round the standard have defined tolerance ellipsoids. Unfortunately only the J and P Coats formula has been published (3,4). Called the JPC 79 formula it applies corrections to ΔL, ΔC and ΔH according to the position in ANLAB (43.909) colour space of the standard. Hence -

$$\Delta E_t = \left[\frac{\Delta L}{L_t}^2 + \frac{\Delta C}{C_t}^2 + \frac{\Delta H}{H_t}^2 \right]^{\frac{1}{2}} \quad \ldots.(6)$$

The ways L_t, C_t and H_t vary with the lightness, chroma and hue angle of the standard are illustrated in graphs 1 and 2.

As part of his M.Sc. project at UMIST, Mr. D. P. Oulton of Salford College of Technology, developed a program for pass/fail judgements to be run on an Apple II microcomputer which has been interfaced with a Macbeth 2020 measuring head (5). This program enables ΔE_t to be obtained either by direct measurement of standard and sample or by typing in values for XY and Z from the keyboard, and was used in the two investigations described below.

Comparison of ΔE and ΔE_t tolerances for 4 shade sets.

In order to test his program Oulton used 4 sets of polyester/cotton sheeting samples around 4 standards, kindly supplied by Dorma Sheets Ltd., (5). Seven observers were asked to look at each set in turn under a daylight tube in a matching cabinet and classify each sample as pass, borderline pass, borderline fail or fail against the standard. The average results for the panel were then compared with ΔE(CIELAB) and ΔE_t (JPC 79) values (tables 1-4). Optimum tolerance levels for ΔE and ΔE_t were determined, and it is clear that ΔE gives better agreement with the panel average than ΔE_t. This is true whether a single number is selected for all 4 shades (table 5), or a variable tolerance is set according to the shade (table 6).

TABLE 5

Number of Disagreements for Fixed Tolerance Levels

(ΔE and ΔE_t)

Tolerance / Shade	ΔE_t 1.2	ΔE_t 1.4	ΔE_t 1.6	ΔE 2.0	ΔE 2.2	ΔE 2.3
Red	2	2	4	3	1	1
Dark Brown	9	6	2	3	2	2
Green	0	1	1	0	0	0
Blue	2	0	0	3	2	0
TOTAL	13	9	7	9	5	3

The reason ΔE_t shows up as worse than ΔE when used as a pass/fail tolerance limit in this restricted set of shades is entirely due to its performance for the Dark Brown shade. In this instance some large ΔE_t values were obtained for visual passes because of the exageration of hue differences in the JPC 79 formula. This caused ΔE_t to be larger than ΔE in 5 cases out of the 24. From this it would appear that the panel of 7 observers, some of whom have had experience as industrial colourists, are not as critical of hue differences as the J and P Coats colourists.

When the performances of the individual members of the panel were assessed it was clear, as is well established, that no single colourist produced as few disagreements with the measured colour differences as the average result of the panel did. The observer with the most disagreements (C.J.H.), was found to have a bias towards passing shades which were darker (fuller) than the standard, since from his industrial experience he was aware that these could not be readily corrected by making additions to dye to the dyebath. This provides evidence of the need to be able to include a bias into tolerance ellipsoid specifications (6).

Comparison of ΔE and ΔE_t over a range of 78 shades.

Since we at UMIST do not have access to a large bank of pass/fail information as would be available in a commercial dyehouse, a student project was devised which used numerical values for the standards instead of physical samples (7). This was based on measurements of the colour of 78 standards which consisted of coloured cards covering a wide range of lightness, chromas and hues. The values of X, Y and Z of the standards were varied in turn to provide simulated samples. It was decided to change each tristimulus value such that ΔE_t was approximately 1 in each case. This was done by trial and error. ΔE was recorded in each case and $\Delta E / \Delta E_t$ calculated. The way the ratio changed with lightness, chroma and hue of the standard was then studied.

The results are given in tables 7-9, and illustrated in graphs 3-7. From these it can readily be appreciated that the most significant factor over a broad range of colours is the chroma of the standard. Variation in the lightness of the standard appears to have little, if any, effect on the ratio of ΔE to ΔE_t. The relationship with the hue angle of the standard is more complex, with H_t having minima of 55° and 280°. However, it seems likely that a bias factor in favour of hue <u>differences</u>, and independent of hue <u>angles</u> is most appropriate. In this respect the colour difference equation proposed by McLaren and McDonald viz:

$$\Delta E = \frac{\left[(\Delta L)^2 + (\Delta C)^2 + (2\Delta H)^2\right]^{\frac{1}{2}}}{1 + 0.018C} \qquad \text{(CIELAB UNITS)}$$

appears to be a simple and valuable alternative (8, 9).

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1. McLaren and Rigg, JSDC, <u>92</u>, (1976), 336.

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TABLE 1

RED COLOUR DIFFERENCE AGAINST STANDARD

SAMPLE NO	PANEL CLASSIFICATION	ΔE	ΔEt	ΔEt COMPONENTS ΔLt	ΔCt	ΔHt
2	PASS	1.89	1.04	0.79L	0.46B	0.49B
3	"	2.07	1.22	0.96L	0.06S	0.74B
5	"	2.12	1.05	0.16F	1.00D	0.27B
7	"	0.66	0.35	0.30F	0.17D	0.07S
14	"	0.66	0.36	0.33L	0.08S	0.12B
15	"	1.57	0.87	0.61F	0.45D	0.44B
1	BORDER PASS	1.56	0.78	0.42L	0.66B	0.08S
6	" "	1.52	0.91	0.40F	0.47D	0.67B
12	" "	1.59	0.81	0.06S	0.74B	0.32B
13	" "	1.42	0.74	0.09S	0.64B	0.36Y
4	BORDER FAIL	3.73	1.99	1.94L	0.30D	0.35B
8	" "	2.70	1.39	0.89L	1.04B	0.21Y
11	" "	1.61	0.79	0.42L	0.67B	0.04S
9	FAIL	2.92	1.49	0.76F	1.17B	0.51Y
10	"	2.93	1.49	0.78F	1.16B	0.52Y

Hue subscripts B = bluer Y = yellower S = same Hue

Chroma subscripts B = brighter D = duller S = same

Lightness subscripts L = Lighter F = Fuller S = Same

TABLE 2

DARK BROWN COLOUR DIFFERENCE AGAINST STANDARD

SAMPLE NO	PANEL CLASSIFICATION	ΔE	ΔEt	ΔEt COMPONENTS ΔLt	ΔCt	ΔHt
2	PASS	1.35	1.48	0.57F	0.30B	1.33G
4	"	1.19	1.09	0.54F	0.32B	0.90G
16	"	0.87	0.50	0.46F	0.18B	0.10S
20	"	1.22	0.70	0.67F	0.01S	0.21G
23	"	1.42	1.46	0.31F	0.80B	1.18G
24	"	0.92	1.12	0.26L	0.37B	1.02G
1	BORDER PASS	1.26	1.27	0.11F	0.78B	0.99G
3	" "	1.76	1.22	0.80F	0.68B	0.62G
8	" "	1.76	1.41	0.86F	0.38B	1.05G
13	" "	2.16	1.80	0.97F	0.66B	1.37G
14	" "	2.03	1.53	1.04F	0.29B	1.08G
15	" "	2.33	1.39	1.27F	0.04S	0.55G
21	" "	1.53	2.01	0.08F	0.76B	1.86G
5	BORDER FAIL	3.13	1.76	1.67F	0.55B	0.11R
6	" "	2.46	2.10	0.42F	1.58B	1.32G
7	" "	2.03	1.85	0.34F	1.27B	1.30G
9	" "	2.37	1.71	0.79F	1.33B	0.74G
10	" "	2.90	2.24	1.22F	1.23B	1.41G
18	" "	2.34	2.26	0.52L	1.32B	1.76G
22	" "	2.56	1.66	1.13F	1.10B	0.54G
12	FAIL	3.16	2.38	0.03S	2.21B	0.87G
11	"	3.49	2.51	0.42L	2.39B	0.64G
17	"	2.73	1.92	0.48L	1.81D	0.42R
19	"	3.56	3.35	0.13L	2.33B	2.40G

Hue subscripts G = Greener R = Redder

TABLE 3

GREEN COLOUR DIFFERENCE AGAINST STANDARD

SAMPLE NO	PANEL CLASSIFICATION	ΔE	ΔEt	ΔEt COMPONENTS ΔLt	ΔCt	ΔHt
1	PASS	1.67	1.00	0.43F	0.64B	0.63Y
2	"	1.25	0.96	0.24L	0.07S	0.93Y
3	"	1.20	0.73	0.35F	0.35B	0.53Y
5	"	1.52	0.90	0.44L	0.51D	0.60Y
6	"	0.77	0.61	0.07S	0.13B	0.59Y
7	"	0.90	0.64	0.23L	0.09S	0.60Y
8	"	0.90	0.51	0.31L	0.20B	0.35Y
4	BORDER FAIL	2.64	1.25	1.03F	0.59B	0.37Y
10	" "	2.55	1.91	0.01S	0.90B	1.69Y
13	" "	4.44	2.30	1.78F	0.17B	1.45Y
9	FAIL	2.76	2.28	0.13F	0.06S	2.27Y
11	"	6.23	3.13	2.54F	0.62D	1.73Y
12	"	5.39	3.33	0.82F	2.65B	1.84Y
14	"	3.53	2.22	0.62F	1.61B	1.39Y
15	"	3.32	2.26	0.98F	0.03S	2.04Y
16	"	6.19	3.38	1.43F	3.05B	0.33Y
17	"	4.27	2.34	1.10F	1.93B	0.75Y

Hue subscripts Y = Yellower B = Bluer

TABLE 4

BLUE COLOUR DIFFERENCE AGAINST STANDARD

SAMPLE NO	PANEL CLASSIFICATION	ΔE	ΔEt	ΔEt COMPONENTS ΔLt	ΔCt	ΔHt
9	PASS	1.43	0.70	0.67L	0.10D	0.19G
10	"	0.52	0.25	0.25F	0.01S	0.03S
11	"	1.72	0.85	0.79L	0.15D	0.28R
12	"	0.46	0.32	0.11L	0.16B	0.25R
13	"	1.67	0.85	0.77L	0.20B	0.30R
14	"	1.21	0.61	0.48L	0.32D	0.18R
15	"	0.57	0.43	0.13L	0.12B	0.39R
16	"	0.67	0.46	0.21L	0.07S	0.40R
17	"	0.77	0.42	0.24L	0.34B	0.07S
18	"	0.35	0.19	0.11F	0.14D	0.07S
6	BORDER PASS	2.24	1.23	0.97F	0.16B	0.75R
7	" "	2.21	1.16	0.99F	0.28D	0.54R
8	" "	2.01	1.25	0.80L	0.06S	0.96R
3	BORDER FAIL	3.63	1.89	1.63F	0.18B	0.94R
1	FAIL	3.52	1.97	1.41F	0.58B	1.25R
2	"	5.86	4.19	1.74F	0.83D	3.72R
4	"	4.05	2.15	1.33F	1.69D	0.01S
5	"	5.02	3.05	1.45F	1.93D	3.05G
19	"	4.05	2.78	1.31F	0.62D	2.37R
20	"	6.94	3.76	1.86F	3.24D	0.39G
21	"	6.36	4.18	1.46F	2.45D	3.05G

Hue subscripts G = Greener R = Redder

A PHYSIOLOGICALLY PLAUSIBLE COLOUR ORDER SYSTEM BASED ON THE CIE 1931 STANDARD COLORIMETRIC OBSERVER

by

R.W.G.Hunt (The City University) and
M.R.Pointer (Kodak Limited Research Division)

Summary

A physiologically plausible model of colour vision, based on the CIE 1931 standard colorimetric observer, is shown to provide a colour order system giving reasonably good predictions of the unique hue loci, of constant hue loci, and of constant saturation loci, as judged by comparison with the Munsell and NCS systems, for daylight illumination. When combined with a chromatic adaptation transform of the Von Kries type, the model is also shown to give quite good predictions for real surface colours seen in daylight (D_{65}) and in tungsten light (S_A) illuminants. For pseudo-surface colours it is shown that a transform of the Nayatani type gives better predictions than those given by a Von Kries type.

Introduction

To be able to make reasonably accurate quantitative predictions of the appearance of colours is an important requirement in the fields of lighting, and of the reproduction of colours in pictures. It is also a requirement to be able to make such predictions for illuminants of different colours. A recent model of colour vision (Hunt, 1982) provided a basis for predicting colour appearance that was in good accordance with the Munsell and NCS colour systems, for a daylight illuminant. This paper summarizes work carried out to extend the model so as to provide predictions of colour appearance for a tungsten light illuminant in addition to a daylight illuminant. Extension to illuminants of other colours, and to cover the effects of changes in the intensities of the illuminants, and in the nature of the surrounds to the arrays of colours viewed, are also required; but the great importance of daylight and tungsten light illuminants justifies an initial study confined to them. In extending the model to these illuminants, the opportunity has been taken to use the CIE 1931 standard colorimetric observer; this results in a model that is more readily applicable to practical colorimetric problems than that based on the more physiologically-likely observer (Estevez, 1979) used in the original model.

The model

In this extended model, the cone spectral sensitivity curves used (for light incident on the cornea) are given by:

$$\begin{aligned}
\bar{r}(\lambda) &= 0.4708\bar{x}(\lambda) + 0.8324\bar{y}(\lambda) - 0.0951\bar{z}(\lambda) \\
\bar{g}(\lambda) &= -0.2681\bar{x}(\lambda) + 1.3809\bar{y}(\lambda) + 0.0542\bar{z}(\lambda) \\
\bar{b}(\lambda) &= 1.0000\bar{z}(\lambda)
\end{aligned}$$

These curves are shown in Fig. 1, together with those used in the original model which they were designed to imitate as closely as possible.

The signal processing scheme consists of the formation of an achromatic signal, A, and three colour difference signals, C_1, C_2, and C_3, as follows:

$$\begin{aligned}
A &= 2R^{\frac{1}{2}} + G^{\frac{1}{2}} + (1/20)B^{\frac{1}{2}} \\
C_1 &= R^{\frac{1}{2}} - G^{\frac{1}{2}} \\
C_2 &= G^{\frac{1}{2}} - B^{\frac{1}{2}} \\
C_3 &= B^{\frac{1}{2}} - R^{\frac{1}{2}}
\end{aligned}$$

This scheme is the the same as that used in the original model, except that A was then equal to R + G. It is now considered more physiologically plausible for the signals comprising A to be added after their compression by the power law (with exponent of $\frac{1}{2}$) than before; the constants, 2 and 20, are to allow for the probability that there are about twice as many R cones, and about one twentieth as many B cones, as G cones, in the retina (Walraven and Bouman, 1966). The following criteria are used:

Achromatic colours	$C_1 = C_2 = C_3 = 0$
Constant hue	$C_1 : C_2 : C_3$ in constant ratios
Unique red	$C_1 = C_2$
Unique green	$C_1 = C_3$
Unique yellow	$C_1' = 0$
Unique blue	$C_1'' = 0$

Blueness-Yellowness	$M_{BY} = \frac{1}{2}(10/13)(C_3 - C_2)e_s/4.5$
Redness-Greenness	$M_{RG} = (10/13)(C_1 - C_2/7)e_s$
Colourfulness	$M = (M_{BY}^2 + M_{RG}^2)^{\frac{1}{2}}$
Saturation	$s = M/(R^{\frac{1}{2}} + G^{\frac{1}{2}} + B^{\frac{1}{2}})$
Chroma	$C = s\left[116(A + M)^{\frac{2}{3}}/A_n^{\frac{2}{3}} - 16\right]$
Brightness	$Q =$ a function of $A + M$

where $C_1' = R^{\frac{1}{2}} - (8G^{\frac{1}{2}}/7 - B^{\frac{1}{2}}/7)$ and $C_1'' = R^{\frac{1}{2}} - (5G^{\frac{1}{2}}/4 - B^{\frac{1}{2}}/4)$, and represent inhibition of the $G^{\frac{1}{2}}$ signal by the $B^{\frac{1}{2}}$ signal; e_s is the eccentricity function used in the original model; and A_n is the value of A for the reference white considered. These criteria are all the same as in the original model except for a slight change in C_1' by the use of 8 and 7, instead of 12 and 11, as the constants: this change has been introduced to result in predictions of unique yellow that agree better with a wider range of data than that used previously.

Predictions from the model

In Fig. 2 the spectral luminous efficiency curve based on $A = 2R^{\frac{1}{2}} + G^{\frac{1}{2}} + (1/20)B^{\frac{1}{2}}$ is shown; it is similar to the CIE $V(\lambda)$ curve (although higher around 600nm) and lies within the spread of experimental results for such curves.
In Fig. 3 the predicted hue lines and saturation contours are shown and are seen to be similar to those of the NCS system, except for the prediction of a redder unique yellow locus (which is intentional, in order to fit other data, as will be considered later). In Fig. 4 the predicted hue lines and saturation contours are compared to those of the Munsell system (at Munsell Value 5) and are seen to be similar (although there is some under-estimation of Munsell Chroma for purples and some over-estimation of Munsell Chroma for yellow-greens).

Chromatic adaptation

The model, normalized for Standard Illuminant S_C, has been used with four different types of chromatic adaptation transform, to predict hue and colourfulness for Standard Illuminants D_{65} and S_A. These predictions have been compared with eighteen sets of experimental data for colours scaled for hue and colourfulness (or saturation or chroma) in illuminants having the same chromaticities as Standard Illuminants D_{65} and S_A. The sets of data used were the same as those used in a previous study (Pointer, 1982).

A criterion of goodness of fit for the predictions was derived as follows. For each data set, the relationship between the predicted hue, H_p, and the scaled hue, H_s, was expressed as a linear equation:

$$H_p = a_H H_s + b_H$$

using a least-squares criterion to determine the values of a_H and b_H. In a similar way the relationship between the predicted colourfulness, M_p, and the scaled colourfulness, M_s, was expressed as:

$$M_p = a_M M_s + b_M$$

A perfect prediction requires that a_H and a_M be equal to unity, and b_H and b_M be equal to zero. A good fit was then defined as one in which $a_H = 1 \pm ta$ and $b_H = 0 \pm tb$, where a and b are the standard errors in determining a_H and b_H, respectively, and t was set by the number of degrees of freedom (number of samples - 2) for each data set, and a probability level of 0.05; similar criteria were used for a_M and b_M.

The four different types of chromatic adaptation transform used were as follows: VK (Von Kries type, in which R, G, and B are multiplied by factors that give equal results for all illuminants); CJB (Bartleson, 1979); YN (Nayatani, Takahama, and Sobagaki, 1981); and KR (Richter, 1980). In analyzing the results, a distinction was made between data sets that had been obtained with real surface colours, and those that had been obtained with pseudo-surface colours (usually self-luminous colours with surrounds). The results of the analysis are shown in Table I, together with those obtained by using a Munsell type of hue and chroma grid (for S_C) with the same four transform It was found that, for real surface colours, the model together with the Von Kries transformation gave the highest proportion of good predictions yet obtained in our studies (6 out of 10 for D_{65}, and 7 out of 10 for S_A). For pseudo-surface colours the Nayatani transform with either the model or the Munsell grid gave the best results (7 out of 8 for D_{65}, and 4 out of 8 for S_A). In Fig. 5 the unique hue loci and a high saturation contour are shown for the model with each of the four different transforms: it is clear that the Von Kries transform is rather different from the other three in that its saturation contour is compressed in the blue-yellow direction. The analysis summarized in Table I indicates that this type of compression is appropriate for predicting the appearance of real surface colours in tungsten light, at least for the viewing conditions used in obtaining the eighteen sets of data considered.

Conclusions

A physiologically plausible model of colour vision, based on the CIE 1931 standard colorimetric observer's colour matching functions, when combined with a Von Kries chromatic adaptation transform, gives quite good predictions of the colour appearance of real surface colours seen in daylight (D_{65}) and tungsten light (S_A) illuminants.

TABLE I Number of data sets for which good predictions were made.

	Real colours		Pseudo-surface colours	
	D_{65}	S_A	D_{65}	S_A
Model + VK	6	7	7	0
CJB	7	1	7	3
YN	7	2	7	4
KR	4	1	7	2
Munsell + VK	4	3	6	2
CJB	4	3	7	1
YN	3	2	7	4
KR	2	3	7	2
Maximum	10	10	8	8

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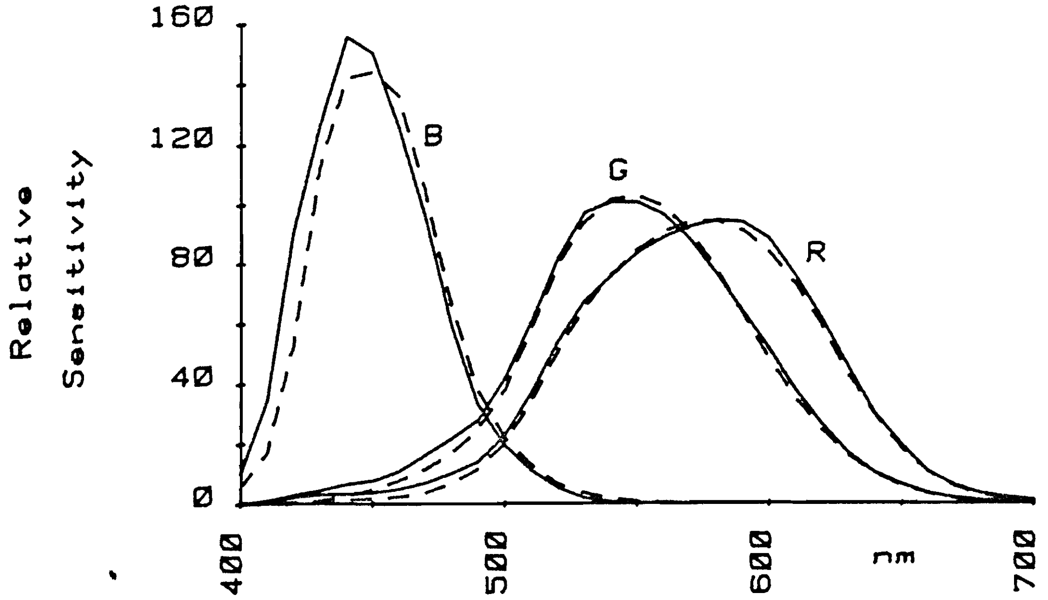

Fig. 1 Cone spectral sensitivities (for light incident on the cornea). Full lines: as used in the original model (after Estevez, 1979). Broken lines: as used in this paper, based on the CIE 1931 standard colorimetric observer

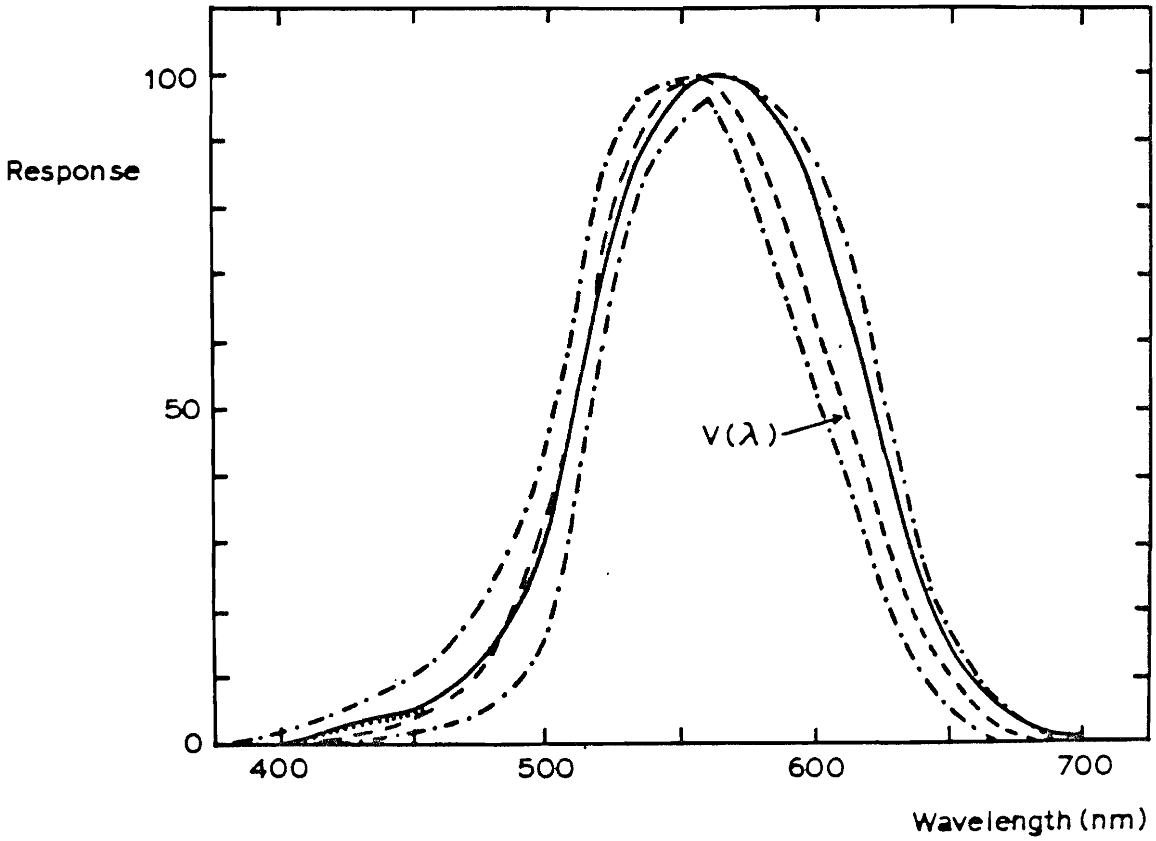

Fig. 2 Relative spectral efficiency curves. Full line: based on an achromatic signal $A = 2R^{\frac{1}{2}} + G^{\frac{1}{2}} + (1/20)B^{\frac{1}{2}}$, plotted as A^2 and normalized to give a maximum of 100 (it is necessary to plot A^2, not A, because these functions all relate to intensities of stimuli, not of visual signals). Broken line: the CIE V(λ) curve. Dotted line: Judd modification of the V(λ) curve. Dot-dash lines: the range of curves found for individual observers.

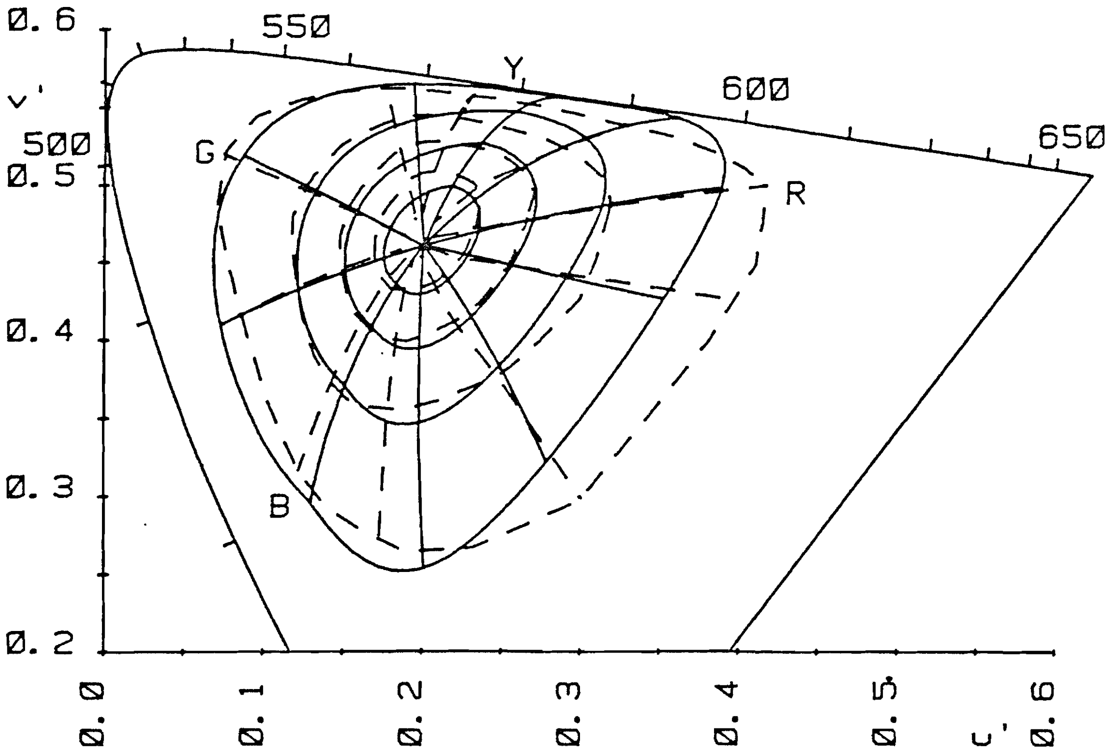

Fig. 3 Hue and saturation loci. Full lines: predicted by the model. Broken lines: for the NCS system.

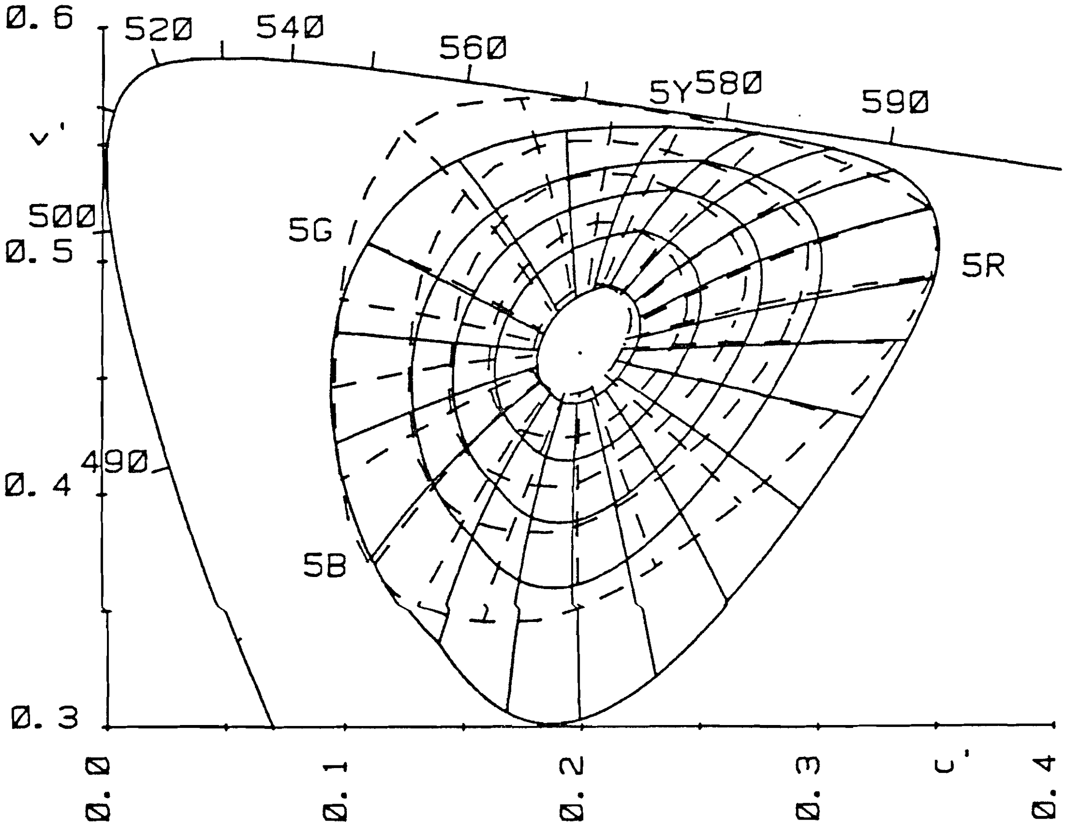

Fig. 4 Hue and chroma loci: Full lines: predicted by the model. Broken lines: for the Munsell system at Munsell Value 5, for Munsell Chromas 2, 4, 6, 8, and 12.

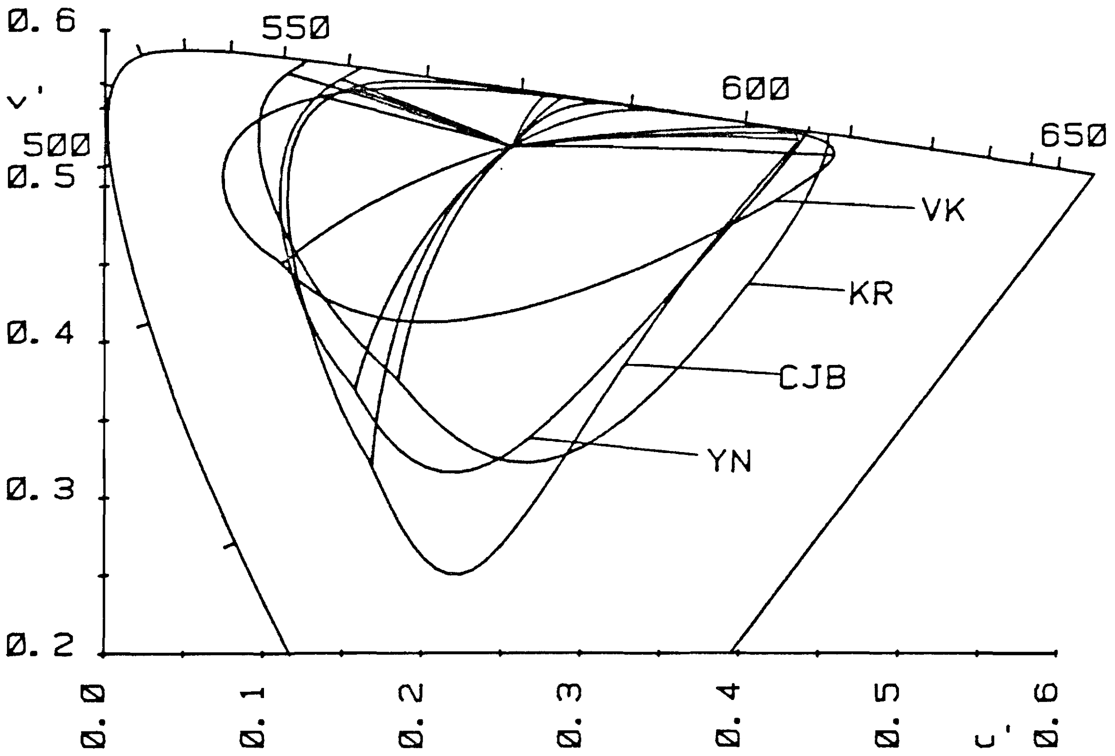

Fig. 5 Hue loci and one saturation contour, as predicted by the model for tungsten light (S_A) using four different chromatic adaptation transforms: VK (Von Kries type); CJB (Bartleson); YN (Nayatani); KR (Richter).

Paper at the Forsius Symposium
on COLOR ORDER SYSTEMS
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Anders Hård
Lars Sivik

DISTINCTNESS OF BORDER AS A CONCEPT FOR A UNIFORM COLOR SPACE

The R&D-work of the despriptive color system NCS (Hård & Sivik, 1978) consisted of a phenomenological analysis of color as appearance, together with extensive and well controlled experiments which were carried out in order to

1... demonstrate how observers with surprisingly high accuracy are capable of scaling colors psychometrically, in terms of **resemblance** to the imaginary elementary colors, without any other help than their eyes.

2... establish despriptive color notations of colors by psychometric scaling of that kind. The NCS descriptive color space was thus defined without relating it to any physical definitions of stimuli used.

3... co-relate the NCS psychometric color space with physically based specifications of color stimuli (for example CIE). It must be noted, however, that such a psychophysical relationship is true only under specific viewing and lighting conditions.

4... produce a number of color samples that illustrate the NCS color-describing system. These constitute the NCS Color Atlas (Swedish Standard, 1978). The Atlas and other collections of samples published by Scandinavian Color Institute are specified according to CIE with certain tolerance values compared to the nominal NCS-notations given.

5... make clear that the NCS color ordering and notation system does not rely on its samples but can be used to identify and specify in descriptive terms the color of an object in an arbitrary situation.

6... show that the difference between two colors - either two different color objects under the same viewing conditions, or the same color object under different conditions (e.g. different illuminations) - can be determinened by the difference in NCS- notations.

However, when studying the problem of "color difference" we found this to be a very ambiguous concept. Many unanswered questions appeared regarding the perception and conceptualization of color differences and to begin with we have concluded that we have to consider at least two different aspects of perceptual interpretation as response to a stimulus difference. (This is easily demonstrated and should have been obvious for all who have studied color differences: When giving observers the instruction to judge or estimate "the color difference" between two colors there are alway some "naive" persons who ask "What kind of difference? What do you mean?". This indicates of course that color difference is multidimensional as a phenomenon and not only as regards the stimulus.

One of the aspects of difference concerns the way the perceptual system "detects" an object, how the objects are differentiated and seen against their surroundings by color-discrimination.

The other aspect concerns the fact that by identifying the specific color of an object we receive information of the object. This was in fact indicated in W.D. Wright´s lecture 1966 in Luzern and before that we have found the same kind of philosophy in S.A. Forsius´ book Physica, 1611.

We have named these two kinds of interpretation:

A. the discriminative or distinguishing, and
B. the identifying/informative aspects of color perception.

The R&D-work of NCS was mainly dealing with type-B questions. The basic goal for the NCS project was to create a color notation system, and an atlas, in order to supply a need regarding color communication in environmental design.

When we started to study the use of color in art and design - in order to find a basis for a "color combination theory" (Hård & Sivik, 1975) - we found, however, that the type-A aspects were also of essential importance. One can notice, for example, in a complex visual field how two color elements, juxtaposed with a border in common, sometimes seem to almost fuse together, in spite of the fact that they may be very different. In other words, a colored field or object is hardly seen at all against some background colors and very distinctly against others. This may seem a banal statement and the phenomenon is well known indeed. But as a matter of fact it is not sufficiently explained and certainly not adequately accounted for by the existing color-difference equations recommended by CIE. We have tested several of them from just that point of view - with poor results.

Our further analysis of the phenomenon finally led us to the concept of "distinctness of border" which previously had been studied by Boynton, Kaiser and others (e.g. Boynton, 1973). We found that this definition of a color difference was useful also in our studies which concerned attributes of the "color-gestalt". Here, for example, we noticed that the formation of total surface patterns was dependent on the border-distinctness between adjacent color elements.

Consequently we started to examine the nature of distinctness of border, mainly in order to elucidate its relationships with other color parameters, and those of the NCS in particular. From a forthcoming report about these experiments we will here extract and pinpoint some of our findings.

1. First of all we could confirm that distinctness of border (DB) is a unidimensional visual phenomenon, which our observers were able to estimate - seemingly without caring about the identity of the two colors involved.

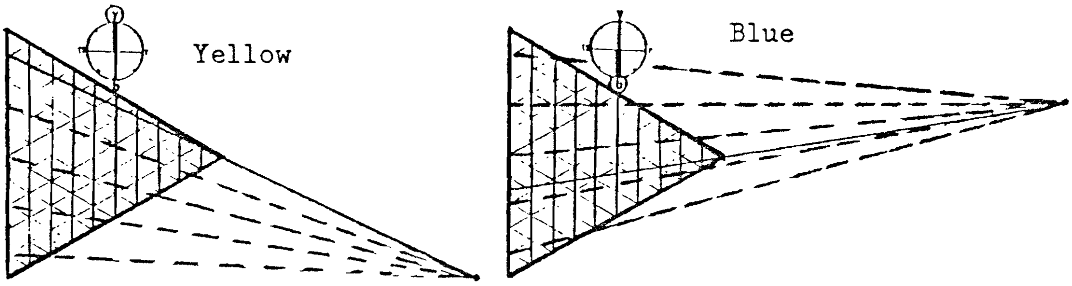
2. The observers were also able with high accuracy to quantify DB by a number, from an instruction saying that DB=0 when they do not see any border at all, and DB=10 for the most distinct border they can imagine. (All of these axperiments were carried out with pairs of object-colors, with one border in common.)

3. In comparison with the scale from black to white, or lightnes-scale, (the only one in NCS - or any other color space we know of that is phenomenologically unidimensional) it was found that constant difference in NCS blackness (s) resulted in a constant DB, independent of the position along the blackness scale of the blackness-interval. No statistically significant deviation from this was found.

For achromatic colors we have determined the relationship between Y_{CIE} and NCS blackness to

$$s = 100-156Y/(Y+56) \qquad (1)$$

4. Also for chromatic color-pairs, where the hue and the chromaticness was kept constant, the same uniform relationship between DB and blackness-difference was found. As lines for constant Y are convergent in the NCS constant hue triangle for pairs of this kind, the s-value above has to be reduced with a constant <1 depending on chromaticness and the convergence which varies with the hue (fig. 1). From this we conclude that a given difference in reflectance factor Y will show a lower DB for two chromatic colors than for two achromatic ones.



Figur 1.

5. DB was found to vary with difference in NCS blackness according to a power function. In our latest series of experiments with achromatic pairs where the difference in blackness varied from 0.3 to 82 NCS units, the following function was arrived at:

$$DB = 2.5(\Delta s-0.4)^{0.4} \qquad (2)$$

where 0.4 within the paranthesis represents the threshold. The average confidence interval for 20 observers on the 0.05-level was 0.35.

In fact, the NCS blackness-scale shows perceptually uniform differences not only with respect to blackness s, (and whiteness w), but also with respect to the "contrast" phenomenon defined as distinctness of border DB (the DB being a power function of Δ s).

The most spectacular result, however, seems to be that this equation of prediction (2) has a correlation with the observed data of 0.9958!!!

6. From a series of pilot experiments, reported at the AIC Midterm Meeting in Tokyo, (Hård, 1979), we found it most probable that the relationship between DB and differences in NCS chromaticness c, and hue φ, also may be descibed by some power function. A tentative equation was set up and tested against available observation data, which however were too few for general conclusions.

7. We now considered it worthwhile to perform a broader investigation. 20 observers estimated DB of 272 different pairs of object-colors, spread all over the NCS color space. The DB observed varied between 0.11 and 8.5. For all the pairs were also calculated the differences in NCS blackness Δs, chromaticness Δc, and hue $\Delta\varphi$, derived from instrumental measurements. By a multiple regression analysis we finally found an equation for prediction of DB from NCS differences:

$$DB = 2.5(\Delta s^{*}-0.4)+0.46(\Delta c-0.6)+0.73(c/100\,\Delta\varphi-0.6)^{0.4} \qquad (3)$$

(Figures within paranthesis represent tentative thresholds and c/100 means that has to be corrected for chromaticness; Δs^{*} is a blackness difference derived from lightness difference).

The average confidence interval for observed data was 0.39 which includes all possible reasons of variation in the results. The above equation may be interpreted so that the "stimulus" for perceived DB is a power function of the sum of differences in the three NCS dimensions.

Also here there was a remarcable correlation between the observed data and those predicted by the equation: 0.9666.

CONCLUSIONS

I. From the multidimensional phenomenon of color difference between two given colors we have chosen one of its aspects, distinctness of border (DB), and designed a psychometric scaling procedure which have proved to give reliable and significant data. It was now possible to correlate such DB-data with the various difference-data from other NCS parameters by which the actual colors were identified.

II. We have assumed that distinctness of border DB is one relevant concept for expressing the visual phenomenon of color contrast. This kind of contrast must be of tremendous importance for our visual perception of the environment as it is crucial for how we see patterns, and contrasts, and figure-ground relations.

The experimental results were compressed into an equation of good validity, by which the DB is predicted from the NCS descriptions of the two colors that form the contrast. This equation represents a DB-color-difference space and is of a city-block type with a power function. This implies that a perceived difference, defined as distinctness of border, cannot be represented as a distance between two points in a eucledian coordinate system.

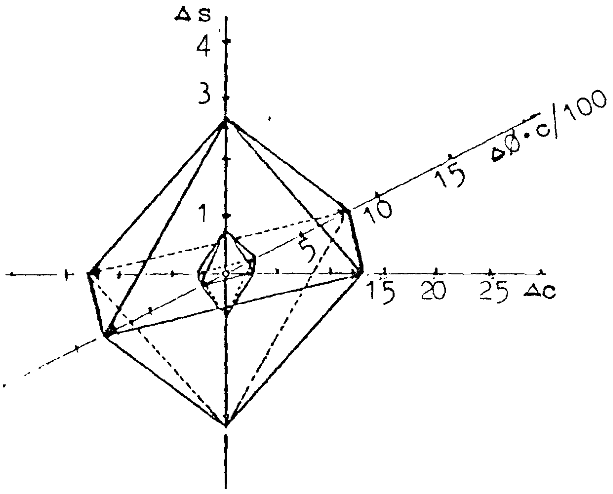


Figure 2.

In figure 2,. above, is shown how 8 triangular planes represent the loci of all points of constant DB from the central point. The three coordinate axes represent differences in NCS blackness (Δs); chromaticness (Δc); and hue (Δφ). The axes are scaled in accordance with the equation. The smaller "space" represents DB=1 and the larger DB=2.

III. In comparison with other equations for predicting color differences and their reported correlations with observed data we consider our correlation of 0.97 remarcably high. In studies by Kuehni correlation values are reported not better than 0.76 for the best color difference equation (CIELAB). And for the OSA-UCS, published by McAdam, the unweighted correlation between calculated and observed data is only 0.64.

As the aim of all these equations is to predict the perceived difference (defined in one way or another) from the given stimulus difference, it must be of of major interest to know the accuracy of the predictions. Using the statistic "index of forecasting efficiency" E, (Guilford 1973):

$$E = 100(1-\sqrt{1-r^2})$$

For the above mentioned studies, E will be

Study	E
Hård-Sivik DB (total)	0.76
" (achromatic colors)	0.91
Kuehni, CIELAB	0.35
OSA-UCS	0.23

The predictive values above of the CIELAB and the OSA-UCS equations for color differences are not very impressive compared with that of the DB. The reason is, of course, that they try to grasp the whole multidimensionality at one mouthful, while the DB equation only deals with one of the aspects of color difference. It seems to us a promising possibility to solve the notorious problem of color difference if we could identify the relevant visual dimensions of this phenomenon. Studying one perceptual and psychometric dimension at the time and relating it to stimulus differences will provide far better psychophysical equations. We think that we have demonstrated this by our research on distinctness of border DB, which is one of many possible aspects of visual color difference. Measures of DB is probably the most relevant color difference dimension for some, well-defined applications - in other contexts there may be others. And the only way to identify them is by an analysis of the visual phenomenon as such.

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Uniform Color Scales of Optical Society of America

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Arrangements of colors in orderly sequences according to visually perceived attributes of color, such as hue, saturation, and lightness, are useful for storage and retrieval of color samples and facilitate assembly and examination of many varities of combinations of related or contrasted colors. Many systems of color arrangements have been devised and used for such purposes. Some of them have been found useful by various artists and designers. Rules or theories of color-scheme preference or harmony have been explained in terms of some such systems, and have even been derived from them.

Most color systems exhibit series (sometimes called "scales") of colors that are characterized by constancies of pairs of perceived attributes of color, such as hue and lightness (Munsell called the latter "value"), hue and saturation (Munsell's "chroma" is related to the latter), value and chroma, hue and tint, or hue and shade. In each such scale, a third attribute changes in an orderly way, e.g., chroma in the first case, value in the second, hue in the third, shade in the fourth and tint in the fifth.

In the development of some systems, efforts were made to provide perceptually equal changes of the third attribute (e.g., chroma) along each scale. More rarely, perceptually equal changes of one or of both of the constant attributes (e.g., hue) characterized the difference (e.g., of hue or value) from scale to neighboring scale throughout the system. Even though such "uniformity" of spacing of scales was not attempted in the design of a system, it is often taken for granted by users, who seem to feel that equality of cross-scale intervals should be incorporated.

The Committee on Uniform Color Scales was appointed in 1947 by the Optical Society of America[1] to study the possibility of producing a color system in which all color scales would have perceptually equal steps, with all cross-scale differences equal to those steps.

Dr. Deane B. Judd was chairman of that committee from its beginning until his death in 1972.

The Committee soon realized that a system that fulfills the requirements cannot be organized on the basis of any circular, spherical, cylindrical, or conical plan. That is for the same reason that the spokes of a wheel (homologous to scales of constant hue) are not equally distant from each other from hub to rim. Therefore, a scale from black to white cannot play a special, central, pivotal role in the system sought by the Committee. For the same reason, neighboring scales cannot be characterized by constant hue or saturation (chroma).

A plain cubic-lattice arrangement, with colors arranged as at the intersections of equally spaced, mutually orthogonal sets of planes would satisfy the requirements. With it, each color would be a member of three color scales and would have six equally different nearest neighbors (other colors). However, a slight modification of that arrangement - at the lattice points of a face-centered cubic crystal[2,3] permits each color to be a member of six different color scales, and to have twelve equally different nearest neighbors.

Instead of nomenclature or notations based on the cycle of hues and differences from gray (saturation or chroma), the Committee was forced to develop a notation that corresponds to a rectangular coordinate system. One of the variables, L is similar to Munsell value. It is, however, more closely related to the perception of lightness: highly saturated colors have lower luminance factors (CIE Y) than have grays of equal L, whereas colors of high chroma appear lighter than the gray that has the same Munsell value (equal Y).

The other two descriptors of the OSA/UCS colors are j (the initial of the French word jaune for yellow, to avoid confusion with the CIE chromaticity coordinate y) and g (qualitatively referred to as green). Negative values of j are qualitatively referred to as blueness, and negative values of g indicate the complementary bluish-redness.

In the OSA/UCS system, every color is identified by numerical specifications of the three quantities L, j, g, which are explicitly defined[4] in terms of the CIE values Y, x, y. Each of those quantities may be specified to any desired degree of precision. All gray colors have j = 0, g = 0. Lightness, L, ranges from -7 to +7 (which, for grays, correspond to Y = 3.75 percent and Y = 98 percent, respectively). A medium gray (with luminance factor Y = 30 percent) that was used as the background for all of the judgements on which the OSA/UCS Committee based its system has L = 0.

To select colors at the lattice points of a face-centered cubic arrangement, the Committee specified all that could be produced with permanent pigments in an acryllic paint,[5,6] with combinations of even-integer values of L, j, g and with combinations of odd integers. Any of the integers could be either positive or negative. Zero values were considered even. The Committee calculated[7] the corresponding CIE values Y, x, y by itterative use of the nonlinear formulas[4] for L, j, g in terms of Y, x, y.

In order to produce equally perceptible steps, whether or not they involve lightness differences, units of L are represented by (vertical) distances $\sqrt{2}$ times longer than (horizontal) units of j and g in the Committee's uniform color space[4]. Consequently, in terms of the Committee's unit of color difference, the difference between any two colors (whether or not of the Committee's set) is

$$\Delta E = \sqrt{2(\Delta L)^2 + (\Delta j)^2 + (\Delta g)^2}.$$

Application of this formula to the Committee's rule for selection of its basic set of colors shows that the difference between all pairs of nearest neighbors is $\Delta E = 2$. The 424 colors of the basic set can form 2058 such pairs.

The Committee also obtained 134 extra colors that bisect all 2-unit color differences in the range $-2 \le L \le 2$, $-2 \le j \le 2$, $-2 \le g \le 2$. Some of the extra colors have mixed sets of even and odd values of L, j, g. Others have half-integer values from -3/2 to +3/2. Included in the extra 134 are eight colors that have $L = \pm 1/2$, $(j = \pm 1/2, g = \pm 5/2)$ or $L = \pm 1/2$, $(j = \pm 5/2, g = \pm 1/2)$, with which a cubo-octahedium of half steps can be completed. Together with the colors of the basic set in the range

$$-2 \le \begin{pmatrix} L \\ j \\ g \end{pmatrix} \le 2,$$

the extra colors provide for 740 pairs that have $\Delta E = 1$. The half-integer colors also provide 138 pairs of colors for which $\Delta E = 2$, in addition to the 2058 pairs provided by the basic set of 424 colors.

The sides of the unit cell of the face-centered cubic lattice[3] correspond to $\Delta E = 2\sqrt{2}$. The height of that unit cell spans two units of L, i.e., from one even value to the next even value, or from one odd value to the next odd value. The Committee's original description[4] of its system as a regular rhombohedral crystal lattice involved unit cells (regular rhombohedra) whose side lengths correspond to $\Delta E = 2$, which is the step length throughout the OSA/UCS system. Each rhombohedral unit cell spans only one unit of L.

The twelve nearest neighbors of any point (color) are corners of a cubo-octahedron - a cube (as big as the unit cell of the face-centered cubic lattice, but displaced one-half of a side length, $\Delta E = \sqrt{2}$, on all three axes) with its eight corners cut away to leave equilateral triangular faces that have their corners at the midpoints of the 12 edges of the cube[8,9]. Those midpoints, which are the corners of equilateral triangular faces of the cubo-octahedron, are the points that represent the twelve nearest neighbors of the color that is represented by the center of the original cube.

The top surface of the original cube is at one unit greater value of L than the center (color). The bottom surface of the original cube is at L one unit less than the center. The corners of the top and bottom surfaces of the original cube are at $j \pm 2$, $g \pm 2$, where j and g are those of the central color. The midpoints of the twelve edges of the original cube are at $(L, j \pm 2, g \pm 2)$ and $(L \pm 1, j \pm 1, g \pm 1)$ which are consistent with the rules for selection of the OSA/UCS colors.

A model that displays all of the OSA/UCS colors in the space-lattice arrangement will be portrayed at the Forsius Symposium. Charts that display the colors and scales that appear in 30 typical cross sections (cleavage planes) through the lattice will also be exhibited.

In total, more than 80 such charts can be assembled from the 424 basic OSA/UCS colors, and 35 more from the 134 half-step colors combined with the intermediate and immediately surrounding colors from the basic set.

With the basic set of colors, scales characterized by constant values of L (from -7 to +5) can be assembled in 13 charts. They correspond to horizontal cleavage planes in the model. Scales with constant values of j and g intersect at right angles in those charts. Other scales with larger but equal steps can be selected at other angles, e.g. 45°, with step size $2\sqrt{2}$.

Scales of L for about 100 combinations of j and g, including gray ($j = g = 0$) can be selected from alternate charts (for L even or L odd). The step sizes $\Delta L = 2$ in those scales are also $2\sqrt{2}$.

Eleven charts characterized by constant values of $j + g$ (from -8 to +12) can also be assembled. They correspond to parallel, equally spaced, vertical cleavage planes. They are parallel to two faces of the original cube. In nine of those planes, from 8 to 23 color scales appear, in each of which L varies and j or g varies so as to keep $L \pm j$ constant (as well as $j + g$ constant).

Thirteen charts with $j - g$ = constant can be assembled. They correspond to parallel, equidistant, vertical cleavage planes that are perpendicular to the vertical planes for $j + g$ = constant. Eleven of the charts for $j - g$ = constant display from 4 to 20 color scales all of which are different from any shown in the charts for constant L or constant $j + g$. Again L and j or g vary in each scale.

The 424 basic OSA/UCS colors can be arranged in 422 scales that consist of from 3 to 9 colors. They are all shown in the horizontal (L = constant) and vertical ($j \pm g$ constant) planes. Most of those color scales are of kinds that have not been shown in any color systems.

Four other sets of parallel, equally spaced cleavage planes occur in the space model of the OSA/UCS colors. Those planes are parallel to the four slanted, triangular, corner faces at the top (or bottom) of the cubo-octohedra. In each of those slanted cleavage planes, three sets of parallel, equidistant color scales intersect at angles of 60°. In any one of those planes, each color is surrounded by six nearest neighbors.

All color scales in the slant planes are exhibited also in the horizontal planes of constant L or in the vertical planes of constant j + g or constant j - g. The scales are merely arranged differently in the slant planes. Each of the slant planes has a set of equally spaced, parallel, horizontal color scales that appear in different constant L planes. Intersecting them at 60^{o} is a set of equally spaced, parallel color scales that appear in different vertical planes and have different values of j + g. Intersecting those scales and also the horizontal scales, both at 60^{o}, is a third set of equally spaced, parallel color scales from vertical planes that have different values of j - g.

One of the sets of slanted cleavage planes is characterized by L + j = constant. Another set, which corresponds to another triangular face of the cubo-octahedron, has L - j = constant. The third set has L + g = constant, and the fourth set has L - g = constant.

All equal distances in the L, j, g space correspond to perceptually equal differences, most of which include lightness differences as well as chromatic differences.

Examples of arrangements of the OSA/UCS colors in the seven kinds of cleavage planes will be exhibited and discussed at the Forsius Symposium. Some of them have been reproduced in color in references 10, 11, 12, and 13.

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THE ESTABLISHMENT AND MAINTENANCE OF ABSTRACT AND CONCRETE COLOR ORDER SYSTEMS

C. S. McCamy

Abstract

Color order systems must be distinguished from colorant order systems and other systematic ways of relating colored objects. Abstract systems require definition of dimensions and scales. Ostensive definition may be required. A concrete system is a collection of specimens exhibiting properties specified by the dimensions and scales of an abstract system, under specified viewing conditions. Since there is no unique embodiment, we seek to optimize properties and liberalize viewing conditions. Optimum objectives may change. The precise relationship between a colorimetric specification and a color order notation depends on the method of colorimetry or spectrophotometry and the method of computation.

Abstract Systems

A set of colorants may be mixed in various proportions to produce a wide gamut of colors. The results of such mixtures may be arranged in accordance with the proportions in the mixture. Such an arrangement is know as a "colorant mixture system" or "colorant order system".(1) Each such system is peculiar to the set of colorants chosen and the results may even depend on the method of preparation, mixing, and application of the colorants. This peculiarity of a set of colorants is clearly evident within one medium, such as paint, and is all the more apparent as we go from paints to dyes, inks, or other colorants. Thus, no one colorant mixture system is universally applicable.

We may select primary colored lights to be mixed in various proportions or primary colored surfaces to be presented as visual mixtures by means of a rotating sector-disk or unresolved fine pattern. These are "color mixture systems". The results, of course, depend on the primary colors chosen and the mixture scheme.

In the image sciences such as photography, television, color printing, and other multicolor display technology, arrays of colors may be produced by systematic variations of the parameters of the process, the results depending on the process. Full variations produce the possible gamut.

A "color order system" or "color appearance system" is quite different from all of these. It is a systematic arrangement of colors according to appearance. Unlike colorant order systems, color order systems are universally applicable to all normal observers. One can identify an array in which each color differs from each of its nearest neighbors by an equal amount, as was done by a committee of the Optical Society of America. One can organize color space according to uniform scales of the psychological attributes of color, as was done by A. H. Munsell.(2) There are other well-known systems that are in use and are well documented.(1) I will take the Munsell System, the one I know best and the one most widely used, to illustrate the issues that must be considered and resolved in any case. Munsell identified the three psychological attributes of surface color as hue, value, and chroma. The attribute he called "value" is more generally called "lightness" and his "chroma" is often called "purity" or "saturation". When a child is first taught the meaning of such words as "red" and "green", the only way the terms can be defined is by ostensive definition, i.e. by showing examples. The defintions of the psychological attributes ultimately depend on such definitions. Differences in hue and lightness are readily recognized by people with normal color vision and are commonly mentioned in everyday conversation by people untrained in color. Chroma is a slightly more abstruse concept, but is readily recognized once it is understood. It takes very little training to be able to compare two different colors and describe the qualitative difference in terms of differences in hue, value, and chroma. This is not the case with the OSA equispaced array. The transition from a color to a nearest neighbor often involves components of change in all three psychological attributes. Most observers resolve the difference into components of hue, value, and chroma. This illustrates the importance of the ease of comprehending a system intended for general use.

The three attributes are the three dimensions of the psychological color space. They are orthogonal; that is, independently variable. The hue scale is circular, in that a continuous hue progression returns to the starting point. Munsell represented colors in a cylindrical space with black at the bottom, white at the top, all neutral colors along a vertical central axis, hues arrayed at various angles about the axis, and chroma extending laterally outward from the neutral axis. He described a left-handed system. If the left thumb points in the direction of the positive V axis, the fingers point in the direction of increasing hue. People represent the system either left or right handed. The Color Tree available from The Munsell Color Company is left-handed. If the Munsell Book of Color is stood on edge, with pages spread, it embodies a right-handed system. When the Munsell System is mapped on the CIE-1931 chromaticity disgram, if the positive Y and V axes are considered to be upward from the page, the mapping is right-handed. In the interest of consistency, I recommend that all representations be made right-handed. For all systems, the geometry should be well designed to be compatible with usage in associated arts and sciences.

Having selected the dimensions of the system, one must state the principles of scaling. In the Munsell system, for example, the value scale extends from 0, for the blackest conceivable black, to 10, for the whitest conceivable white, the nine intermediate steps being uniformly spaced visually. The hue circuit is divided into 100 visually uniform steps, with pure red at 0. Vermilion was assigned a chroma of 10 on a visually uniform scale. Munsell proposed the symbols H, V, and C for Munsell Hue, Munsell Value, and Munsell Chroma and proposed that the group of symbols in the form H V/C be used as a standard form of notation, now known as "Munsell Notation". In establishing a system, the scaling must be explicit and notation should be convenient.

Once Munsell had formulated his ideas, as outlined here, the Munsell System existed. It was only in abstract form. The plan for constructing a colorant-mixture system, color-mixture system, or color appearance system constitutes an abstract system. It is hardly possible to contemplate or discuss some of the important issues involved with color order systems without maintaining a clear distinction between an abstract system and a concrete system, which is a physical embodiment of the plan. An abstract system may propose a scheme that is useful or not so useful; that may be realized easily, with great difficulty or not at all; or that is precisely and completely defined or only loosely defined. Thus, an abstract system may in these regards be good or bad, but since it is only a prescriptive definition it cannot be true or false.

Concrete Systems

At first, there were no readily available examples illustrating the scales of hue, value, and chroma. There were no physical standards for visually assigning Munsell Notations. In 1915, Munsell published "The Atlas of the Munsell Color System", a series of charts showing visual scales of hue, value, and chroma. In February of 1918, he incorporated The Munsell Color Company to produce color standards identified with his notation. His color atlas became the "Munsell Book of Color". This was a concrete system embodying his abstract system. The Munsell Book of Color was and is made up of painted paper chips. A similar embodiment, using other paints is produced by the Japan Color Research Institute. Recently, an embodiment in dyed textiles has been produced by Kensaikan in Japan, to be available from the Munsell Color Company under the name "SCOT" (Standard Colors of Textiles). The three different embodiments involved three different formulations. However universal a color order system may be, any conventional embodiment has its own peculiar nature. Since a color can be produced in a variety of ways, there is no unique embodiment.

Optimum Properties

If there is no unique embodiment, are there any desirable features that might guide us to the optimum embodiment? Yes, certainly durability and cost come to mind. Ideally, if standards are to be used for judging one kind of material, the standards should be made of the same kind of material. Comparisons are more reliable if the only aspect that may differ is the color. This suggests the need for both glossy and mat paint standards. To minimize the effects of metamerism, it is desirable to use the colorants most likely to be used in industry. This principle led to the use of lead pigments in early Munsell formulations, but to other pigments when the use of lead was later banned in commercial paints. This illustrates the fact that optimum conditions can change for unforeseen reasons.

The peculiar nature of various embodiments "comes to light" when we compare them under various light sources. In retrospect, it seems strange that in the early writings of Munsell little attention was given to viewing conditions. Photographers of that time certainly knew that a gray scale that appeared to have uniform steps in full sunlight would blend together in the darker tones, when viewed in dim light. Indeed, this fact had to be taken into account every time a print was made in the dimly lit darkroom! The apparent uniformity of a value scale depends on the level of illumination. Likewise, the spectral quality of the illumination is important when hue and chroma are judged. Illumination is now standardized.(3) The geometric and spectral conditions of illumination must be specified as an integral part of any concrete system involving reflecting or transmitting materials.

The colors of chips may remain reasonably constant as we observe them in different kinds of illumination, or we may find that they change so much that the system would not be valid. Since different formulations are required as we progress from one part of color space to another, we may find shifts in spacing as we go from one illumination to another. Current studies of the general principles of formulation to achieve color constancy, at the Rensselear Polytechnic Institute, should shed light on this problem.

When we have a physical embodiment, we can ask about accuracy. How well does the array of chips fulfill the defined objectives of the abstract system? The concrete system can be true or false. How repeatable is the manufacturing process? How reproducible are such embodiments from one process or manufacturer to another? How repeatable is the process of a single producer over a period of many years? For answers to these questions we turn to colorimetry.

Colorimetry

For purposes of communication and for the preservation of color order systems it is desirable to measure specimens and publish in an archival journal the relationship between the colorimetric specifications and the system notations. This was done for the Munsell Book of Color by the Optical Society of America.(4) They defined a modified and enlarged Munsell solid. They smoothed some irregularities observed in the book and defined the Munsell Hue and Chroma in terms of CIE chromaticity relative to Illuminant C at nine values, and Munsell Values in terms of CIE Tristimulus Value Y. The smoothing for the renotation was based on visual observations by expert colorists.

Measurements were made with General Electric spectrophotometers, which had spheres smoked with magnesium oxide, and magnesium oxide was used as the reference white. The bandwidth was 4nm. The specular component was neither wholly included nor excluded. The final report of the O.S.A. stated that the absolute luminous reflectance factor of MgO was 97.5% based on measurements made about 1939. On this basis, the committee set the top of the Munsell Value scale at a Y value of 102.57%, relative to MgO. By 1955, the absolute luminous reflectance factor of MgO was reported to be 99.0%. The CIE later agreed to report on an absolute basis as of January 1, 1969, but this is merely a matter of the reporting of data. Colorimetric practice differed materially from modern practice. This is a caution to those who attempt to maintain color order systems and those responsible for the evolution of the science of colorimetry.

The Munsell System is essentially abstract and based on human vision. The ties to the past are through colorimetry and the O.S.A. Report. The Munsell Color Company laboratory uses a General Electric spectrophotometer to maintain close ties. The instrument is kept under strict statistical control with a number of stable physical standards. Spectrophotometers and colorimeters that differ from the G.E. in geometric or spectral conditions may provide data that do not agree with the G.E. The use of the OSA-ASTM conversion may lead to Munsell Notations outside the tolerances established for Munsell chips. This may necessitate some adjustment of the OSA conversion relationships. The current Munsell Book of Color is being studied with other instruments. Fortunately, if all standards and instruments were lost, the system could again be constructed on the basis of visual judgments.

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CIELAB : THE IDEAL COLOUR ORDER SYSTEM FOR INDUSTRIAL APPLICATIONS

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Summary

CIELAB is the ideal colour order system for industrial applications because it is uniform and its colour co-ordinates can be readily calculated from XYZ values. This means that colour differences can not only be quantified but partitioned into the three Munsell variables and also into the colourist's variables which are quite different. If the ISCC - NBS method were revised to be based on CIELAB co-ordinates instead of Munsell renotations its success as a colour order system could be very much greater.

The quantification of small colour differences

The quantification of the perceived size of small colour differences has always been one of the two most important targets of applied colorimetry and the simplest method of doing this is to create a three-dimensional colour space in which the position of any colour can be precisely defined by three numbers and the distance between the positions of two specimens is proportional to the perceived colour difference between them. This distance is given the symbol ΔE (delta E or DE) and the simplest method of quantifying colour differences is to calculate the distance in XYZ space by the simplest of all the colour difference equations -

$$DE = \left[(DX)^2 + (DY)^2 + (DZ)^2\right]^{0.5}$$

where DX is X_1-X_2 etc. This equation failed, however, because the DE values of equally perceptible colour differences varied by as much as 30:1. XYZ space was therefore markedly non-uniform.

One method of overcoming this defect was to transform the XYZ values mathematically into three derived values which would define a uniform colour space and after many years work involving more man-hours than were required to set up the CIE System the CIE, in 1976, defined such a space by three co-ordinates, $L^*a^*b^*$, the space and its associated colour difference equation being known as CIELAB. During the past seven years it has become the most widely used of all the 20 or more colour difference equations which have been published some of which (those based on MacAdam ellipses) being based on a different principle.

Unfortunately, however, CIELAB space is far from being uniform with respect to small colour differences, the DE values of equally perceptible differences varying by at least 5:1. This defect, however, has been successfully overcome by the development of optimised equations but this research revealed that CIELAB space has a major advantage as a colour order system which none of the many alternatives possess: the co-ordinates can be easily calculated from XYZ values.

The configuration of CIELAB space

If the L*a*b* co-ordinates of CIELAB space are converted into the cylindrical co-ordinates L*C*h it has the configuration of most logical array of colours, that first discovered by Forsius and later, quite independently, by Munsell: this is shown in the diagram on page 5. Whilst Munsell space is ideal for understanding the variables of perceived colour and is suitable for colour identification by artists and designers it has one weakness that has prevented its use in industry. The calculation of Munsell co-ordinates from xyY values or vice versa requires a computer powerful enough to contain all the Munsell renotations and although spectrophotometers today are usually interfaced to microprocessors or computers, these are rarely suitable. This gives CIELAB space an immense advantage over all the other systems and there are two other advantages over Munsell space viz:-

1. CIELAB space is more uniform because although the spacing within each variable in Munsell space is uniform, that between variables is not: 1 Munsell value step is equal to 2 steps of Munsell chroma and 3 steps of Munsell hue at chroma 5;

2. Munsell hue designations are a combination of letter and numbers and thus not suitable for computation; whilst Munsell did propose an alternative 0-100 hue scale, this has rarely, if ever, been used.

Whilst the major use of CIELAB space has been to quantify colour differences, a subject outside the theme of this symposium, it has also proved to be of considerable value in industry as a colour order system. It can be used to qualify the nature of colour differences in words which are immediately meaningful to anyone familiar with the Munsell system or in other words understood by the professional colourist in industry.

The derivation of colour difference descriptors

L*C* and h values quantify the natural variables of perceived colour and this c acteristic permits the nature of any colour difference to be expressed in words which are immediately meaningful. Differences in L* are described as lighter or darker, differences in C* as weaker or stronger, the terms refer to the strength of the chromatic response. Differences in h can usually be described by quoting the first ab axis to be crossed when the radial axis - the chroma axis - passing through the position of standard is rotated to pass through the position of batch, the axes being designated -

a+ red; b+ yellow; a- green; b- blue.

(It is in this respect that the configuration of CIELAB space differs from the Swedish Natural Colour System. Because the a b diagram is a uniform chromaticness diagram, the axes locating the psychological primaries red, yellow, green and blue cannot be orthogonal: this is of no concern to the industrial colourist). This method of deriving the hue difference descriptor fails whenever the first axis to be crossed has the same hue name as the colours being compared: a professional colourist would never describe one yellow as being yellower than another yellow, for example and wouldn't know what a designer meant if he or she used the phrase. To overcome this serious limitation the hue name associated with the second axis to be crossed is always quoted in brackets. For example, in the case of all colours called yellow, rotation in an anticlockwise direction will generate the terms -

yellower (greener) or greener (bluer)

Only the term greener is meaningful to a colourist if he considers the standard to be a yellow. If the standard is a reddish yellow, however, many colourists would describe it as an orange and to such individuals the term yellower is the meaningful one. This system has been widely used for over five years and has never failed.

The colourist's variables of perceived colour differences

The colourist's terms for describing hue differences are those associated with the four psychological primaries redder, yellower, greener, bluer which are universally recognised. The terms used to describe differences in the remaining two variables are quite different. The first of these is depth which is the amount of non-white colorant present. If the colorant is a yellow then increasing depth corresponds to an increase in chroma; if it is a black, then this corresponds to a decrease in lightness. In the case of all other colorants an increase in depth corresponds to decrease in lightness and initially an increase in chroma: eventually, however, a decrease in chroma often occurs, a paint containing only Prussian Blue, for example, would have to be sold as a black to avoid infringing any trade description legislation. The remaining variable is that associated with the presence of more or less black colorant, the former being described as duller, flatter, sadder or dirtier, the latter by brighter or clearer. Colour differences in CIELAB units can be partitioned into these variables.

The derivation of colour names from CIELAB co-ordinates

The Munsell Colour order system cannot be regarded as being entirely satisfactory for designating colours for two reasons. The first is that Munsell had a rooted objection to using names of objects as colour names which prevented words such as orange and violet, which are in everyone's colour vocabulary, being used. The second is that he used words only for designating hues which eliminated other common colour words such as brown, olive and pink.

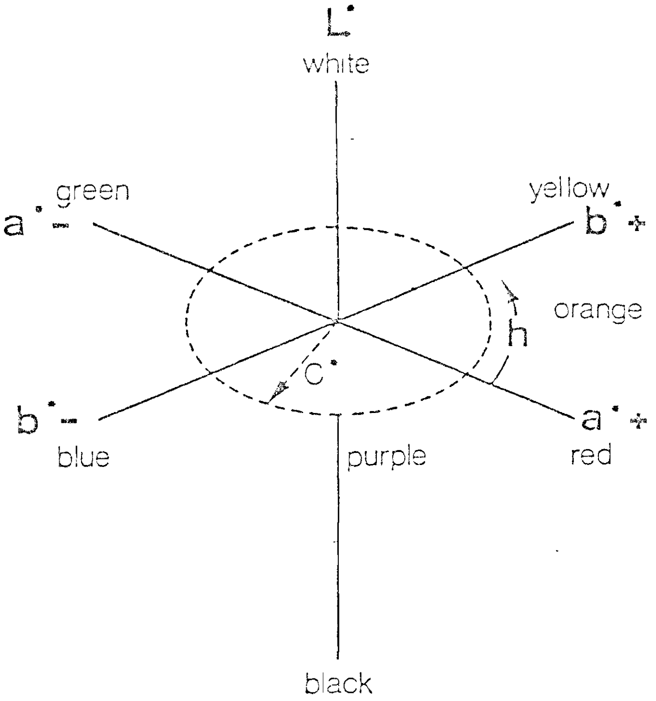
Many colour dictionaries have been published which illustrate hundreds, if not thousands of colours but the fact that there are so many has prevented any single one from becoming widely used.

The most ambitious attempt to bring order out of chaos was the ISCC - NBS system which illustrated 267 centroid colours which were in the centre of volumes in colour space defined by Munsell renotations. Each of the centroid colours was given a simple, easily understood name consisting of not more than three words, for example, very deep purple, light reddish gray. These colours were accompanied by a dictionary of some 7,500 colour names which identified the nearest centroid colour and gave all the names referring to each centroid colour.

In spite of it being the most comprehensive yet simple method of designating colours it does not seem to have been widely used and the most likely reason is the difficulty of identifying the centroid colour from xyY co-ordinates. If this system could be replaced by one which retained the centroid colours but defined the surrounding volumes by six CIELAB co-ordinates (minimum and maximum L*C* and h) it would make it extremely attractive to industry. Increasing numbers of firms using colorants i.e. dyes or pigments rely on spectrophotometers interfaced to computers for match prediction and it would be a simple matter to program these to display the ISCC - NBS designation if these were re-defined by CIELAB co-ordinates.

This would greatly facilitate the use of one of its unique features, its ability to describe or define colours with different levels of accuracy. Up to level 3, colour space is divided into 13, 29 or 267 blocks identified by colour names; in level 4, conventional Munsell notations are used which are increasingly sub-divided to give 100 000 blocks in level 5 defined e.g.

as $9\frac{1}{2}$ YR 6.4/$4\frac{1}{4}$ and 5 million blocks in level 6 defined e.g. as 9.6 YR 6.45/4.3 or, of course, by XYZ or xy Y values. Level 6 was considered in 1976 to be "the greatest presently meaningful accuracy of colour identification" but today routine pass/fail determinations in industry correspond to level 7 for which the Munsell notation is clearly unsuitable, but for which CIELAB has proved ideal especially when the overall size of colour difference is modified by the use of an optimised equation.



$$C^* = \left[(a^*)^2 + (b^*)^2\right]^{0.5}$$

$$h = \arctan b^* / a^*$$

The relationship between Cartesian and cylindrical co-ordinates.

A Formulation of Nonlinear Model on Chromatic Adaptation for a Light-Gray Background

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The authors proposed and formulated a nonlinear model on chromatic adaptation considering a nonlinear process supposed to exist in human visual system[1,2]. Further, they studied exponents of power functions in the nonlinear process, and specified the functions of exponents[3] which were most probable at the present stage of knowledge. Given tristimulus values of a test sample in a test field under a test illuminant, the proposed method[1,2] could derive tristimulus values of a corresponding sample in a reference field under a reference illuminant. The corresponding sample in the reference field elicits the same color perception as the test sample in spite of different states of adaptaion between the reference and the test field to the same normal observer. The reference illuminant could be different from the test illuminant in chromaticity or illuminance level.

In the previous studies[1-3], the test and the reference background were nonselective and had the same reflectance of 0.20. In usual chromatic-adaptation experiments, however, the background used is sometimes different from a medium gray and has reflectance higher than 0.20. The authors extended their nonlinear model to predict chromatic-adaptation effects for a light-gray background. The detailed and strict formulation of the extended model will be reported elsewhere[4]. In this paper, only the computational procedure is given for light-gray backgrounds in a special case that the test illuminance E is kept equal to the reference illuminance E'.

Equations for predicting chromatic-adaptation effect

The following steps can be applied to any background condition satisfying $\rho_0 = \rho_0' \geq 0.20$ in the situation of Fig.1 for the condition E = E', where ρ_0 and ρ_0' are the background reflectance of the test and the reference field, respectively. In addition, the steps also can be used for the condition E ≠ E', only when $\rho_0 = \rho_0' = 0.20$ holds.

Given tristimulus values X, Y, Z of a test sample in the test field, the proposed method can derive tristimulus values X', Y', Z' of a corresponding sample in the reference field which elicits the same color perception as the test sample in spite of different states of adaptation between the reference and the test field.

In the procedure, the quantities related to the test field are shown by the notations without prime, and those of the reference field with prime. The subscript zero refers to the background.

The procedure consists of the following three steps.

Step 1: Transformation from X, Y, Z to R, G, B:

$$\begin{aligned} R &= 0.07114\,X + 0.94940\,Y - 0.01562\,Z, \\ G &= -0.44617\,X + 1.31733\,Y + 0.09794\,Z, \\ B &= 0.91876\,Z. \end{aligned} \tag{1}$$

Step 2: Transformation from R, G, B to R', G', B':

$$\begin{aligned} R' &= (100\rho_0'\xi' + 1)\cdot\left(\frac{R + 1}{100\rho_0\xi + 1}\right)^{p_r} - 1, \\ G' &= (100\rho_0'\eta' + 1)\cdot\left(\frac{G + 1}{100\rho_0\eta + 1}\right)^{p_g} - 1, \\ B' &= (100\rho_0'\zeta' + 1)\cdot\left(\frac{B + 1}{100\rho_0\zeta + 1}\right)^{p_b} - 1. \end{aligned} \tag{2}$$

Step 3: Transformation from R', G', B' to X', Y', Z':

$$\begin{aligned} X' &= 2.54653\,R' - 1.83529\,G' + 0.23892\,B', \\ Y' &= 0.86248\,R' + 0.13752\,G', \\ Z' &= 1.08842\,B'. \end{aligned} \tag{3}$$

Note 1: Quantities in eq.(2)

Quantities ξ, η, ζ are computed by eq.(4) from the chromaticity coordinates (x,y) of the illuminating source in the test field.

$$\begin{aligned} \xi &= (\ 0.08676\,x + 0.96502\,y - 0.01562)/y, \\ \eta &= (-0.54410\,x + 1.21939\,y + 0.09794)/y, \\ \zeta &= 0.91876\,(1 - x - y)/y. \end{aligned} \tag{4}$$

Similarly, the quantities ξ', η', ζ' are derived by

$$\begin{aligned} \xi' &= (\ 0.08676\,x' + 0.96502\,y' - 0.01562)/y', \\ \eta' &= (-0.54410\,x' + 1.21939\,y' + 0.09794)/y', \\ \zeta' &= 0.91876\,(1 - x' - y')/y', \end{aligned} \tag{5}$$

where x' and y' are the chromaticity coordinates of the illuminating source in the reference field. Quantities p_r, p_g, p_b are derived by

$$\begin{aligned} p_r &= \left(\frac{1.757 + 1.728\,R_0^{0.4495}}{6.469 + R_0^{0.4495}}\right) \Big/ \left(\frac{1.757 + 1.728\,R_0'^{0.4495}}{6.469 + R_0'^{0.4495}}\right), \\ p_g &= \left(\frac{1.757 + 1.728\,G_0^{0.4495}}{6.469 + G_0^{0.4495}}\right) \Big/ \left(\frac{1.757 + 1.728\,G_0'^{0.4495}}{6.469 + G_0'^{0.4495}}\right), \end{aligned} \tag{6}$$

$$p_b = \left(\frac{1.851 + 1.780\ B_0^{0.5128}}{8.414 + B_0^{0.5128}}\right) \Big/ \left(\frac{1.851 + 1.780\ B_0'^{0.5128}}{8.414 + B_0'^{0.5128}}\right),$$

where

$$\begin{pmatrix} R_0 \\ G_0 \\ B_0 \end{pmatrix} = \frac{\rho_0\ E}{3.1416} \begin{pmatrix} \xi \\ \eta \\ \zeta \end{pmatrix}, \quad \text{and} \quad \begin{pmatrix} R_0' \\ G_0' \\ B_0' \end{pmatrix} = \frac{\rho_0' E'}{3.1416} \begin{pmatrix} \xi' \\ \eta' \\ \zeta' \end{pmatrix}. \qquad (7)$$

Note 2: Background Condition

In case of the background with Munsell Values 5 to 6, the proposed procedure is effective for any different illuminant color and for different illuminance level at the test and the reference field. In case of the background with Munsell Values 7 to 9, the procedure can be used for any different illuminant color at the test and the reference field. However, the illuminance of the test field should be kept equal to that of the reference in this background condition.

Prediction of Helson-Judd Effect

Helson-Judd effect[5] was predicted for the background reflectance of 0.5. The test illuminant used has a highly saturated yellow color. Its chromaticity is shown by open circle Y in Fig.2. Standard illuminant C is used as the reference adaptation, and is shown by large dot C in the same figure. Test samples are nonselective and have various Munsell Values. The chromaticities of the corresponding colors are shown in Fig.2 by dots with numeral. The numeral at each dot corresponds to the Munsell Value of the test sample. As clearly found in Fig.2, the chromaticity of standard illuminant C coincides with that of corresponding color to the nonselective test sample with the same reflectance as that of the background. The figure shows that the samples with reflectance higher than that of the background are perceived as having the test-illuminant hue, and those with lower reflectance have the complementary hue of the test illuminant. These results confirm that the achromaticness constancy always holds for the nonselective test sample with the same reflectance as that of the background. Similar results are obtained for test illuminants with highly saturated red, green, and blue color.

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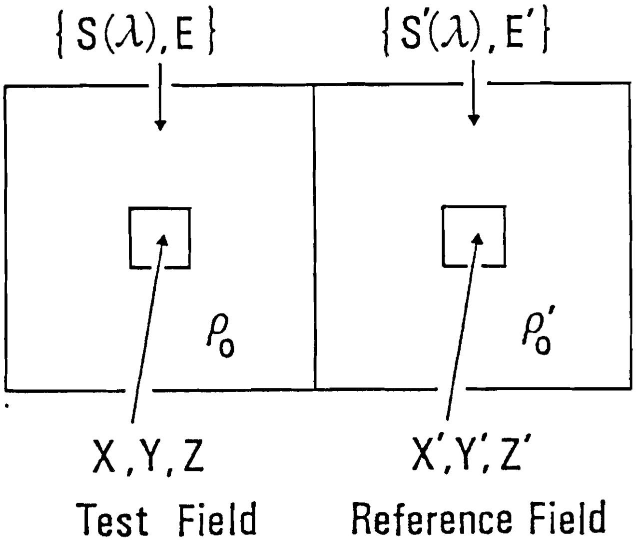

Fig. 1 The situation studied by the model. The quantities without prime correspond to the test field, and the quantities with prime correspond to the reference field. S(λ) represents relative spectral power distribution of illuminant; E the iluuminance(lux) at the background and its central sample surface; X, Y, Z the tristimulus values of the central sample; and ρ_0 the reflectance of the nonselective background.

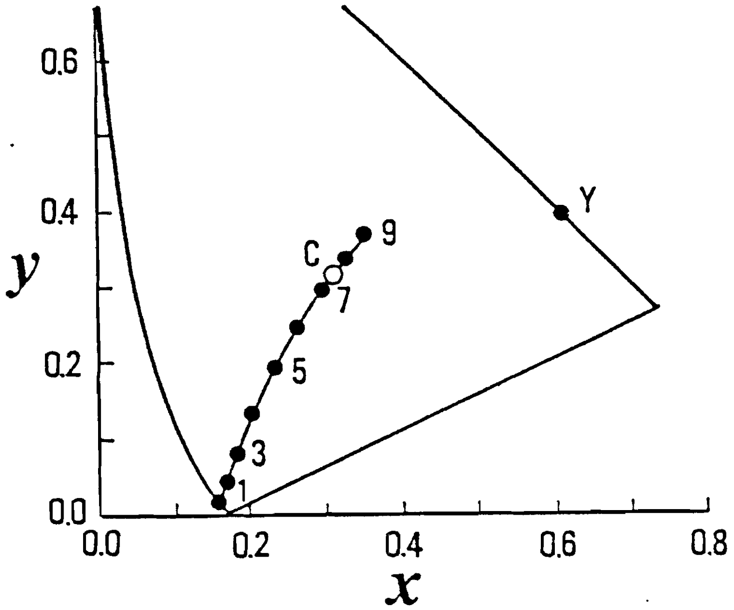

Fig.2 Prediction of the Helson-Judd effect corresponding to the background reflectance of 0.5. Dot Y is the chromaticity coordinates of the yellow test illuminant. Open circle C is the chromaticity coordinates of standard illuminant C used as the reference illuminant. Dots with numerals show the chromaticity coordinates of corresponding colors under standard illuminant C to different nonselective samples illuminated by the yellow test illuminant. The numerals show Munsell Values of the nonselective samples used.

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VARIOUS CONCEPTS OF THE SENSIBLY EVEN COLOUR SPACE

Colour systems MUNSELL, DIN, NCS, COLOROID are intended to simulate sensibly even colour spaces. One possibility to define differences between these colour systems is to define termine their correlation to a "sensibly even, ideal colour space". To this aim, first of all, the concept "sensibly even, ideal colour space" has to be unambiguously defined. Throughout the special literature, and in particular, in connection with the MUNSELL system, two interpretations of the concept are encountered, adopted by the MUNSELL Renotation, and by the COLOROID colour systems, respectively.

Colour space based on tests by threshold measurements

The distinction threshold dL means the just perceivable impulsion increase, in other words, the just notable difference /J.N.D./. In tests by threshold measurements, it is attempted to empirically divide an impulse series to dL units.

A colour impulse is described in terms of three parameters. Variation of the colour impulse may entrain modification of the brightness, saturation and hue of the thereby elicited colour sensation. Brightness variation being of quantitative character, it is more or less subject to WEBER's statement. On the other hand, variations of saturation and hue are definitely qualitative, hence they are ruled by other relationships.

To find these relationships, tests may be made in several points of the colour space in respect of all three parameters where size of the dL units is defined by the offset of the indeterminacy of the limit between adjacent fields of the considered scale upon the variation of some colour parameter in some of the fields.

By performing these tests for all possible scales of the space of colour impulses, an ideal colour space of elements dL is brought about /Fig. 1/. Now, the scales will be evenly distributed in all three directions of the ideal colour space. In the resulting sensibly even colour space, an equal number of dL units are between each two scale divisions /Fig. 2/.

Colour space of the MUNSELL Renotation colour system approaches the concept of the sensibly even colour space outlined above. In this colour space, scale element differences are products of the least sensible colour difference by the same factor. This built-up makes indices of the colour system arising from this colour space rather suitable for defining small colour differences. Within the theory of environmental design, however, colour composition rules are based on other than these properties, expected to define relations between any colours of the colour space. To establish these relations, the entity of the colour space has to be kept in mind, requiring to determine great colour differences. A colour space composed from such relations is called aesthetically even, as distinguished from the sensibly even one.

The aesthetically even colour space

A complex of colours created from aesthetic purposes, raising pleasant feelings in the observer is called a harmonic composition. The question arises whether there is any relation permitting to decide what colours to unite in such a composition, or at least, what colours to never unite in such a composition.

To decide this question, let us make a test. Let us make colour scales by painting tens of thousands of colour samples of a few sq.cm surface. One part of the colour samples should have the same saturation and brightness but a different hue, the second and the third parts would differ by brightness and by saturation, resp., both other parameters being equal. The solely varying colour sensation parameters of neighbouring colour samples in the scales should differ by dL units alone, that is, distinguishable only if closely adjacent.

Now, let us make compositions of these colour samples, 50 to 80 pieces of 15 to 20 hues in each composition. Some samples should be sharply contrasting, while others should not differ by more than a few dL. Colours just distinguishable under circumstances above will be found to be definitely distinct within the composition, permitting to be considered as independent colours of the composition.

Having defined colours well distinguishable within the composition, aesthetically appreciable, differing by hue, saturation and brightness, on the proper, sensibly even dL scale referred to the starting colour, sensible differences of each two colours from each of the three directions are denoted by dh and termed harmony intervals /Fig. 3/. Now, let us consider the new colours as starting colours in ever new compositions, defining neighbouring colours spaced at harmony intervals referred to them. This will be continued until all dh units are marked out in each three directions of the colour sensation space, between origin and end point of as many scales as possible. Juxtaposing scales of colours spaced at dh units will show that considering a scale all along, with its origin and end point, colours compose a uniformly varying row, that is, from the aspect of great colour differences, they are sensibly equally spaced from each other, in spite of different numbers of dL units between them /Fig. 4/.

Comparison of colour spaces based on ds and on dh units

In a sensibly even colour space of small colour differences, a colour parameter difference between adjacent colours, elementary spacing between adjacent points of the colour space, will be denoted by ds.

This colour space of ds units is approximated by the colour space of the MUNSELL colour system, and also by transformations of the CIE XYZ system made to this purpose, including CIELAB and CIELUV. In the sensibly even colour space considered as aesthetically even, referring to great colour differences, a colour parameter difference between each two colour sensations, as elementary distance between adjacent points of the colour space, is denoted by dh. Such a colour space built up of such dh units is approximated by the colour space of the COLOROID colour system.

Brightnesses and saturations of the two colour systems are related as:

$$V_{sz}= 10\ 1,2219V_m-0,23111V_m^2+0,23951V_m^3-0,021009V_m^4+0,000840V_m^5$$

$$T = ab^3\ C^2$$

where V_{sz} - COLOROID brightness;
V_m - MUNSELL brightness;
T - COLOROID saturation;
C - MUNSELL chroma,

a and b in the second formula indicate the dependence of the expression of the sensation of colour saturation in terms of either MUNSELL or COLOROID indices both on the brightness and the hue of the colour. Formulae reflect the different relationships ruling the series of indices assigned by each system to sensations elicited by the same varying impulses. Thus, the two systems involve different suggestions to measure colour sensations.

One of the colour systems lends itself to describe colour differences, the other the relationships of colour composition.

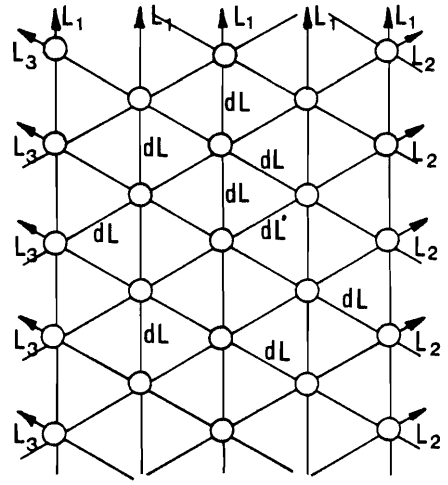

Fig.1.

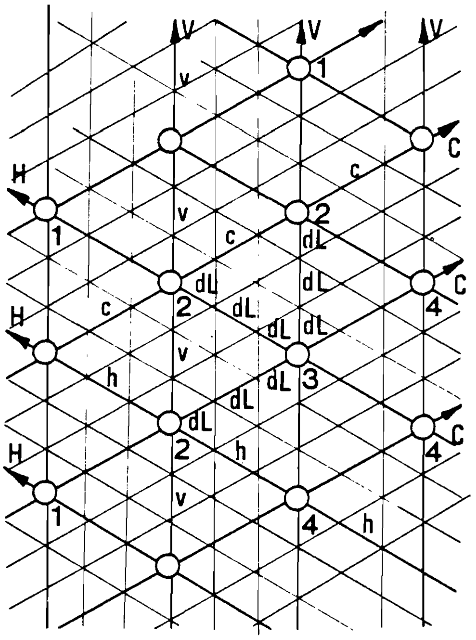

Fig.2.

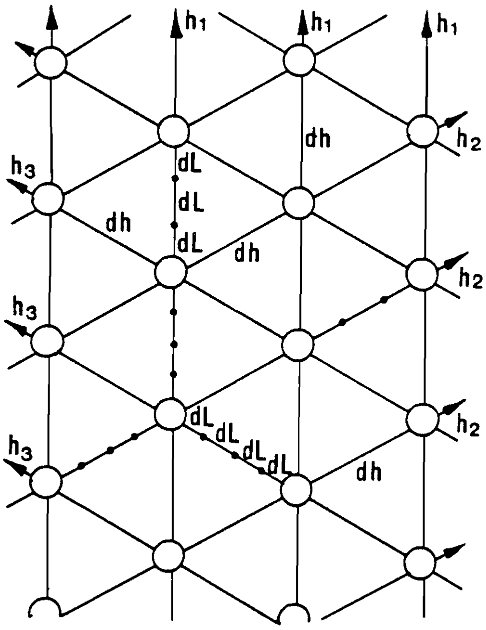

Fig.3.

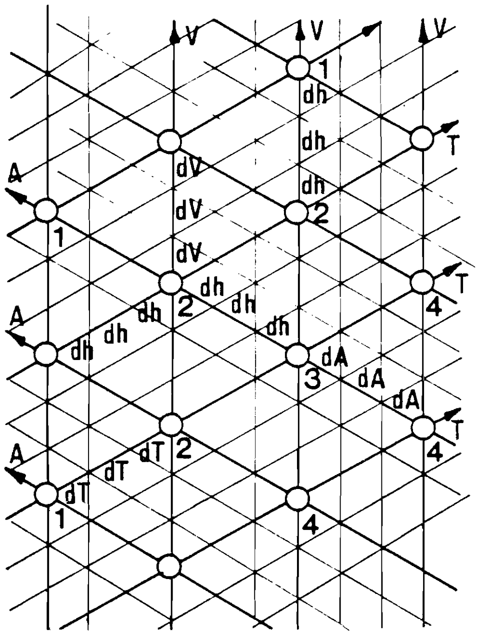

Fig.4.

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PSYCHOLOGICAL DIFFERENTIAL COLOUR ORDER SYSTEM ACCORDING TO CHILDREN PREFERENCES.

The interior decorator is often faced with the need of learning more about the "coloured world" of children. The classical branches of research include:

A. Assessment of the preferred colour, in an abstract sense, by the use of tools like the Luescher Test, the Pfister Pyramid, etc.
B. Estimate of colour discrimination by the use of tests conceived for adults adequately adapted at the site of instruction (Verriest, 1982) or by the use of specialized tests (Fletcher, 1980).

The general idea that the hue preferred (item A) is red in infants and turns to cooler hues as age increases has not been confirmed by the data recorded during the past two decades (Verity, 1980; Passigli, 1981), probably because of the accelerated maturation mediated by the spread of mass media. The well-known improvement of colour discrimination (item B) as age increases (below 14 years) can be easily checked in relation with the occurrence of a tritan-like defect in the earliest years of life (Ohtani, 1978; Passigli, 1980). One should expect, of course, that both infants tritan-like deficiency (even if mild) and the lack od adequate education in matter of colours interact to some extent with the "preferences" which should be basically dictated by psychological factors.

In order to find some possible practical solutions, we attempted a direct approach to the problem. We instructed a number of specialized teacherswho, following a prefixed routine, gave their pupils some sheets of paper where a classroom was drawn with China ink (Fig. 1). The pupils task consisted in painting it, having at disposal a set of 24 felt-pens of different colours, whose distribution of spectral reflectance was well-known.

We noticed (Passigli, 1981; Ronchi, Villani, Passigli, 1982) that the majority of the children assigned to the teachers- desk a colour <u>different</u> from the one assigned to the pupils-desk (Fig. 2). It was as if the children were making use of colours to denote the (symbolic ?) difference they felt when comparing themselves to the teacher.

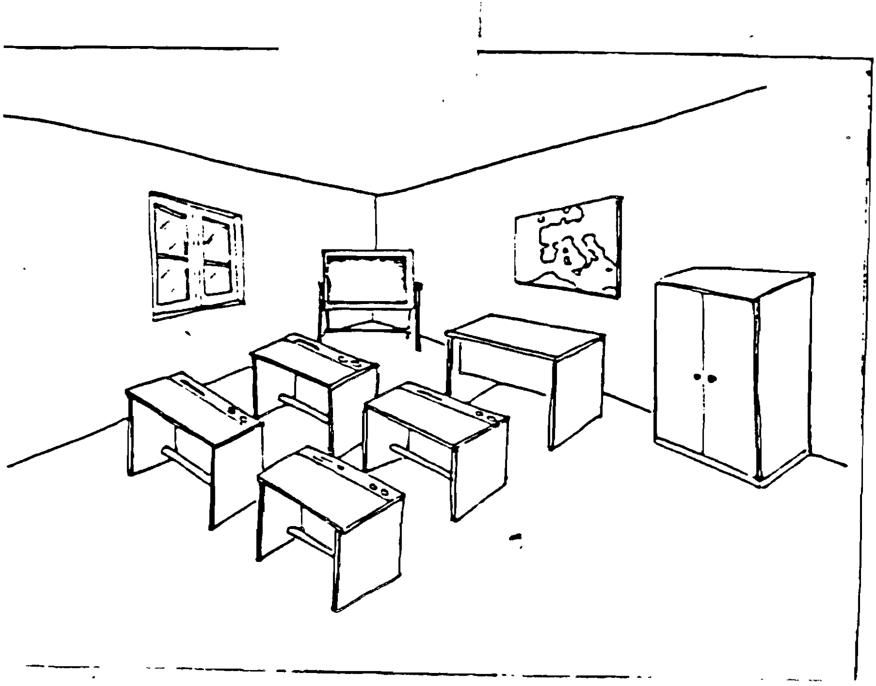

Fig. 1

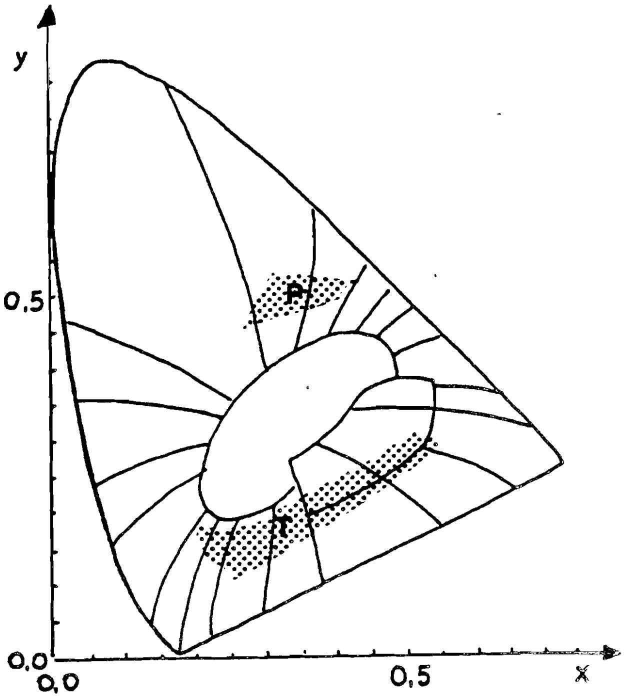

Fig. 2

Fig. 1 - Sample of classroom to be painted (reduced to 62% of the original size).

Fig. 2 - CIE chromaticity diagram. The dotted areas include the representative points of the colours used by the majority of children to paint their own desk (P) or the desk of the teacher (T).

This kind of work has been meanwhile further developed. We tested as a whole 85 children from 4 to 6 years, and 52 children from 7 to 10 years.

Faced with the painting task shown in Fig. 3, the majority of them assigned to the parents bedroom a colour different from that of their own bedroom (Fig. 4). This finding is confirmed when children are faced with the task of the selection of actual samples of coloured tissues, to be used as surface materials for either room (Fig. 5a, 5b).

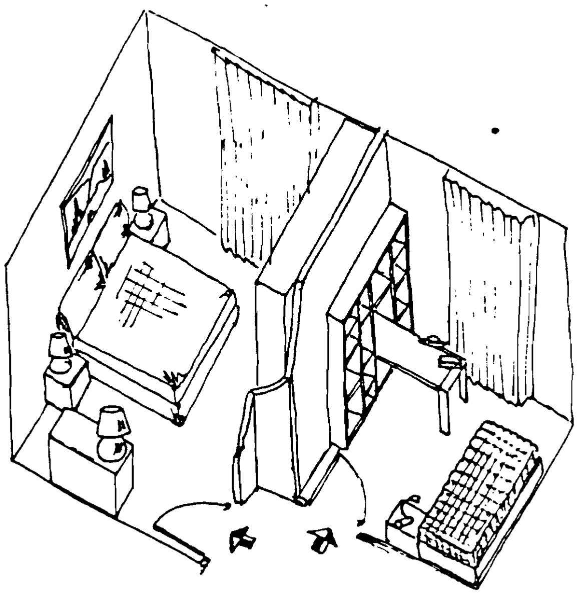

Fig. 3

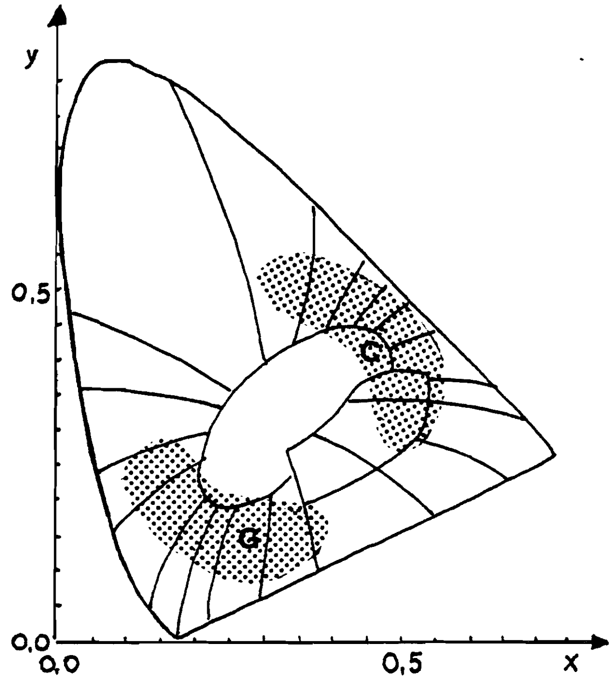

Fig. 4

Fig. 3 - Sample of set of family bedrooms to be painted (reduct to 62% of the original size).

Fig. 4 - CIE chromaticity diagram. The dotted areas include the representative points of the colours used by the majority of children to paint their own bed (C) or that of the parents (G). This diagram is for children of 4-6 years. The representative points, in the case of children from 7 to 10 years, are so spread that no area including them can be delimitated. However, all these children ascribe to the parents a colour different from their one.

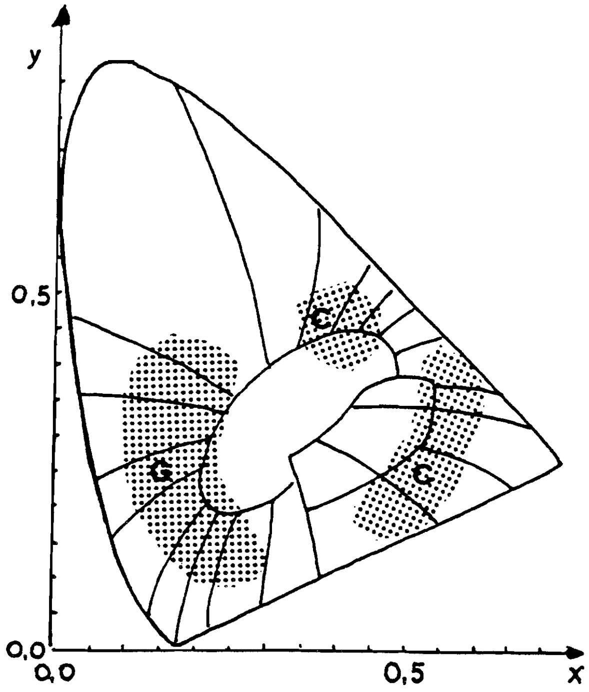

Fig. 5a

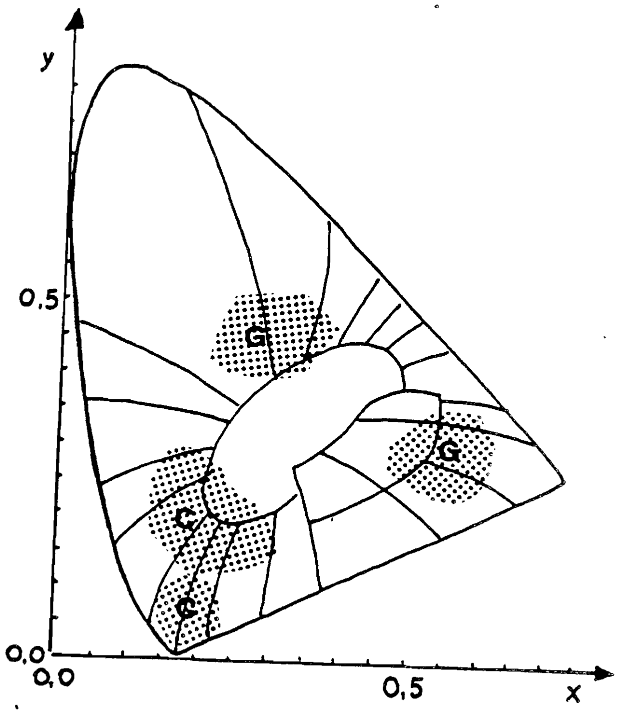

Fig. 5b

Fig. 5 - CIE chromaticity diagram. The dotted areas include the representative points of the colours of the tissues chosen by the majority of children to cover (ideally) their own bed (C) or that of the parents (G).

Fig. 5a - Children of 4-6 years.

Fig. 5b - Children of 7-10 years.

In conclusion, our data seem to indicate that in practice children seem to use their preferences according to differential criteria: the colour assigned to teachers and parents differs from the one they adopt for their own desk or bed; this is most likely accounted but their consciousness of the different roles they play in their social life.

7

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POLYCHROMY IN THE SOUTHEASTERN BRAZILIAN ARCHITECTURE

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To show various modes of applications of colour on architectural façades of different periods we chose two examples in the Southeast of Brazil.In the first, colour is normally integrated in the architecture. In the second, architecture was used as a support, almost as a pretext for colour in environmental design. We are talking about two towns : Parati and São Paulo.

Parati, a little sea-side town, founded in 1660, is part of the state of Rio de Janeiro and is considered as a historical site, protected by the "Patrimônio Histórico e Artístico Nacional". Therefore we can observe a typical XVII^th^ and XVIII^th^ century colonial architecture with its original coloured façades.

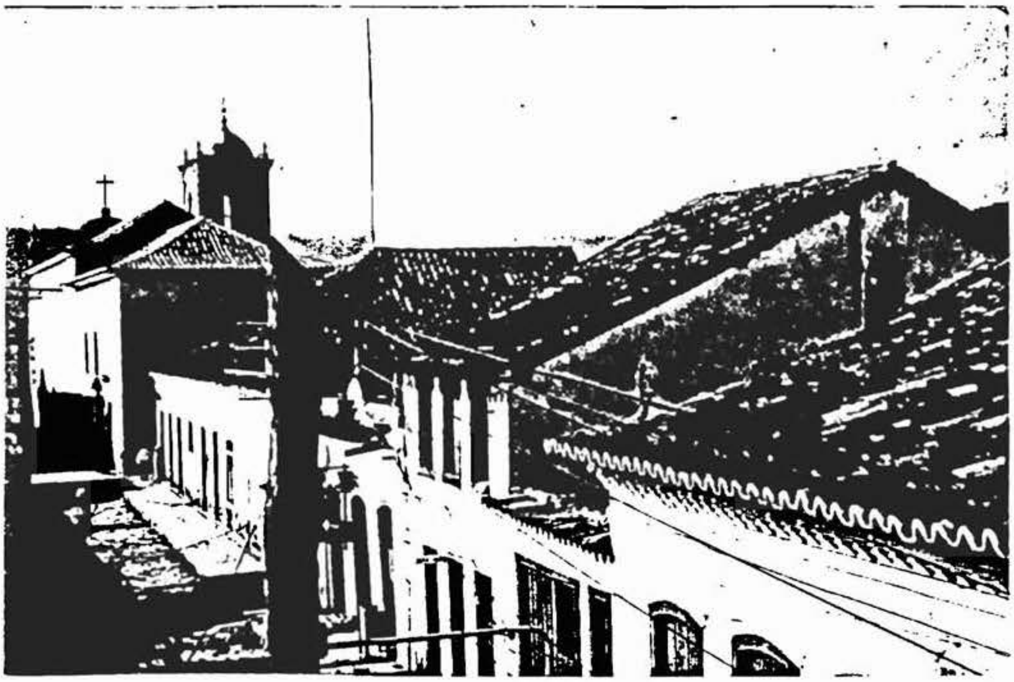
As for São Paulo, created before Parati,it has developped hugely and lost its primitive pattern. In the beginning of 1970, very curious environmental colour manifestations started to appear in São Paulo.

We hope that the transmission of two cases will arouse relevant discussions in the group, and confrontations with other related researches: in order to consider and develop eventual new ways of studying future applications of Colour Order Systems in architecture and in urban space in general.

It is well-known from reports and studies by historians, botanists and travellers that in traditional Brazilian architecture the house-fronts were whitewashed. The wooden parts, though, were painted in various colours, as it can be observed in the old town of Parati (picture n°1) . White was frequently used in hot countries because of its reflection capacity. The materials used to make lime in that time were stone, shells and the "tabatinga", a white clay extracted from river banks.

For the painting on doors, windows and all wooden details, they used a preparation with glue, tempera or oil (from whales, linseed or "mamona") and several natural colouring matters. For instance,ochres were obtained from different kinds of clay; the "cochonilha-do-carmim", parasite of the "nopal", a tropical plant, gave a very bright carmin; the saffron roots, squashed and boiled with water containing alum, gave a yellow colour; the Brazilian indians already used the fruit called "urucum" to obtain a red colouring. Black, pink and others colours came from different woods, like "ipê", "tatagiba", etc.

We could quote many others exotic names to prove that the dyeing materials used in that period were prepared mainly with vegetals, as well as minerals. We have many interesting clues owing to Karl Friedrich Philipp von Martius's researches, which above all can be found in "Reise nach Brasilien" (1817-1820) and in "Flora Brasiliensis", published in 1829.



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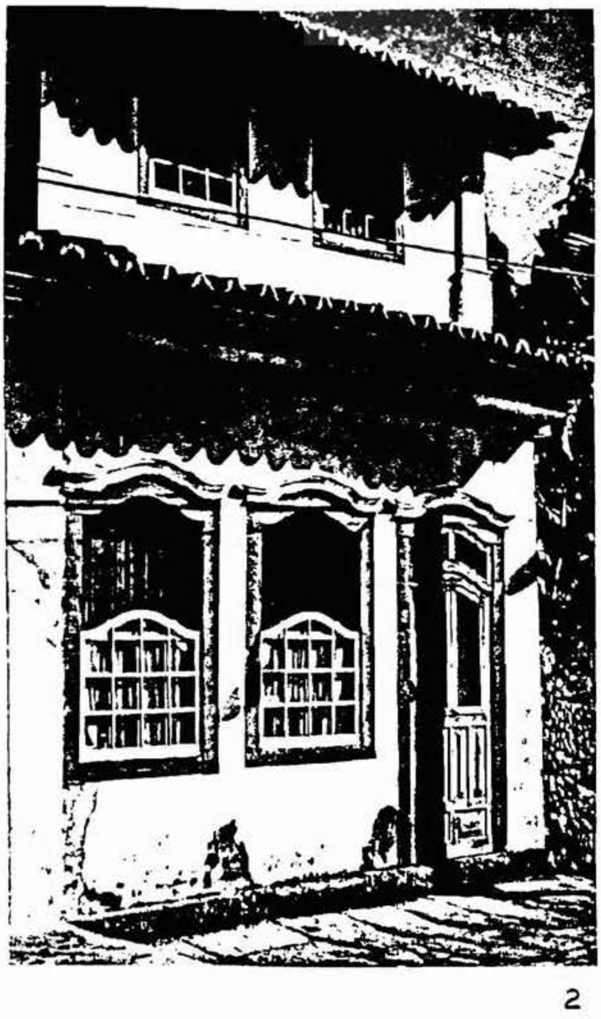
We can notice that the colours which were largely used on the wooden surfaces were saturated hues like yellow, bright red, pure green and a special blue that became so popular that it is even today known as the "azul colonial" (pictures nº 2 and 3). On the houses of Parati, they contrast with the radiant white of the walls, which sometimes are ornated with friezes (nº 4).



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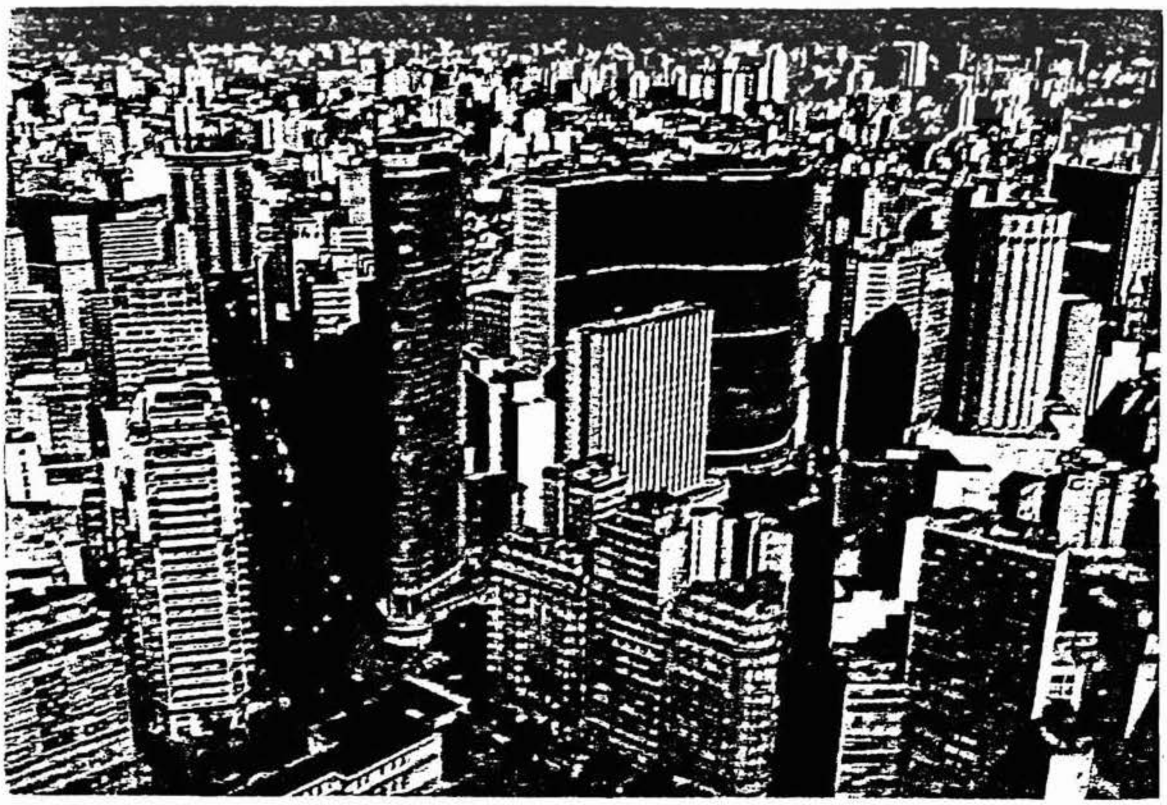
It is important to remind that this architecture stands out in the middle of a colourful landscape and against a very intense blue sky, in perfect harmony with its natural environment. It seemed to us interesting to note, eventually, that the hues available at that time were less varied than nowadays but, with their precarious means, the colours in Parati belonged to a natural order. The present industry floods us with innumerable synthetic colours; however the contemporary architecture doesn't always reach such an ideal accord with its environment.

In the first half of the decade of the 1970, a very signifiant change in the look of fronts became noticeable among houses in São Paulo: spots of vivid colours dotted a predominantly grey architecture. This tendency came simutaneously with the polychromic architectural movement particularly in the U.S.A. and Canada. In the Southeast of Brazil we found two basic factors explaining it.

First, a psychological reason, related to an attempt to balance off with colour the absence of Nature in this "concrete jungle", as São Paulo is usually called. If you fly over São Paulo, you have the impression of seeing a big American town like New York (picture n° 5). São Paulo is "colourful" in its essence because it is a melting-pot. Many differents cultures — Portuguese, Italian, Spanish, Japanese and others — participated in its demographic development. We shouln't forget the internal migration from the North to the South of Brazil. And today it reaches around twelve million inhabitants. This cosmopolitan city grew inordinately asserting a dynamic will towards the future. As we already suggested above, colour was the spontaneous expression for an inconscious desire of São Paulo people to look for immediate solutions. It was as though this complex megalopolis had then needeed to breathe, recover colours from landscapes that still remained in the memories of its inhabitants.



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In the second place, we have another easily detectable and confirmed reason. With the population growth of the town of São Paulo, the traditional commercial center exploded and its shops started to invade the residential neighbourhoods. Consequently, some of these streets became more noisy and polluted, because of the traffic increase. Many residents decided to move out to quieter and more distant flats or houses. The owners sold or rented their former houses to shopkeepers or other professions, interested in settling in these areas. They were built to serve as homes and needed some renovation in their structure; for instance front gardens were changed into parking-lots. But obviously, the most necessary transformation concerned the front of houses.

They had to deliver an informative message in order to stand out from the others. What better solution could be found by architects, designers or even private individuals to attract attention on the commercial functions of these buildings ? Painting them in an unusual way.

Figurative and geometric images, graphic devices and above all colours introduced a new plastic connotation to these streets. The Augusta street, for exemple, an important commercial artery since the forties, linked the center to the residential districts and has spread out in the bordering neighbourhoods; fifty out of the three hundred shops in that area were given a new colourful skin between 1973 and 1974. This explosion of colours and creativity which could be considered as an urban decoration, has offered original examples related to Op-Art, Pop-Art, with graphism sometimes similar to advertisements and directly influenced by outdoor posters.

We included (with the text) some black and white pictures, as was expected, but colour slides could also be shown in the working groups.

We can see in picture 6 that the message on the foreground façade is very clear: the gigantic painting of the white sole of a foot on an orange background is the sign for a shoe-shop. The picture n° 7 refers to the chain stores "Jean Store", specialized in blue-jeans. Naturally the predominant colour is blue but the details are in red or yellow.

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On picture nº 8 the information is more subtle: the shop sells material for artists. The creators of this façade, Antonio Celso Sparapan e Auresnede Pires Stephan, were inspired by the real tree on the pavement which served as a model. The white strips of the blinds drawn on the façade seen on picture nº 9 contrast with the bright intense blue.

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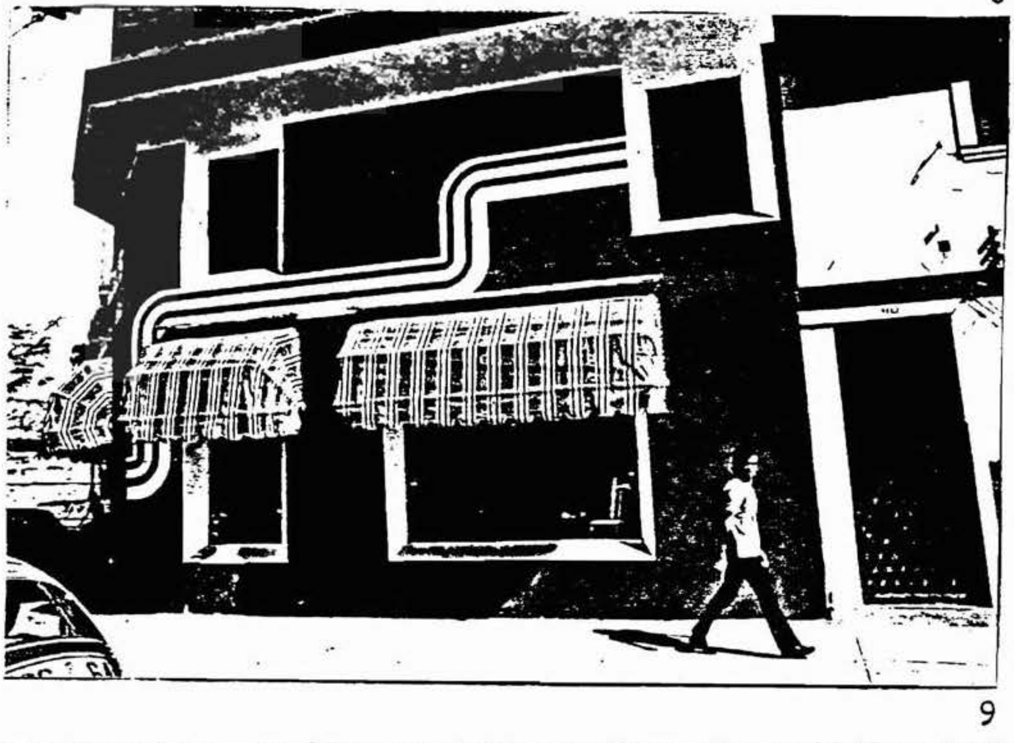

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In pictures 10 and 11, we have variations where the painting took hold of the front, hiding and disguising the architecture details.

This polychromic phenomenon, in São Paulo, extended to residential houses too: the picture nº 12 offers us a good demonstration of the desire to separate two symetrical attached façades with colour. A sense of community can be felt in picture 13, where the colours are harmonically integrated on a line of semi-attached houses. A more eccentric instance is a painted lamp_post, which must have passed unnoticed from the public authorities. It was made by the inhabitants of a street in the district of Sumaré, who were willing to express their artistic skills and to break the visual monotony of their urban space (picture nº 14). Another similar event ocurred on a larger scale. It provoked a reaction from the Town Council, and the authors were fined. Under the guidance of Mauricio Fridman, inhabitants became artists, painting fronts, pavements and walls of their street.

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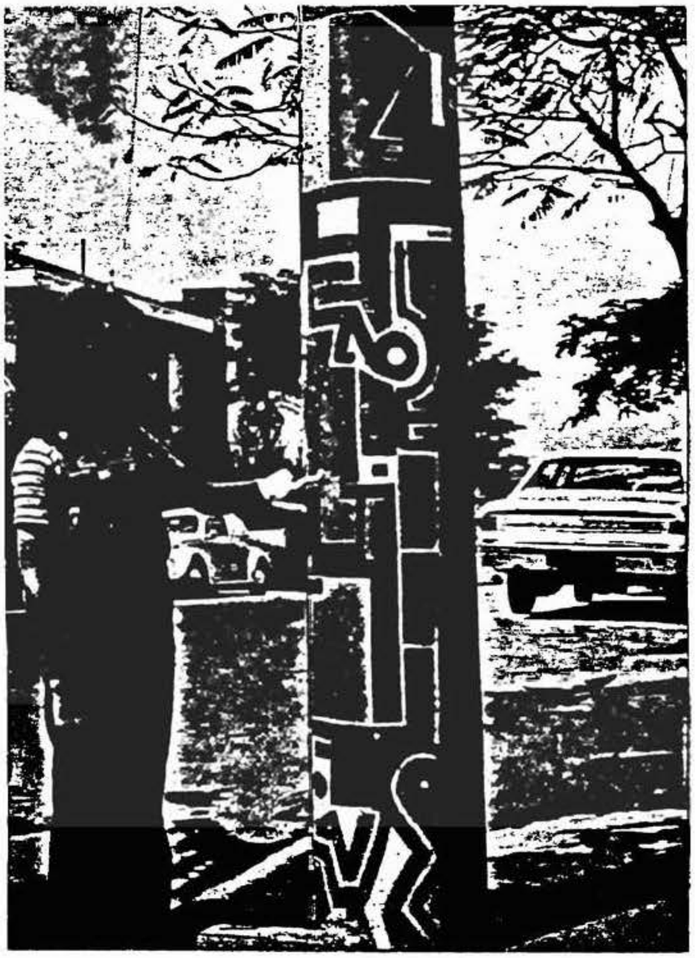

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These happenings prove that colour was very gladly accepted from the inhabitants of São Paulo. From then on, buildings started to have a more colourful apparence, as we can see in picture 15: intercalated orange and beige hues give a certain rythm to the heavy edifice structure. The 1970 trend is now giving way to less spectacular polychromic creations, which were the results of studies by architects, reflecting on the subjet. But would it be possible to have direct applications of already known Colour Order Systems ?

15

Recently, much has been written on colour in architecture and scholars are concerned with the matter — architects and colorists of course, but also plastic artists, psychologists, anthropologists, physicists and sociologists. All of them are interested in improving the urban environment. We are conscious of the energizing power of colours, that mankind needs colours to live, as Léger once said. In the rush to build new cities we'll have to choose colours that will be at least "comfortable" for the eyes.

It is necessary that the humanist as well as the scientist unite their efforts in finding a system which would actually help in the application of colours in architecture. The problem remains to know if the ideal solution would be one system or different specific systems applying to various architectonic situations... Anyway, we should keep our common sense and mantain a creative freedom — inside a team-work, which would gather specialists in different subjects minded to create around the architect.

As a conclusion, this thought written by Le Corbusier in 1931 in an unpublished text about "polychromie architecturale" can contribute to our reflection: "To create objects of satisfaction: isn't it really what the architect's task is all about? There are many degrees in that satisfaction; everyone to the degree that suits him and that is his own".

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Advantages and requirements of colour-order-systems based on instrumental techniques.

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Colour atlases

Many colour-order-systems are presented by a number of colour samples generally arranged into a so called "colour-atlas".
As long as colours exactly present in such an atlas are concerned, these systems are a good auxiliary mean for communication about colour. Problems arise if other colours are concerned, because interpolation between the samples in the atlas in order to estimate the codification of any given colour, is far from exact.
This inexactness is raised by the fact, that even if the number of colour samples in an atlas is over thousand, there is a rather big colour difference between two adjacent samples. Moreover it is difficult to interpolate visually between 6 or 8 samples (along three different axes), which is generally necessary.
In order to obtain an impression of the (in)exactness of the interpolation procedure, we asked 8 experienced people to estimate the codification of 4 different colours in 3 different atlases (DIN, Munsell and N.C.S.).
In those parts of the respective colour atlases where the 4 colours were located, the mean colour difference between two adjacent colour samples varies from 8 to 12 CIE $L^*a^*b^*$-units (dependent on the colour-order-system concerned) in each of the three dimensions.
The codifications, obtained by different people for one colour in one atlas showed a mean standard deviation of 2 to 4 CIE$L^* a^* b^*$ units, again dependent on the colour-order-system and again in each of the three dimensions of the system concerned.

These deviations are much greater than most visual colour acceptability tolerances and therefore the potentiality of colour atlases as reference specimen and in judgment procedures is very limited.

If at least a moderate degree of exactness is required, either an exact colour sample or a reliable colour measurement result is essential. Therefore, for many technical purposes colour-order-systems based on colour characteristics, which are obtained by colour measurements (reflectance measurements) are strongly preferred.

Colour measurements

To obtain reliable and adequate colour characteristics by colour measurement a number of requirements have to be fulfilled, such as colour samples showing a proper surface condition. An instrumental result is much more sensitive to defects in or on the surface the human perception is.
Colour measurement results are also strongly influenced by the geometry in use (particularly the processing of the specular component), the calibration procedure and some instrumental characteristics of each individual (make of) instrument. For this reason results, obtained with different instruments, are only comparable, if the above mentioned aspects are very well controlled, or in other words: colour-order-systems based on colour measurement have to be attended with stringent instructions for the colour measurements.
A stringent calibration procedure has to guarantee the long term constancy, necessary for the comparability of codifications obtained at greater time-intervals.

Correlation visual perception - colour measurement result

There should be a close relationship between the colour characteristics derived from colour measurement results and the visual perception of colour, with respect to the nature of these characteristics as well as to their magnitudes.
As for the nature of colour characteristics the frequently used X,Y,Z,- (or x, y, Y-) co-ordinates are not easily interpreted in terms of visual perception. To a lesser extent the same applies for the L^*, a^*, b^*- co-ordinates. Much better is to translate the results in terms of hue, saturation and lightness or similar ones.
With respect to the magnitude of colour co-ordinates in the past very little attention has been paid to the question which measurement procedure gives results that are optimally related to visual perception. Up to

now this aspect is neglected in the colour measurement procedures of many colour-order-systems. Nevertheless these colour-order-systems are applied to a wide variety of materials.
Furthermore it has to be realised, that not only colour measurement results but also visual perception of colour can be affected strongly by illumination and viewing conditions. Above all this applies for the lightness and the saturation, which generally are influenced in a mutually opposite direction, in case of colour measurement as well as in case of visual observation.
Therefore the colour measurement procedure has to be related to the conditions for visual observation.

A very frequent problem is the comparison of coloured paint or plastic samples of different degrees of gloss, i.e. the problem to eliminate the gloss influence in order to obtain a real colour characterisation.
One of the scarce publications is from D.B. Judd (1), which refers to the work of an I.S.C.C. committee in the 1940's. The conclusion was, that a combination of measurement results, one obtained by sphere - geometry (specular component included), and the other by 45% - geometry - the latter weighted twice - gives the best results in this respect.
Our own investigations led to a somewhat different conclusion: to obtain adequate colour characteristics of mat, semigloss and high gloss paint panels, the reflectance values obtained with sphere-geometry including specular component have to be corrected with 0%, - 2,8% and - 3,2% (abs.) respectively. Notable is the small difference in "gloss-correction" for semi- and high gloss panels.
For plastics of different degrees of gloss a similar solution was found.

More difficult is the comparison of colours of quite different materials, like paints and plastics on the one hand and textiles on the other.
The spaces between textile fibres have the capacity to work more or less (strongly dependant on its structure) as lighttraps. In this case an extra amount of light is withdrawn from reflectance, whereas in case of smooth glossy surfaces there is an addition of an extra amount of light (specular component).

In order to achieve a close relation between the visual comparion of colours of paint versus textile samples and their codifications, it turned out to be insufficient only to vary the correction of the reflectance values.
In the A.C.C. (Acoat Colour Codification) system (2) we succeeded to obtain the close relation referred to above by an additional change in the calculation procedure, viz. a change in the lightness-correction-factor of this system 1).

In this way one of the main objectives of the A.C.C.-system has been achieved: an objective basis (colour measurement) for a colour-order-system which correlates very well with visual perception of colour, independent of the material concerned.

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(2) G. Döring, Die Farbe 29, 53-75 (1981)

1) This work was carried out by the Enka division and the Corporate Research Department of Akzo.

Paper at the Forsius Symposium
on COLOR ORDER SYSTEMS
KUNGÄLV SWEDEN 1983

Lars Sivik
Anders Hård

"ON THE APPEARANCE OF COLOR ORDER SPACES"

(Abbreviation of: **Distances between colors - a comparison of different structures**)

The sensible meaning of the concept of color is the subjective color sensation in a living organism - but here we shall limit ourselves to human beings. Color and color sensations seem always to have interested most people, including physicists, pigment chemists, neurophysiologists, psychologists and artists - and any prolonged study of their work on what color is and what it means, leads to a state of confusion. The uninitiated reader of this paper may complain that he has thus been led into it himself. To draw attention to existing confusion is, however, not actually to add to it, but the first step toward reducing it to order.

There are many colors, and those who have studied the question claim a good eye can distinguish millions. Color names abound not least in the terminologies of haute coiture and art criticism. But everyday speech uses few, there are the assumed colors of the rainbow and a couple of other words. Each of these consequently has to include quite a number of different color perceptions; the word brown, for example, covers a large part of the "color world".

To describe colors precisely demands a "color language" with a well defined structure. Many exist, few are stringent enough. The most common words denoting color comprise a simple, very imprecise category system, varying only slightly between different cultures and language areas according to the need. In well developed languages, however, the most common words denoting color always denote approximately the same colors.

Each of the diverse contemporary color order systems stems from the specific, sometimes scientific, point of view of its originator. An expert of pigments sees the whole world as pigments, e.g. Ostwald, a physicist sees it as rays of different wavelengths and energy-quanta and his nomenclature has been taken over by the neurophysiologist in studying the retina.

A psychologist of perception wanting to reduce **color perceptions** to order will naturally start with perceptions, and theories of their interrelations. The Hering theory of opponent colors is one, and the Natural Color System (NCS) is a logical attempt to convert it into a systematic and useful language of color.

Disputes are frequent and futile over what colors are primary, an argument valid in one context being meaningless in another. Artists must know what mix produces what they want, a lighting engineer should know the special composition of light-rays, and so on, from one specialist point of view to the next.

The language of one area of expertise is esoteric, particularly to the denizen of another, and it is notorious that experts in different subjects cannot make sense to one another. It is desirable (which perhaps means merely over-optimistic) to suppose that specialists in color might know the different languages of color or at least the one most "natural" for a layman, a language that requires no knowledge of electrophysics but simply arranges colors according to a phenomenological analysis of how they are perceived. Hering´s theory and the NCS seem best fitted for this.

The problem become clearer when the different color structures are related to one another. The properties of color stimuli are better known than the means whereby physical energy is translated by neural activity into perception, while the associated psychological interpretations put on different colors and other subtle influences they convey are even less explicable.

We now compare four color structures of different conceptual origin:

I. The formal arrangement of colors according to the NCS metric;
II. A structure of semantic distances;
III. A structure of unspecified similarity distances;
IV. A structure in which distances between colors are defined as contrast;

Semantic color structure. Semantic differences associated with color meaning have been identified in many investigations, (summarized by Sivik 1974 a,b,c,d), also showing how factors of the meanings of colors could be related to the perceptual NCS-space employing a method of direct mapping with "iso-sematic lines". In the present study we examine data of the same sort to see what structure the different colors might form, as regards their semiotic content. Suppose a strong red and a strong green, that are perceptually very different, have the same values on different factors of meaning (e.g. from semantic differentials); this would indicate that they are semantically the same, and would thus occupy the same position in the "semantic color space". Such a space would be entirely different from a perceptual one, which, however, does not seem to be the case. The extreme opposite of this example would be that the perceptual distances between colors were the same as the semantic distances - but that is as unlikely.

Similarity between colors. Experiments with color similarity were reported by Ekman as early as 1954; he used a number of color stimuli around a hue-circle. Since then his data have been frequently used as a routine all over the world to examine new species of what is called multi-dimensional scaling (MDS). This method has also been applied in pure color-metric research (Indow & Ohsumi 1972), for example, who studied the similarity structure of Munsell color samples.

In the present study we have kept constant the dimension of hue, so as to hypothesize only two dimensions. The same set of constant-hue color samples was used in two similarity studies with different groups of subjects and different methods of MDS analysis.

Distinctness of border. We have examined elsewhere problems of color-combinations and contrast. (Hård & Sivik 1974). Contrasts between different areas are of course important when perceiving forms and patterns. In the experiments we defined one kind of contrast that is hypothetically crucial in the formation of patterns as "distinctness of the borderline that is perceived between two fields". This concept has earlier been used by, for example, Boynton (1973).

METHODS

The NCS space. In NCS a color perception is defined by reference to how closely it is perceived to resemble each of the elementary colors. These grades of resemblance represent the perceptual attributes of color called blackness, whiteness, yellowness, redness, blueness and greenness. As they are not mutually independent, they can form a structure of only three dimensions. Each color is specified separately and within certain definitions. The distance between the placings of any two colors is consequently a secondary measurement in terms of the graphical model used; by way of an example see figure 1.

The color similarity space was constructed from distances defined as "the perceived similarity (or dissimilarity) between two colors". These subjective estimates were treated as distances and we used MDS methods to bring the distances into a configuration, here of two dimensions. Two different studies were performed using the ten colors with NCS-positions as in figure 1.

LI. (Similarity study no 1) used 30 heterogenously sampled subjects. The lighting was a 60W incandescent lamp 1m from the color sample. The used MDS was Shepard and Kruscal´s non-metric method in Torgersons version (TORSCA)(Young 1968).

LII. used 21 Ss who were all students of psychology. The lighting was a Luma Colorette (fluourescent tubes well simulating daylight). Data were here transformed by INDSCAL (Carroll and Chang´s metric method, 1970), which also traces differences between the styles of judgement of the individual subjects.

In both studies the two colored surfaces (with a white frame) were presented as in figure 2. Each S judged the similarity between the colors on a 10-step scale in which 1 meant minimal and 10 maximum similarity; 10 thus corresponded to colors perceived as identical.

Semantic space. A difference in meaning between two colors can be defined as a distance in a semantic space (Osgood et. al.1957). In our study the space was defined by three "principal components" derived from semantic differential judgements of the ten colors (15 SD-variables). In the experiment, which was carried through individually, the color samples measured 13 x 18 cm; the Ss and the experimental conditions were the same as in LI described above.

The principal components were: 1) Evaluation (beautiful-ugly); 2) Excitement (exciting-soothing); 3) Forcefulness (energetic-lazy). The distances in this space were adapted to a two-dimensional configuration by the TORSCA-program.

Distinctness of border. Subjective measurements of this variable, as we defined it previously, were taken to be distances between the judged colors and were transformed by the INDSCAL program to a two-dimensional constellation. The estimations were made by 21 psychology students, but not those who had taken part in the similarity experiment LII. The color fields bordered each other; angles of lighting and observation were adapted to eliminate undesirable optical artifacts.

RESULTS AND DISCUSSION

As shown in figure 1, three of the studied colors chosen lay along the black-white variable (the gray-axis) and the others were of approximately constant hue.

Figures 1-3 depict the MDS configuration of the two-dimensional solutions described.

The first thing one notes when comparing the different outcomes is that the colors appear in almost the same constellations, in the same order and the same dimensions. As to the dimensions one may say, however, that the those derived from the TORSCA method are arbitrary and so must be rotated into a meaningful direction. The INDSCAL procedure, on the other hand, fixes the dimensions and they emerged as the figures show, i.e., as one dimension of lightness and one of chromaticness. That the constellations of colors recur honors the methods. It may also be noted that the two similarity experiments give almost identical results - despite the differing experimental conditions of outer conditions as well as methods of treating data.

Noteworthy too is the clear reflection of the NCS structure in the semantic color space in two dimensions. We will comment on this later.

Most interesting is the systematic change that has occured in some places to the relative distances between the colors, for this may be of value in research on color attributes.

NCS vs. similarity. In the NCS configuration in figure 1, it will be recalled that the colors are defined and thus placed by the resemblance of each to each of the elementary colors, but not, be it noted, by comparison one to another. The similarity study, on the other hand, compares each to all the others.

When one compares the two configurations of similarity (figure 3 and 4) with the NCS positions (figure 1) the colors 1, 2 and 3 - i.e. the achromatic ones - have conspicuously been pushed away from the others in the similarity judgements. This is easy to interpret; these three are all gray while the other seven are chromatic, although in varying degrees.

This chromatic/nonchromatic division is the most obvious categorization in the relatively small material of ten colors, but it would seem that the method of comparing similarity data with NCS data (derived from a kind of magnitude ratings) could trace in more extensive experiments other attributes of colors as well.

NCS - similarity - borderline. In the perceptual border-structure (as previously described) we did not find that chromatic and achromatic colors, as it were, repelled each other. This also supports our suggested explanation of categorization in the (cognitive) similarity-structure. In judging "the distinctness of border" there is no reason to classify the color content, the variables in question in this direction seeming to be a monotonous function of the chromaticness (the abscissa).

It seems that the dimensions of the borderline-configuration, as scaled by INDSCAL with its fixed axes, are the variables of lightness (ordinate) and chromaticness (abscissa) and it shows a considerable concordance with NCS. The lateral compression of the border-structure may be explained by the fact that the differences in chromaticness has a weaker influence on the distinctness of the border than a difference in lightness.

We studied separately the relationship beween the NCS and measurements of contrast and this work is to be presented in a forthcoming report.

Semantic space. To recapitulate, the ten colors were separately judged on 15 semantic differentials (SD), the averages of which were intercorrelated and factoranalysed to an orthogonal, three-dimensional structure. We would not deny that this is somewhat dubious because the colors are too few in relation to the number of SD-scales. In this three-dimensional space, however, our colors may be found as points with coordinates defined by the factor-scores. In the NCS-, similarity- and the borderline-spaces the colors were spread out in an approximately two-dimensional plane, and we were prepared to advance the hypothesis that this would be the case in the semantic space also. The color positions in the semantic factor space were transformed by the TORSCA program to the two-dimensional solution shown in figure 5. This program provides for each solution what is called a stress value that tells by how much the procedure of approximation has violated the given data; the stress here, being .11, is unaccepatable.

Having considered the deficiencies of both factor analysis and the MDS solution that we have described, we think it remarcable that the constellation of the colors in figure 5 still closely resembles the other outcomes and yet more so that the displacements to be observed may be interpreted in psychological terms. The small distance between colors 2 and 5 shows that they have both been categorized semantically as dull-ugly-distasteful, being dominated by their grayness. Compare this with the similarity structure in figure 4, in which differences are to be emphasized, where these colors seem to be separated from each other. Colors 4 and 7 too have been placed close together in the semantic space for each may be considered as yellow with a white component and lacking in blackness and thus of the same character. Number 10 is away off from the others being an extremely strong yellow with prabably specific associations.

A space of color meaning, as defined here, takes its form from the variables of meaning it illustrates, and the position in it of each of a number of colors is influenced by the total range and number of colors thus presented; in addition the sample of subjects also affects the outcome. These facts should not be regarded as experimental handicaps but should be used systematically, not only, as is repeatedly done, to prove that they are influential; one should try to elucidate when, where and by how much they influence the results of this kind.

We would say, in conclusion, that although the color relations of the present studies are tentative they have demonstrated at least how structures of color perceptions vary from one point of view or method to another; a color space is a result of the concept on which it is based, of the principles chosen for its parameters and of the scaling methods. These remarks may sound trivial if they had not hitherto been only inadequately recognized. The comparisons have further shown that systematic differences between different structures can be analysed so as to provide information relevant to research and color perception in the broadest sense.

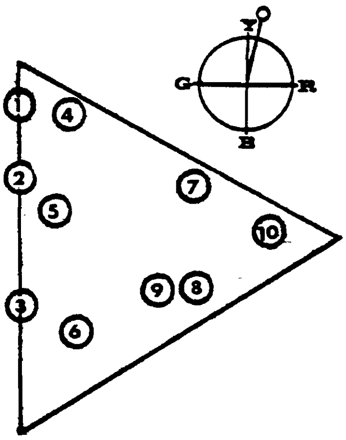


Figure 1.

NCS-positions of experiment colors

Figure 2.

Similarity studies, stimulus design, diminished 4 times.

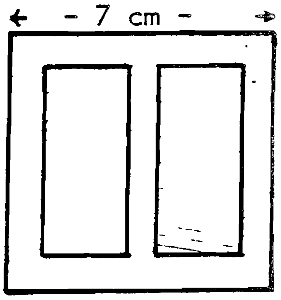
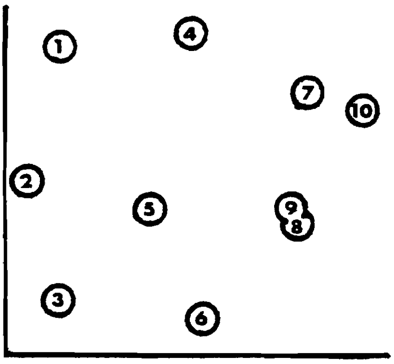


Figure 3.

Similarity study LI: Configuration of colors, incand. light, TORSCA



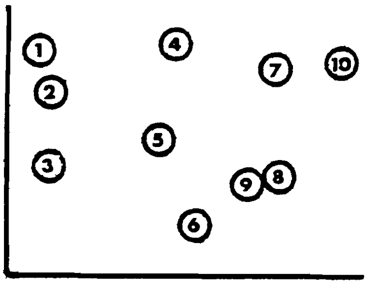
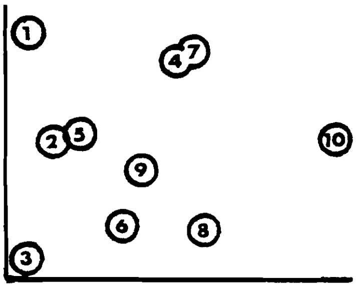


Figure 4.

Similarity study LII, Configuration of colors, light C INDSCAL

Figure 5.

Semantic study: Configuration in 2 dimensions of the colors in a 3D semantic space.



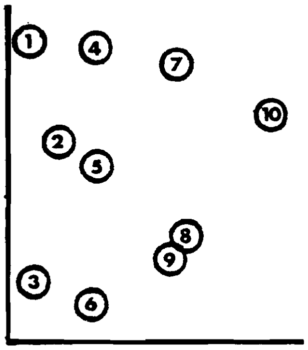


Figure 6.

Distinctness of border: Configuration INDSCAL 2D.

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SUMMARY

Sivik, L & Hård, A. Distances between colors - a comparison of different structures. **Göteborg Psychological Reports**, 1976, 6, No.7. - The concept of color can be variously defined. This study compares four different structures, each defining a specific structure of the numerous color perceptions. A eucledian two-dimensional configuration of ten colors of constant hue were defined by: a) NCS-coordinates, b) multidimensional scaling of perceived differences between the colors, c) factor-coordinates derived from variables of meaning (SD-data), and d) perceived distinctness of borderline between two color surfaces. The face-validity of the results suggest these methods of comparison as fruitful in investigating the nature of color and color differences.

NCS - as a basis for colour training at the National College of Art, Craft and Design, Bergen, Norway

Grete Smedal

Do we need a colour system in order to learn about colours? And do we need a colour system in order to teach this subject?

If the answer is yes, then which of the available systems is the "correct" or "best" foundation or aid in colour training?

Questions such as this must be answered before we attempt to build up tuition for colour training, irrespective of the type of school or the level at which our efforts are directed.

For almost ten years I have been responsible for the basic tuition in colour theory at BKHS (National College of Art, Craft and Design in Bergen, Norway), and during this period I have carried out experiments and gained experience which might perhaps be useful as a point of departure for a discussion on the use of colour systems in tuition.

BKHS is one of Norway's two colleges in the field of art, craft and design, and each year trains about 35 students in the sectors ceramics, graphics, furniture design, interior architecture and textile design. The basic tuition in colour theory is given to all disciplines, in courses of 120 periods during the first year of college.

The various departments work quite differently with colour with regard to technique, pigment mixture etc. The type of colour training which deals with textile dyeing, glaze chemistry, silk printing, colour mixing for graphic techniques, etc. is related to the tuition given in the individual department.

In courses in freehand drawing/painting, a comprehensive subject taken in all departments, the students work with colour as a pictorial element, and are given instruction in the qualities of colour as a means of pictorial expression.

In the subject Art History instruction is given in the significance of colour in pictorial art throughout the ages, and as an expression of different cultures and environments.

The object of the elementary, inter-disciplinary colour training is first and foremost that of discovering colour as a visual phenomenon.

The actual visible result of pigment mixtures and combinations is thus common to all students, and the elementary course attempts to create a conscious relationship to "what one sees". Often "what one does" becomes a barrier to the actual visual experience. One expects a certain result because one knows the technique, and "sees" something different from that seen by someone who views the product with no preconceptions.

It is just this difference between technique and visible result that convinced me that it would be particularly useful to make use of a perceptive colour system such as NCS, to permit the translation of experience "as it looks".

The actual learning of the system is extremely simple. This takes only a few days, during which we to some degree employ collage technique, combined with study material from the Scandinavian Colour Institute. The use of existing colour (magazines, textiles, etc.) means that it is the eye itself, and not the colour mixture which determines the place of a colour in the symbols. NCS's graphic symbols, the hue circle and the nuance triangle,thus become our "language" when we talk about what we see.

As the colour mixing exercises start, each experience is recorded in a circle or triangle. The visible result of the mixture is thus registered both with regard to hue and nuance. It is not long before the students discover the "three main colours of the pigments" and their location in the circle. The reproduction exercises are concerned with just the problem of describing a colour visually (NCS) before producing it by mixing. This trains both colour memory and sensitivity to minute variations.

With regard to phenomena such as after-image, simultaneous contrast, etc. we work again with no other aids than the eye itself. We experiment, we use our eyes, and we record in the NCS circle and triangle the experience we have gained, so that it becomes a useful piece of knowledge.

In this way we sum up many colour systems, all based on various basic concepts, and we make them into a body of knowledge based on the phenomenon of sight itself. As the "complementary colour pairs" differ somewhat according to the definition given to the concept (additive or subtractive colour mixing, after-image, etc. it is of particular interest to record these differences in one and the same symbolic idiom. If two colours are "complementary" it is, after all, because they interact in a special way, not "because they are located in opposite parts of the circle".

On this basis we can, for instance, discuss what "visually complementary colours" are.

It is essential for a design student to acquire a knowledge of the components which control a colour composition. What constitutes form, what likenesses and contrasts must be dealt with in the environment or in a product design? If things don't function as desired where can we start to put them right, what ways can we take to alter an expression, to influence the interpretation, etc.?

In other parts of the elementary course NCS is used as an idiom for the formulating of work processes and for discussion of the result of these. Without uniform terms it is difficult to give exercises structure, and even more difficult to discuss the result.

The object of this part of the course is to give a picture of the components of the colour gestalt, and I have found Anders Hård's colour combination model extremely useful in structuring work in this sector.

The three main dimensions: chord, interval, harmony (balance) and their sub-dimensions are treated in exercises in which an attempt is made to keep certain factors constant while varying others, to permit unambiguous discussion of the changes which take place. The influence of a change in hue on an expression, and the significance of the change in nuance can only be discussed if these factors are treated individually. The formative qualities of colour are treated in exercises. In some of these the chroma is constant, in others the hue and in others the lightness.

I shall bring with me to Kungälv some samples of student work from the school, which should show how useful we have found NCS as a basic language in our work with colours.

These exercises should show that exciting processes are often triggered off by a relatively simple point of departure, as there is a structure for the thought.

It is also my experience that if one outlines a work process and then systematically works through the possibilities it contains, one can exceed the limits of one's own taste, and can make new and exciting discoveries.

As a colour system NCS is value-neutral in that it does not give rules for what is ugly and what is attractive, or for what "one ought to do". The system is quite simply built up on the visual qualities of the colours, and is arranged so that visual similarities and differences can be described. Colours with the same relationship between two coloured elementary qualities (with the same hue) have the same location on the circle. Colours which have equal chroma are situated on the same scale of the triangle (parallel with the grey scale). Colours with the same degree of likeness to white are located on scales parallel to the "non-white" scale of the triangle, etc.

At the present it is difficult to form an opinion of the extent to which these visual likenesses form the point of departure for a "harmonic theory". This is however a fascinating and exciting field of study and the purpose of several exercises is just that of "balancing" the colours up to certain likenesses in order to study the importance of these. The symbols give good assistance in the planning of such exercises and discussions of the results.

I am convinced of the value of the individual attempting to work up his or her own "rules of harmony", or rather of becoming conscious of his or her own experience of, for instance, "ugly and attractive". If the experience that has been acquired is recorded in symbol form, spontaneous findings can become firmer knowledge. It is perhaps just here that we find the most important objective of colour theory: that of increasing consciousness. Knowledge must not inhibit creativity, but must open eyes and expand horizons, so that the tool which colour forms can be of service in evoking an image, or in product or environmental design.

Acting without thinking can often be fruitful, not least in the field of art and design. Such action allows spontaneity, sensitivity and personal commitment to find expression. But if we are to develop in relation to ourselves I think we must stress the value of analysis, of thinking about what we have done. This will provide valuable experience. I think that a language is necessary in such an analysis, and that NCS functions as such a language for our purposes.

During the spring of 1983 I have carried out an experiment with an inter-disciplinary group of students from the 3rd and 4th years in an attempt to apply their basic training to problems they have met at school or to phenomena they have been interested in.

I am also showing at Kungälv some of the work done in this connection, to demonstrate how the group used NCS to structure their processes, and recorded the results. The problems facing the world weren't solved, but we were able to share the experience acquired by the group on the basis of their findings, and perhaps we can also pass it on for the use of others.

Art, craft and design cannot be viewed in isolation in the community. As designers of the environment in which people live, or of part of it, the students will, in their future professions, constantly come into contact with trade and industry, manufacturers, architects, economists, consumer groups etc. As members of a team it will be important for them to be able to talk about their trade, discuss projects and put forward arguments in favour of their solutions. A common colour language will be an important precondition if they are to understand one another. I believe that such a common language should be a major part of colour training, forming a useful interdisciplinary platform, not only for communication, but also for further development towards new solutions and increased knowledge.

A Colour-Order System for Environmental Design

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The paper reports briefly on the search of an environmental designer for a suitable colour-order system. It describes a series of experiences with various systems, when used to solve practical colour planning problems. It also includes an important suggestion for further development, considering the matter from a pragmatic point of view. The author teaches colour design to architects and works as a colour consultant.

Having in mind the definition for colour-order systems which was worked out by the AIC Study Group[1], it has to be stressed here that an environmental designer for his practical work is, of course, primarily interested in the percievable colour samples, that means, in systematic colour collections based on real colour-order systems. Furtheron, such colour collections have the following conditions to be fulfilled:

1. sufficient number of colour samples (around 2000),
2. visual interpolation easily possible,
3. reasonable price,
4. covering also the periphery of surface colour space realizable by usual technologies,
5. removable samples of at least A9-size for handing out to painters or industry,
6. available colour papers of at least A4-size for demonstrating colour design concepts or projects.

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[1] AIC Study Group on Colour-Order Systems, Circular Letter No. 2, 5 April 1982.

Müller's Swiss Colour Atlas[2]

Müller's system is based on Ostwald's regular colour solid. The hue circle is better egalised than Ostwald's. The double cone is defined by 60 hue triangles, the legs of which are devided into 10 steps as in the later NCS. The parameters of "Farbwert" are whiteness and blackness, expressed by numbers from 0 to 10. The colour atlas contains 2541 mobile colour samples made of dyed paper circles with a diameter of 20 mm. When still available it was sold at a price of 300 sFr.

Müller's Swiss Colour Atlas was an excellent and inexpensive instrument for developing colour juxtapositions and for their visual control. Its use for demonstrating design ideas was very restricted, and for handing out patterns to the painter the samples were too tiny and delicate. Lost samples, unfortunately, couldn't be replaced.

Müller's Swiss Colour Atlas fulfilled in an optimal way condition 1,2,3.

Hesselgrens Färgatlas [3]

This well-known colour atlas offered supplementary colour blocks in a suitable size (condition 5). But Hesselgren's colour atlas contains only about 600 standards, which are not sufficient for practical work, since the steps between two neighbouring samples are often too big and interpolation of Hesselgren's parameter saturation is rather difficult.

So, the author turned again to Müller's Swiss Colour Atlas. And still, he had to mix his colour patterns himself. There was another difficulty too, with the Swiss Colour Atlas: As the samples are dyed papers, the so-called "dunkelklare Farben" between "Vollfarbe" and black are not very deep colours, they are rather whitish. So, this colour atlas could not be used for sampling deep-coloured synthetic resin coatings which are often used in environmental design. While Müller's Swiss Colour Atlas covers well the periphery of clear and brilliant colours, it does not fulfil condition 4 in the region of very deep colours. So, the search for a suitable systematic colour collection had to go on.

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2) Swiss Colour Atlas, 1965,
Dr. Aemilius Müller, Winterthur, Switzerland.

3) Hesselgrens Färgatlas, 1953.
Prof. Sven Hesselgren,
by T. Palmer AB, Stockholm, Sweden.

Munsell Book of Color (Glossy Finish Collection)[4)]

Its glossy version contains excellent deep colours. The number of 1566 standards is somehow sufficient and visual interpolation is possible without considerable difficulties (condition 1,2,4).

The problem with the Munsell Book of Color was at least in Switzerland that single bigger samples and colour papers were not available within a reasonable period of time. And the price of it was several times as much the price of Müller's Swiss Colour Atlas. So, it could not be recommended to students of architecture in spite of the existence of the inexpensive Munsell Student Set, which is very qualified for explaining the Munsell colour-order system, but which is not differenciated enough for being used as a work instrument for environmental design.

So, the author continued to work mainly with Müller's Swiss Colour Atlas and sampling deep colours with the Munsell Book of Color.

For didactic purposes in the formation of architects he preferred the regular colour solid of Müller's to Munsell's irregular color tree, although he knew, of course, to appreciate the advantage of Munsell's unlimited colour space which can be extended according to the development of the technology of colorants.

Natural Colour System NCS[5)]

At the AIC Colour Congress in Stockholm, in 1969, the author saw for the first time a prototype of NCS. He was, at once, very much interested in its issue especially because of the colour papers which should be available (condition 6).

As far as the system itself, the conflict between regular but limited systems (Ostwald, Müller) and unlimited systems with irregular form (Munsell, Hesselgren) is solved in an elegant way, as it combines the advantages of both (regular colour solid and nevertheless the possibility of extending the periphery of realizable colours).

The colour code using six pregnant colour perceptions combined with the concept of percentage for localizing nuances within a tripolar field, can easily be learned by students.

[4)] Munsell Book of Color (Glossy Finish Collection), 1976,
by Munsell Color Macbeth Division of Kollmorgen Corporation,
Baltimore, Maryland, USA.

[5)] Natural Colour System NCS, 1978,
Anders Hård,
by Scandinavian Colour Institute, Stockholm, Sweden.

While Munsell's parameters "value" and "chroma" are very useful for visual analysis of single colours by interpolation, the NCS parameters "blackness" and "chromaticness" supplied by whiteness seem to the author more suitable for solving problems of colour juxtaposition in environmental design. It is not the place here to prove this statement. The following hint may be enough: The same NCS nuance gives to colours of different hues an optimum of inner relationship keeping on the other hand the natural contrast in value analogous to the spectrum. Equal Munsell value and chroma makes colours of different hues just superficially similar, while the inner relations of whiteness and blackness remain different. But that's a matter of design theory.

The different NCS-Editions:

- NCS Colour Atlas
  The 1412 colour samples include rather deep colours and their number is just somehow sufficient. Of course, the author would prefer having the nuances of 30 % and 20 % chromaticness complete. The scales of low chromaticness (2 % and 5 %) are very welcome. The NCS Atlas fulfils conditions 1,2,3,4.
- NCS Colour Index
  1412 systematically ordered colour samples at such a low price can be recommended even to students.
- NCS Colour Blocks
  They are very handy for rough analysis of existing colours and they can easily be carried along.
- NCS Colour Album (A9-samples)
  It is very practical for atelier work and for handing out patterns to painters or industry (condition 5). As there are three samples of each colour, the collection stays complete when a few samples are removed. Single colour booklets are available and can be replaced.
- NCS Colour Register (A6-cards)
  It is useful for showing colour ideas to a plural number of people, as for instance, met in building authorities.
- NCS Colour Papers A4 and Colour Sheets A2.
  They are enormously welcome to environmental designers for demonstration of whole colour design concepts or projects (condition 6).

The author was very much interested in testing the question if the number of NCS colour standards is sufficient for solving a practical problem like his latest task, the complete colour and material planning of the gynaecological department of the State Hospital of St. Gallen: He experienced that he could find acceptable approximations among the NCS colour standards for every color to be represented in a rather complex colour conception. By using exclusively NCS colour papers, he saved a lot of time.

This is true for the planning stage of conception or project only, but it is not valid without exceptions for the following stage of detail planning[6]. When the real colour coatings have to be harmonized with other chosen materials and exactly prescribed for the painter or for industry, it will happen that the designer urgently needs colours lying between the standards.

By means of a colour code which allows visual interpolation the designer can describe exactly what he needs. But will paint industry be able to deliver interpolated colours determined only by the code?

Suggestion for further development

The aim:
The environmental designer wants to get the opportunity to order every possible colour between existing colour standards as far as realizable by the colorants of paint industry by describing it with the help of interpolated values of the NCS or Munsell colour code and by defining the light source under which the ordered colour must match the original NCS or Munsell colour.

Chance of realization:
As paint industry has already started to offer NCS colours, it will not be too difficult to offer also interpolated colours.

Problems:
But anyway, it is quite clear that problems of metamerism can arise, when any paint factory for producing "NCS colours" uses its own colorants. As long as such colours are used under light source conditions similar to CIE light source C the problems might not be very serious. But solutions have to be found for those cases when the existing light source differs considerably from CIE light source C, which often occurs in interior design.

Conclusion:
If colour-order systems are not for restricting design work, but - as we hope - for promoting a sensitive and differenciated use of colour in environmental design, great efforts have to be made for reaching the above formulated aim in the near future and for findir economic ways for solving arising problems with metamerism.

This will be a considerable instrumental progress for practical design work, made possible by the precisely distinguishing colour code of a colour-order system really useful for environmental design.

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6) Farbgestaltung in der Baupraxis,
Werner Spillmann
in Bauhandbuch '83 BSA/SIA/SBV,
by Swiss Research Centre of Building Rationalization,
Zürich, Switzerland.

Åke S:son Stenius*)

CIELUV, CIELAB, MUNSELL AND NCS AXES TRANSFERRED TO THE CIE STANDARD COLORIMETRIC SYSTEM

For comparing various colour order systems a transfer of their axes to one and the same system has been performed. The CIE Standard Colorimetric System has been chosen the common denominator of this comparison.

The transposition of the CIELUV and CIELAB chromatic axes

The CIELUV uniform colour system is defined by three rectangular coordinates[1]:

$$L^* = 116(Y/Y_n)^{\frac{1}{3}} - 16 \qquad (1)$$

$$u^* = 13L^*[4X/(X + 15Y + 3Z) - 4X_n/(X_n + 15Y_n + 3Z_n)] \qquad (2)$$

$$v^* = 13L^*[9X/(X + 15Y + 3Z) - 9X_n/(X_n + 15Y_n + 3Z_n)] \qquad (3)$$

The CIELAB uniform colur system is also defined by three rectangular coordinates[1]:

$$L^* = 116(Y/Y_n)^{\frac{1}{3}} - 16 \qquad (4)$$

$$a^* = 500[(X/X_n)^{\frac{1}{3}} - (Y/Y_n)^{\frac{1}{3}}] \qquad (5)$$

$$b^* \quad 200[(Y/Y_n)^{\frac{1}{3}} - (Z/Z_n)^{\frac{1}{3}}] \qquad (6)$$

In the eqns.(1) to (6) X, Y and Z are the tristimulus values of the sample and X_n, Y_n and Z_n are the tristimulus values of the CIE Standard Illuminant chosen.

In a rectangular coordinate system the loci of one axis is defined by the points, where the other variable is equal to zero. Hence, equating the variables a^*, b^*, u^* and v^* in turn to zero will give rise to the equation of the line representing the other chromatic variable in the space. Taking into account that the expressions forming the equations for the four axes all contain factors consisting of a difference between two terms, equating these terms and converting their tristimulus values to chromaticity coordinates will give the equations representing the axes when transposed to the CIE chromaticity diagram. For details of these calculations, cf Stenius[2].

So we obtain for u^*: $\quad y_n x + (1.5 - x_n)y = 1.5y_n \qquad (7)$

and for v^*: $\quad (4y_n + 1)x - 4x_n y = x_n \qquad (8)$

and for a^*: $\quad y_n x + (1 - x_n)y = y_n \qquad (9)$

and for b^*: $\quad y_n x - x_n y = 0 \qquad (10)$

The equations (7) to (10) have in common that they pass the achromatic point

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(x_n,y_n), but differ in their intercepts of the x- or y-axis, respectively. Hence, an equation of a line having these properties *will be common for the four axes* a^*, b^*, u^* and v^*:

$$(y_i - y_n)x - (x_i - x_n)y = y_i x_n - x_i y_n \tag{11}$$

where x_i,y_i represent the intercepts with the axes x or y.

The two types of constants x_i,y_i and x_n,y_n in eqn. (11) determine either what axis it represents or what slope the standard illuminant chosen will give to the axis.

The values of the four pairs x_i,y_i may be found from the eqns. (7) to (10) and are collected in Table 1:

Table 1. Corresponding intercepts x_i,y_i of lines given by the eqn. (11) with the (x,y)-axes of the CIE Standard Colorimetric System when representing the CIELUV and the CIELAB axes.

axis	x_i	y_i
u^*	1.5	0
v^*	0	-0.25
a^*	1	0
b^*	0	0

Because each of the transposed axes are straight lines between the achromatic point and the contour of the colour triangle, they represent loci of points of equal dominant wavelengths. However, their inclinations, and thereby the dominant wavelengths, will vary with the standard illuminant chosen. The dominant wavelengths characteristic for the negative and positive parts of the axes are collected in Table 2. In each column of this table the smallest and the largest figure are printed in italics. This facilitates the judgment of the range within which the colour varies for each axis. Since the hue ranges thus are comparatively large, the question arises how well they correspond to the intended elementary colours. Cf. Fig 1.

For obtaining an answer to that question the chromatic axes of the Munsell and the NCS systems were transposed to the CIE chromaticity diagram. The functions used for the elementary colours were third degree parabolas obtained by regression analysis of the chromaticity coordinates of elementary colour samples. For the Munsell system some 10 coordinate pairs of the hues *5Y, 5R, 5P, 5B* and *5G* were used[3]. For the NCS 21 coordinate pairs of the elementary colours Y, R, B and G were used[4]. The result is shown in Fig. 2.

Comparison of the chromatic axes of the four colour order systems reveals

1. the yellow axes b^*, Y and *5Y* are very close to one another. Compared with them v^* has a greenish tint.
2. of the red axes a^*, u* and *5R* are grouped in the blueish red (magenta) region contrary to R at abt. 630 nm.
3. of the blue axes $-b^*$ and B agree, whilst *5B* compared with them shows a greenish

Table 2. Comparative compilation of the CIELUV and CIELAB chromatic axes expressed as their dominant wavelengths in nm when transposed to the CIE standard (1931) and auxiliary (1964) colorimetric systems for various CIE standard illuminants.

CIE std. col.syst.	CIE std. illuminant	CIELUV				CIELAB			
		$-u^*$	$+u^*$	$-v^*$	$+v^*$	$-a^*$	$+a^*$	$-b^*$	$+b^*$
1931	A	*502.0*	616.6	395.6	*579.0*	*508.8*	*-508.8*	*469.2*	*581.6*
"	B	496.6	-496.6	451.0	572.0	499.9	-499.9	477.1	577.7
"	C	494.1	-494.1	455.8	569.7	496.5	-496.5	*477.2*	577.3
"	D_{65}	494.9	-494.9	*456.8*	569.1	497.3	-497.3	477.4	576.2
"	E	495.4	-495.4	452.3	571.4	498.2	-498.2	477.0	578.1
1964	A	495.6	*621.0*	*-575.0*	575.0	503.3	-503.3	469.5	577.8
"	B	490.6	-490.6	439.1	566.9	494.5	-494.5	470.6	573.1
"	C	*488.0*	*-488.0*	446.9	564.1	*490.6*	*-490.6*	470.8	*571.2*
"	D_{65}	488.7	-488.7	447.9	*563.7*	491.5	-491.5	471.0	571.2
"	E	489.2	-489.2	441.2	566.2	492.2	-492.2	470.5	573.4

Table 3. Comparative compilation of the CIELUV, CIELAB, Munsell and NCS psychometric lightness functions in steps of $\Delta Y = 1$. The last column gives the range, i.e. the difference between the highest and the lowest values of lightness.

Y	CIELUV CIELAB L*	Munsell Value 10.1V	NCS-Whiteness 100-s	Range
100	100.00	100.00	100.00	0.00
99	99.61	99.61	99.64	0.03
98	99.22	99.21	99.27	0.06
97	98.83	98.82	98.90	0.09
96	98.43	98.42	98.53	0.11
95	98.03	98.01	98.15	0.14
94	97.63	97.60	97.76	0.16
93	97.23	97.19	97.37	0.18
92	96.82	96.78	96.97	0.20
91	96.41	96.36	96.57	0.21
90	96.00	95.94	96.16	0.23
89	95.58	95.51	95.75	0.24
88	95.16	95.08	95.33	0.25
87	94.74	94.65	94.91	0.26
86	94.31	94.21	94.48	0.26
85	93.88	93.77	94.04	0.27
84	93.45	93.33	93.60	0.27
83	93.01	92.88	93.15	0.27
82	92.57	92.43	92.70	0.27
81	92.13	91.97	92.23	0.26
80	91.68	91.51	91.76	0.25
79	91.23	91.05	91.29	0.24
78	90.78	90.58	90.81	0.23
77	90.32	90.11	90.32	0.22
76	89.86	89.63	89.82	0.23
75	89.39	89.15	89.31	0.25
74	88.92	88.66	88.80	0.26
73	88.45	88.17	88.28	0.28
72	87.97	87.67	87.75	0.30
71	87.49	87.17	87.21	0.31
70	87.00	86.66	86.67	0.33
69	86.50	86.15	86.11	0.39
68	86.01	85.64	85.55	0.46
67	85.50	85.11	84.98	0.53
66	85.00	84.59	84.39	0.60
65	84.46	84.05	83.80	0.68
64	83.97	83.52	83.20	0.77
63	83.44	82.97	82.59	0.85
62	82.91	82.42	81.97	0.95
61	82.38	81.87	81.33	1.05
60	81.84	81.30	80.69	1.15
59	81.29	80.74	80.03	1.26
58	80.74	80.16	79.37	1.37
57	80.18	79.58	78.69	1.49
56	79.61	78.99	78.00	1.61
55	79.04	78.40	77.30	1.74
54	78.46	77.80	76.58	1.88
53	77.87	77.19	75.85	2.02
52	77.28	76.57	75.11	2.17
51	76.68	75.95	74.36	2.32
50	76.07	75.31	73.58	2.48
49	75.45	74.67	72.80	2.65
48	74.82	74.03	72.00	2.82
47	74.19	73.37	71.18	3.01
46	73.55	72.70	70.35	3.19
45	72.89	72.03	69.50	3.39
44	72.23	71.34	68.64	3.59
43	71.55	70.65	67.76	3.80
42	70.87	69.95	66.86	4.01
41	70.18	69.23	65.94	4.24
40	69.47	68.51	65.00	4.47
39	68.75	67.77	64.04	4.71
38	68.02	67.02	63.06	4.96
37	67.28	66.26	62.06	5.21
36	66.52	65.49	61.04	5.48
35	65.75	64.70	60.00	5.75
34	64.96	63.90	58.93	6.03
33	64.16	63.09	57.84	6.32
32	63.34	62.26	56.73	6.62
31	62.51	61.41	55.59	6.92
30	61.65	60.55	54.42	7.24
29	60.78	59.67	53.22	7.56
28	59.89	58.77	52.00	7.89
27	58.97	57.85	50.75	8.23
26	58.04	56.91	49.46	8.57
25	57.08	55.95	48.15	8.93
24	56.09	54.97	46.80	9.29
23	55.07	53.96	45.42	9.65
22	54.03	52.92	44.00	10.03
21	52.95	51.86	42.55	10.40
20	51.84	50.76	41.05	10.78
19	50.69	49.62	39.52	11.17
18	49.50	48.46	37.95	11.55
17	48.26	47.24	36.33	11.93
16	46.97	45.99	34.67	12.31
15	45.63	44.68	32.96	12.68
14	44.23	43.32	31.20	13.03
13	42.76	41.89	29.39	13.37
12	41.22	40.40	27.53	13.69
11	39.58	38.81	25.61	13.97
10	37.84	37.13	23.64	14.21
9	35.98	35.34	21.60	14.38
8	33.98	33.41	19.50	14.48
7	31.81	31.30	17.33	14.47
6	29.41	28.98	15.10	14.32
5	26.73	26.36	12.79	13.95
4	23.67	23.33	10.40	13.27
3	20.04	19.69	7.93	12.11
2	15.49	15.03	5.38	10.11
1	8.99	8.52	2.74	6.25

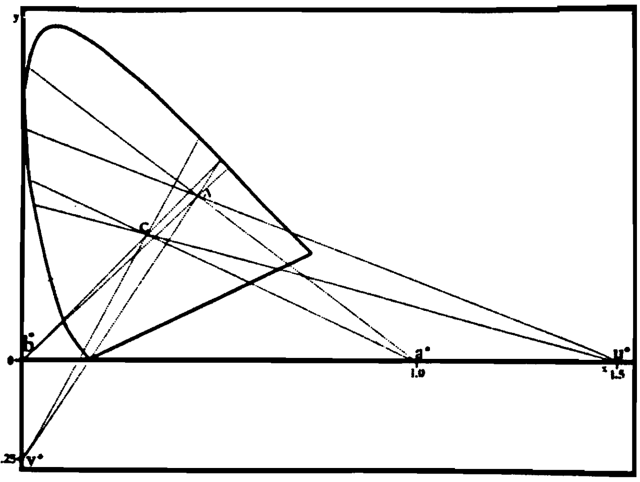

Fig. 1. CIELAB and CIELUV chromatic axes for CIE Standard Illuminant A and C transposed to the CIE Standard Colorimetric System.

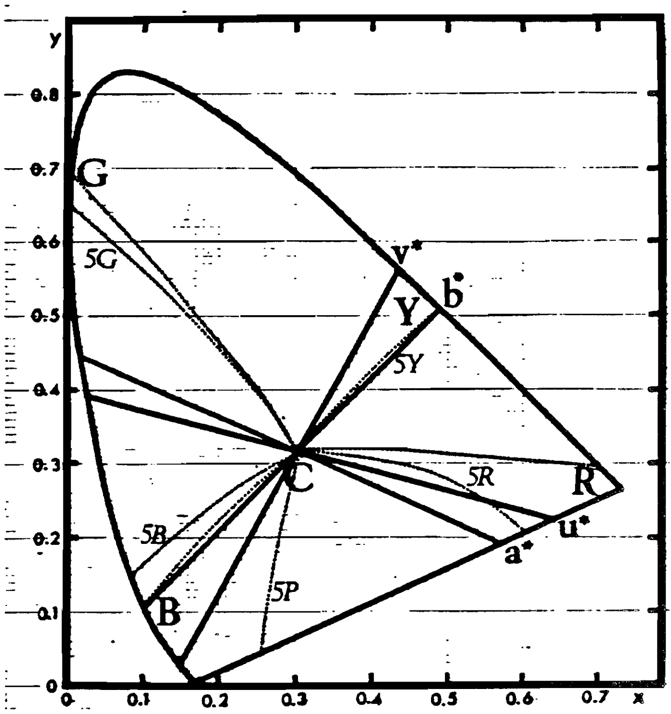

Fig. 2. CIELUV, CIELAB, Munsell and NCS chromatic axes transposed to the CIE 1931 Standard Colorimetric System. Std.ill. C.

4. G and *5G* agree within a few nm, whilst -a^* and -u^* compared with them are clearly blueish greens.

Comparison of the CIELUV, CIELAB, Munsell ans NCS lightness scales

Table 3 shows a computer print of the CIE, CIELUV, CIELAB, Munsell and NCS lightness functions in steps of $\Delta Y = 1$ together with the range of the four latter ones. The Munsell implicit renotation Value function[3], V_y, has been multiplied by 10.1 for normalizing its range to 100. It has been evaluated by an accelerated iterative calculation[5]. In the NCS column the lightness has been replaced by its whiteness[6]:

$$w = 100 - s = 156Y/(56 + Y) \qquad (12)$$

In the upper third of Table 3, $100 > Y > 67$, the range is small, less than one unit. For the next third, $67 > Y > 33$ CIELUV/CIELAB differs from Munsell by roughly less than one unit, whilst NCS is responsible for the main increase in the total range for $Y < 66$. This comparison, however, does not reveal what values deviate most from the correct perceived lightness.

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THE UNIVERSAL COLOR LANGUAGE - A WORLD-WIDE COMMUNICATIONS CONCEPT

Alexander F. Styne

Colors can be described adequately and accurately by the Universal Color Language to meet the needs of the public, the designer, manufacturer and scientist in words that can be translated from one language to another and in terms that can be understood internationally.

The Universal Color Language is a concept by which color can be described on different levels of accuracy for different needs: Consumer and manufacturer, artist and designer, technician and scientist. It is based on human factors, common to human populations all over the world: The sense of vision, the ability to perceive and distinguish colors and the need to communicate this sensory experience to others. Communication is possible on the level of accuracy needed for specific purposes: Common words, that can be translated from one language to another, are used on three levels of accuracy. Although difficulties in translation must be expected, they can be overcome because of the clarity of the boundaries assigned to each Color Name Block. Designation by letters and numbers, used in various systems, apply to the fourth level, such as the Color Harmony Manual, the Swedish Natural Color System or the Munsell System. On the fifth level visually interpolated Munsell notations allow further accuracy and the sixth level is represented by designations resulting from instrumental measurement for the best accuracy available today (Fig. 5).

On Level 1 thirteen colors are identified by dividing the color solid into thirteen large, precisely defined parts. Three are neutrals White, Gray and Black. The other ten have generic Hue names, used in everyday language, such as Red or Blue. Some of these generic "color name blocks" are located one above the other in lightness, such as Orange and Brown or Pink and Red (Fig. 1).

On Level 2 (Fig. 2) sixteen additional colors are identified by placing intermediate hues between the generic ten of Level 1. For example, the Blue hue name block and the Purple hue name block make room for insertion of a Purplish Blue and a Violet block. In Fig. 5 these additional hue names are shown in their abbreviations between the circled Hues of Level 1. These two levels can be easily taught to children from four or five years of age on.

On Level 3 modifiers (Fig. 3) are added to describe lightness and saturation, resulting in a division of the solid into 267 smaller color name blocks (Fig. 4). These names are used in the Color Names Dictionary (Ref. 5) to describe and identify color names in different collections of color standards. The color located in the center of gravity of each block has been identified and 251 have been sampled in the ISCC-NBS Centroid Color Charts (Ref. 6). The accuracy of these samples has made them useful in many industries and in a number of different fields, from dermatology to photogrammetry (Ref. 3). The charts are also well suited to statistical studies of color trends for consumer goods. The simple and logical names used on this level can be translated into many languages: The example given in Fig. 5, light yellowish Brown on Level 3 becomes in

French - Brun clair jaunâtre
German - Helles gelblich braun
Spanish - Carmelito claro amarillento
Japanese - Uguisuiro or Usui kiiropi shairo

On Level 4 the solid is divided into yet smaller parts, that are described by notations, using numerals and/or letters. Fig. 5 mentions "from 943 to 7056 colors", based on the systems listed. These are best exemplified by the Munsell Book of Color, which has approx. 1600 colors (Ref. 7). In this system colors are visually equally spaced when observed under CIE source C and specified viewing conditions (Ref. 2) along the three dimensions or attributes of Hue, Value (Lightness) and Chroma (Saturation). The Munsell system is used in many countries and ties in well with the CIE system. The method of notation together with the visually equal spacing permits visual interpolation and description, if a higher degree of definition is needed. While the OSA system of uniform color scales (Ref. 8) and the Swedish Natural Color system have been studied since the 1940's, they were not yet completed when the Universal Color Language was first published in 1965 (Ref. 4) and so were not mentioned.

On Level 5 approx. 100,000 colors can be identified through visual interpolation in the Munsell system by a well-trained observer and described by adding fractional values to the original Munsell notations used on Level 4. This level is the one most used in many industrial applications where visual judgment and matching of colors are still predominant (Ref. 10).

The greatest accuracy that can presently be achieved and is meaningful in color identification can be described on Level 6. To quote Kenneth L. Kelly (Ref. 5):

> "The first or basic method of color designation is the CIE method in which the color is specified in terms of chromaticity coordinates x, y and daylight reflectance Y (or in tristimulus values X, Y and Z). It is common in careful colorimetric work to specify these coordinates to three figures."

Spectrophotometric measurement permits us to divide the solid into approx. 5,000,000 very small blocks. The second method based on instrumental measurement is exemplified by non-visual interpolation of the Munsell notation to one tenth of a Hue step, one twentieth of a Value step or one tenth of a Chroma step.

The Universal Color Language is a method by which colors can be described for the specific need of the user in clearly defined and correlated levels of accuracy. Additional levels could be arranged, for example a Level 2.5 or 3.7: or with increased capability on instrumentation a Level 7 may become practical through this method. Different systems and color designations can be compared. This was accomplished in the Dictionary of Color Names (Ref. 5) with systems available at the time of its preparation. New systems could be assigned to their respective levels of accuracy and their designations could be compared.

The concept can be taught from the lowest school level on, similar to mathematics, and can be used to convey ideas or specifications amongst users in different fields and from different cultures. It can become a world-wide communication tool (Ref. 9).

* * * * *

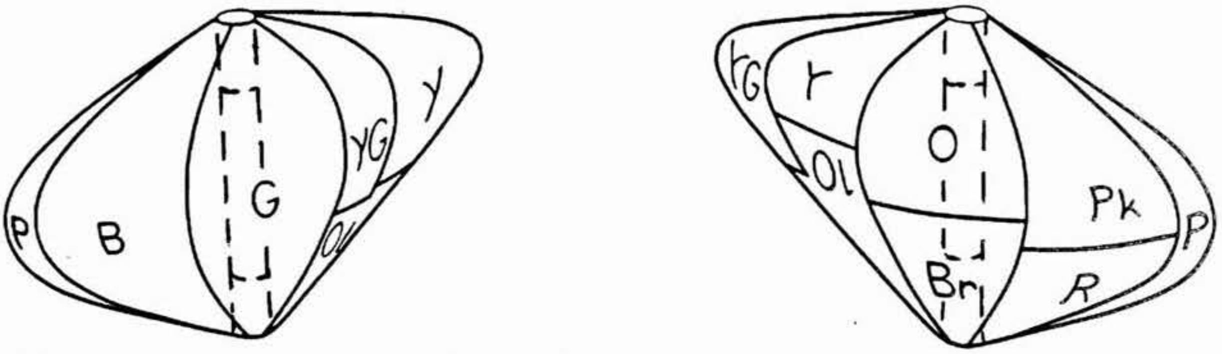


Fig. 1. *Color solid divided into 13 color name blocks on Level I (Copyright 1969 by A. F. Styne)*

Munsell Value (Lightness)

white (Wh)	-ish white (-ish Wh)	very pale (v.p.)	very light (v.l.)	brilliant (brill.)	
light gray (l. Gy)	light -ish gray (l. -ish Gy)	pale (p.) light grayish (l. gy.)	light (l.)		
medium gray (med. Gy)	-ish gray (-ish Gy)	grayish (gy.)	moderate (m.)	strong (s.)	vivid (v.)
dark gray (d. Gy)	dark -ish gray (d -ish Gy)	dark grayish (d. gy.)	dark (d.)	deep	
black (Bk)	-ish black (-ish Bk)	blackish (bk.)	very dark (v.d.)	very deep (v. deep)	

Munsell Chroma (Saturation)

Fig. 3. *Scheme of the hue modifiers, the "-ish" grays and the neutrals with their modifiers. Abbreviations are given in parentheses.*

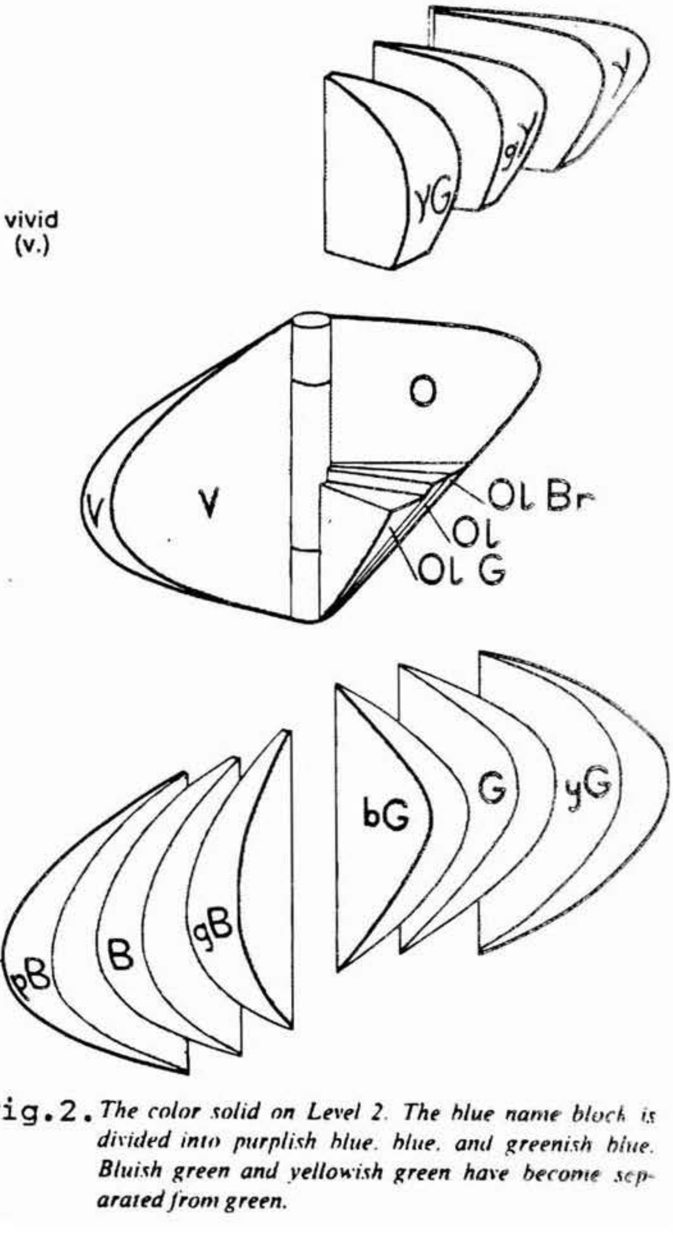


Fig. 2. *The color solid on Level 2. The blue name block is divided into purplish blue, blue, and greenish blue. Bluish green and yellowish green have become separated from green.*

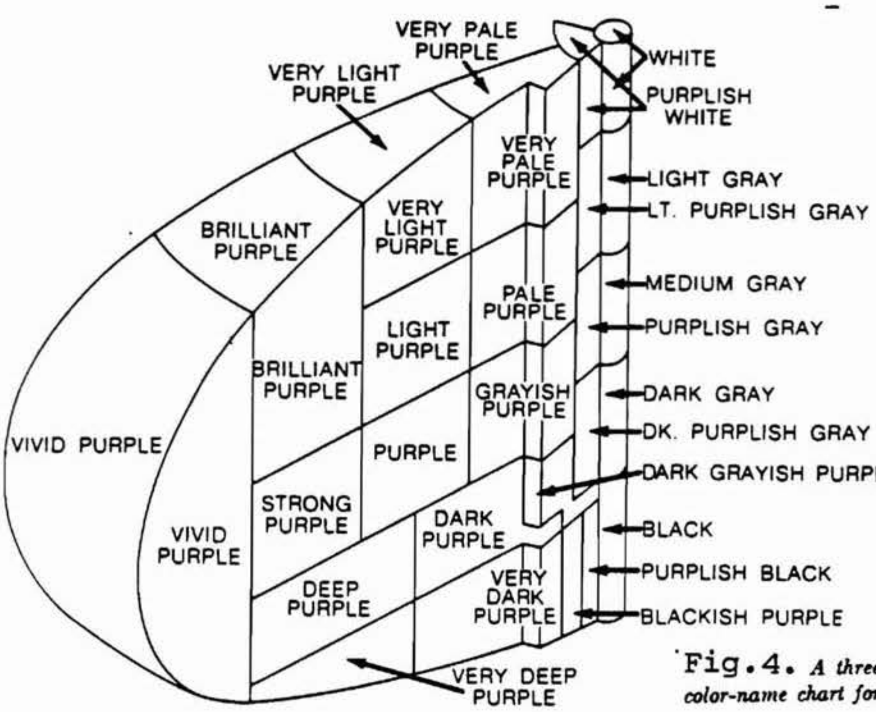
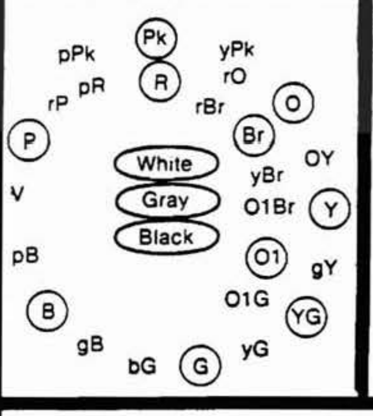


Fig.4. *A three-dimensional illustration of the ISCC-NBS color-name chart for purple showing the color-name block structure.*

	Color Name Designations			Numeral and/or Letter Color Designations		
Level of Fineness of Color Designation	Level 1 (least precise)	Level 2	Level 3	Level 4	Level 5	Level 6 (most precise)
Number of Divisions of Color Solid	13	29	267*	943-7056*	≃100,000	≃5,000,000
Type of Color Designation	Generic hue names and neutrals (See circled designations in diagram below)	All hue names and neutrals (See diagram below)	ISCC-NBS All hue names and neutrals with modifiers (NBS-C553)	Color-order Systems (Collections of color standards sampling the color solid systematically)	Visually interpolated Munsell notation (From Munsell Book of Color)	CIE (x,y,Y) or Instrumentally Interpolated Munsell Notation
Example of Color Designation	brown	yellowish brown	light yellowish brown (centroid #76)	Munsell 1548* 10YR 6/4**	9½ YR 6.4/4¼ **	x = 0.395 y = 0.382 Y = 35.6% or 9.6YR 6.4_5/4.3**
Alternate Color-Order Systems Usable at Given Levels			SCCA 216* (9th Std.) 70128 HCC 800* H407	M&P 7056* (1st Ed.) 12H6 Plochere 1248* 180 0 5-d Ridgway 1115* XXIX 13 "b CHM 943* (3rd Ed.) 3 gc		
General Applicability	Increased Fineness of Color Designation →→→ ←←← Statistical Expression of Color Trends (roll-up method)					

* Figures indicate the number of color samples in each collection

** The smallest unit used in the Hue, Value and Chroma parts of the Munsell notation in Levels 4 (1 Hue step, 1 Value step and 2 Chroma steps), 5 (½ Hue step, 0.1 Value step and ¼ Chroma step) and 6 (0.1 Hue step, 0.05 Value step and 0.1 Chroma step) indicates the accuracy to which the parts of the Munsell notation are specified in that Level.

Fig.5. The six levels of the Universal Color Language

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CREDITS FOR ILLUSTRATIONS: Fig. 1 & 2 see Ref. 9 & 10
Fig. 3, 4 & 5 see Ref.5

SHOULD WE HAVE AN ISO COLOUR NOTATION SYSTEM?

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When in 1979 a *Colour notation system* (1) and a *Colour atlas* (2), both based on the Natural Colour System (NCS), had been issued as Swedish standards, the Swedish Standards Institution (SIS) also set up a new technical committee (SIS HK32/TK7) with the task to

1. supplement the NCS system and atlas with tables of CIE coordinates,
2. encourage the use of the NCS system in other Swedish standards,
3. initiate an international standardization of colour notations, with NCS as an integral part.

The author accepted the chair in the committee, which since then has been rather successful within the first two parts of its terms of reference (3,4,5). With regard to the third part, the British Standards Institution already in 1980 proposed an ISO committee for standardization of "harmonic" colour selections for building purposes. SIS then recommended in the first place an agreement on a colour order and notation system, out of which selections could be made. The British proposal initiated SIS to propose a new committee dealing with systematic colour notations, for which there obviously is a need. However, up to now no agreement has been reached on such a committee, due to the diverging comments from the member bodies of ISO.

Colour stimulus systems

The CIE colorimetric system was the first attempt to define a procedure for obtaining colour specifications from physical stimulus measurements. Its main advantage is the fact that it has become universally accepted as a means of communication in instrumental colorimetry.

The original system was based on three real stimuli RGB, but it was already in 1931 recommended to use three artificial stimuli XYZ, mathematically derived from RGB so as to give a chromaticity chart of suitable geometrical properties.

The fundamental principle of the CIE colorimetric system is to give

> "the amounts of three defined radiations which, when mixed, will produce a complete colour match of the sample under test".

Although an experienced colorimetrist can draw rough conclusions from a set of CIE values as to the colour perception evoked by that stimulus,

> "it has to be recognized that the specification defines the three-stimulus mixture that will produce the same colour sensation as the test stimulus, without actually defining the sensation itself. It is perhaps surprising that a system of colour measurement which does not claim to measure the appearance of colour can have the wide applications which have been found for it ... Of course, there is, under normal viewing conditions, a fairly close correlation between the trichromatic specification of a stimulus and its appearance, but we should be making false claims for colorimetry if we did not acknowledge that a colour specification merely expresses an equivalence between physical stimuli in their capacity to arouse a colour sensation, and

> that the specification itself is a physical specification of stimuli, not of a sensation."

The quotations are from Prof. W D Wright (6). Similar wordings were also used by Dr R W G Hunt in a discussion in 1963, which finally led to the founding of AIC as a seoarate body to deal with colour problems on a broader basis than is possible for CIE whose original interests are those of the illumination engineer.

Many efforts have been made to transform CIE coordinates so as to conform better with visual observations. In most of these the main object is to make equal small colour differences plot at equal distances. In other transformations one has tried to create coordinate axes according to the elementary hues. The problems in defining a "colour difference" are discussed in another paper by Hård and Sivik, and Stenius shows the unacceptable deviations from visual facts in such coordinate systems.

Even if a set of CIE data or its transformations may specify the colour stimulus physically - within the limits set by the fact that spectrophotometers or colorimeters often give significantly different results - this specification can by no means be said to describe the appearance of colours.

Visual appearance systems

When SIS proposed a committee for an ISO Colour notation system, it was a system of *descriptive* colour notations that we had in mind.

In such a perceptive colour order system each colour notation in itself should give a description of the visual percepts of that colour. A set of such spontaneously perceivable and independant variables of the colour, expressed as numerical values, would then jointly define and describe the appearance of the colour. Such values should be possible to determine visually, irrespective of the physical stimulus that has evoked the colour perception.

An examination of colour notations in existing colour order systems reveals varying features. Many concepts are used in two or more systems, although sometimes with different meanings (table 1).

Table 1. VARIABLES AND CONCEPTS IN SOME COLOUR ORDER SYSTEMS

Munsell (7)	Hue	Chroma	Value	
NCS (1)	kulörton * (hue)	kulörthet ** (chromaticness)	svarthet (blackness)	(vithet) (whiteness)
DIN (8)	Farbton	Sättigung	Dunkelstufe	
Ostwald (9)	Farbton		Schwarzanteil	Weissanteil
Coloroid (10)	(hue)	(saturation)	(luminosity)	
OSA-USC (11)	j/g (jaune/green)		lightness	

* derived from the relation between the two chromatic elementary attributes of the colour (if the hue is not that of a chromatic elementary colour).

** derived from the sum of the two chromatic elementary attributes of the colour. (When the hue of the colour is that of a chromatic elementary colour, its chromaticness is identical with that elementary attribute.)

Even if the concept of *hue/Farbton* seems to be common to most colour order systems, the definitions are quite different. In some systems (DIN, Ostwald, Coloroid) equality of hue is defined by additive stimulus mixtures (equal dominant wavelength). This gives considerable variations in perceived hue, which are taken into account by both Munsell and NCS.

In most systems one has aimed at an "equally spaced" hue circle. However, in making the experiments to establish that hue spacing, one usually chooses colour samples that are already equal (more or less) in one or two other parameters (e.g. Munsell Value and Chroma). This choice of parameters then influences the kind of hue spacing that is obtained.

NCS is the only system that, following the principles of Hering, relates the hue scales to the four chromatic elementary colours as perceptually well defined reference points. The difference between Munsell and NCS in the curvature of the loci of constant hue may largely be ascribed to different extrapolation techniques.

Also in their other variables, Munsell and NCS have the perceptual approach in common, but with different scaling principles. Munsell *Chroma* is scaled as equal steps of perceived distance from the neutral axis. NCS *chromaticness* is the perceived sum of the chromatic attributes present in the colour. This is shown to correspond to the perceived resemblance of the colour to the pure chromatic colour, or the perceived sum of the chromatic attributes.

Munsell *Value* is scaled in equal steps between black and white, related to CIE luminance factor by a fifth-degree polynomial, which also may be closely approximated by a cube root expression. NCS *blackness* (like its symmetric counterpart *whiteness*) again is the resemblance of the colour to black (or white). Afterwards the experimental data were found to correlate quite well with an Adams-Cobb equation, already used by Judd.

In spite of the verbal analogies with NCS, Ostwald *Weissanteil* and *Schwarzanteil* are defined as additive mixtures, and so is Coloroid *saturation*. In the DIN system, the locus for *Sättigung*=6 was determined by experiment, whereafter all other saturations were calculated by linear interpolation and extrapolation in a certain MacAdam transformation of the CIE chromaticity diagram. It is also assumed that colours of the same chromaticity (theoretical shadow series) do not only have the same Farbton but also the same Sättigung.

OSA-UCS defines a lattice of colour points, where the total colour difference between neighbours is said to be the same throughout colour space. This makes it impossible to use polar coordinates like hue and saturation. Instead the lattice is plotted in a cartesian diagram, where the axes are called j (*jaune*/yellow - with blue at negative values) and g (*green* - with red at negative values). These notations may indicate an opponent colours system, but the deviations from the true unique hues are far too large.

For UCS *lightness* the Munsell renotation Value scale is used. Coloroid *luminosity*(?) has the same square-root function as the original Munsell system. DIN *Dunkelstufe* is a logarithmic function of the 'Relativhelligkeit', i e the luminance factor of the colour in relation to the luminance factor of the 'optimal' stimulus of the same chromaticity. The experimental scaling of the Dunkelstufe was primarily made with neutral samples. A check on eight chromatic shadow series showed noticeable deviations, nevertheless the same equation was adopted for all chromaticities.

It will be the task of the proposed ISO committee to define unequivocally all these concepts and to select a choice of variables to form a standardized descriptive ISO colour notation system. Thereafter methods may be developed and recommended for the transition of colour notations between different systems.

Colour notation system and/or colour atlas

It has been said in some of the replies to our proposal that a perceptive colour system must be based on a colour atlas, and that such a colour atlas is valid only for a defined illuminant.

This is not correct. The perhaps most important feature of a descriptive colour notation system is the fact that it has been found possible for an observer to determine - with a surprisingly good accuracy - the position of a colour in the perceptual space without any instrumental measurements and without reference to any colour sample, only using his "built-in" references. Irrespective of the physical or physiological cause of tahe perception, the colour notation system describes the colour appearance of an colour object in any illumination or surround. If variations in illumination and surround make the perceived colour of the object change, the colour notation of that object changes as well.

It is true that a colour atlas has to be produced for one specified illuminant. However, practical experience has proved it to be fairly invariant to moderate changes in illumination (such as from C to D65). The colour atlas illustrates the colour notation system with a limited choice of colour samples. Its purpose is to facilitate communication about colour and to enhance the precision in the colour notation.

In Sweden, the colour notation system is published as a separate standard, where the concepts and the structure of colour space are defined. The colour atlas and the CIE specifications are other standards supplementing the first one.

Colour radiation

The desirability of translations between various colour notation systems has already been stressed. As yet stimulus measurements according to CIE recommendations form a rather complicated structure with a number of alternatives in many of its phases. If colour systems are to be really comparable by their CIE specifications, a standardized selection must be made out of existing "standard" observers, illuminants, illuminating and viewing geometries etc. This problem is also discussed in another paper at this meeting.

Conclusions

For a new colour notation system to be accepted as an international standard, it must meet the following requirements.

A set of perceptive colour attributes must be defined. Each attribute should correspond to a spontaneously perceived characteristic of the colour perception, which often makes it difficult to define verbally (e.g. hue).

Each attribute should also be given a standardized psychometric scale, related to some sort of stimulus specification.

There will most probably be more than three such attributes in the defined set, as already indicated in the present Swedish standard "Colour notation system". Some attributes may be mutually interrelated and it will be left to the user to choose those attributes best suited for his particular task.

By means of their stimulus specifications, formulae, or at least tables, for translation from present major systems to the new system, and vice versa, should be given.

When non-perceptive attributes and scales are used as approximations for true perceptive attributes, their definitions and the expected degree of deviation must be given. Such attributes may for instance be based on additive stimulus mixtures like the "dominant wavelength".

Acknowledgements

Parts of this paper are based on discussions in the SIS Technical Committee on Colour Order Systems. The members of the committee, in particular Mr Anders Hård and Mr Åke S:son Stenius, as well as its secretary Mr Gunnar Atterberg have made many valuable contributions, for which the author wishes to express his thanks.

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Constant Saturation Loci of Equally Bright Colors

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Introduction

Chromaticness of colored lights can be physically described by purity and dominant wavelength. Purities increase from 0 to 1 when colored lights gradually change from white to monochromatic lights for all dominant wavelengths. On the other hand, saturations, which are perceptual correlates to purities, do not necessarily increase in the same way from white to monochromatic lights among the different dominant wavelengths. Although the saturation functions for spectral lights have been measured by various methods (Wright and Pitt, 1937; Jacobs, 1967; Kaiser et al., 1976; Uchikawa et al., 1982), the saturations for non-spectral lights have been less investigated. It is important to know how saturation changes in a chromaticity diagram in order to establish a uniform chromaticity space (UCS). In this report we measured saturation of equally bright colors by a saturation scaling method and plotted the constant saturation loci in chromaticity diagrams.

Method and Procedure

We used a conventional Maxwellian-view system with a 1 kW xenon arc source. Two circular stimulus fields were presented to the observers. These fields subtended 45' visual angle and were separeted horizontally by 30'. The left field was a mixture of monochromatic and white (x=0.332, y=0.333) lights, and the right was a reference white (x=0.341, y=0.335) of 150 td.

First, the observers performed heterochromitic brightness matching between two fields. In the left field, 19 dominant wavelengths from 410 to 670 nm and in the purple region, each at 10 excitation purities from 0.1 to 1.0 in 0.1 steps were presented as test stimuli. The excitation purities are expressed here in terms of the 1931 CIE (x,y) chromaticity diagram. The observers adjusted intensity of the mixture so that the test stimulus appeared equally bright to the reference white.

Second, the observers estimated the perceived percentage chromatic content of the stimuli, adjusted to be equally bright, by the method of constant sum (Jameson and Hurvich, 1959; Jacobs, 1967). The reference white was occluded and a white adaptation field, subtending 5° visual angle, was presented between trials in order to reduce the chromatic adaptation effect by a preceeding stimulus. The chromaticity of the white adaptation field was the same as the reference white.

Results and Discussion

In Fig. 1, saturation estimates (percent chromatic content) of equally bright colors are shown as functions of excitation purity for two obsevers. The dominant wavelengths are indicated at the upper-right of each section.

A solid curve in each section represents mean saturation estimates of two observers. It is clearly shown how the saturation estimates, being well consistent between two observers, increase as the excitation purity increases for all dominant wavelengths. In the yellow region of 550, 570, and 590 nm, saturation estimates increase more slowly than in the other regions.

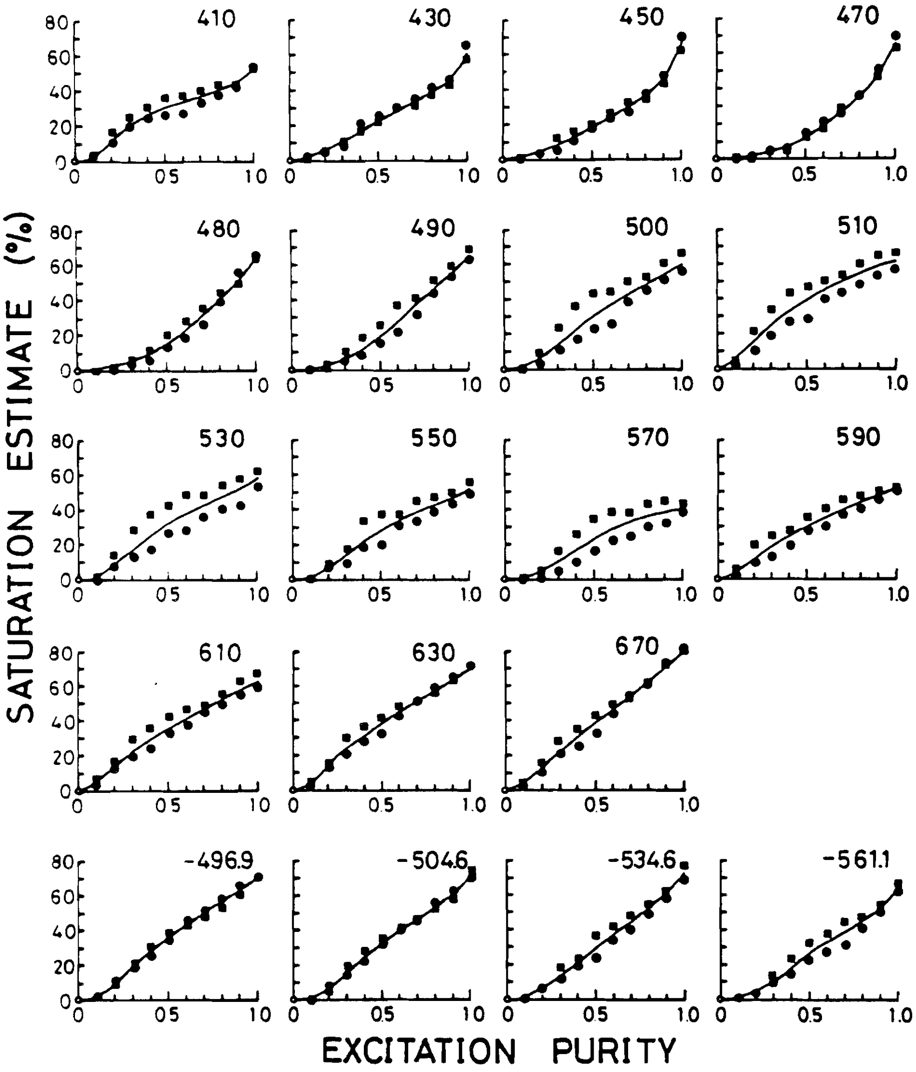

Fig. 1. Saturation estimates of equally bright colors for two observers: KU (●), HU (■).

Figures 2 and 3 show constant saturation loci in the 1931 CIE (x,y) chromaticity diagram, and in the 1976 CIE (u', v') chromaticity diagram. Mean saturation estimates are plotted in 5% steps for all dominant wavelengths, using the mean estimate curves in Fig. 1. The constant saturation loci tend to have larger intervals in the green region in the Fig. 2 and in the purple region in Fig. 3. They show dips at the lower purity values for the dominant wavelengths of 410 and 430 nm in both diagrams.

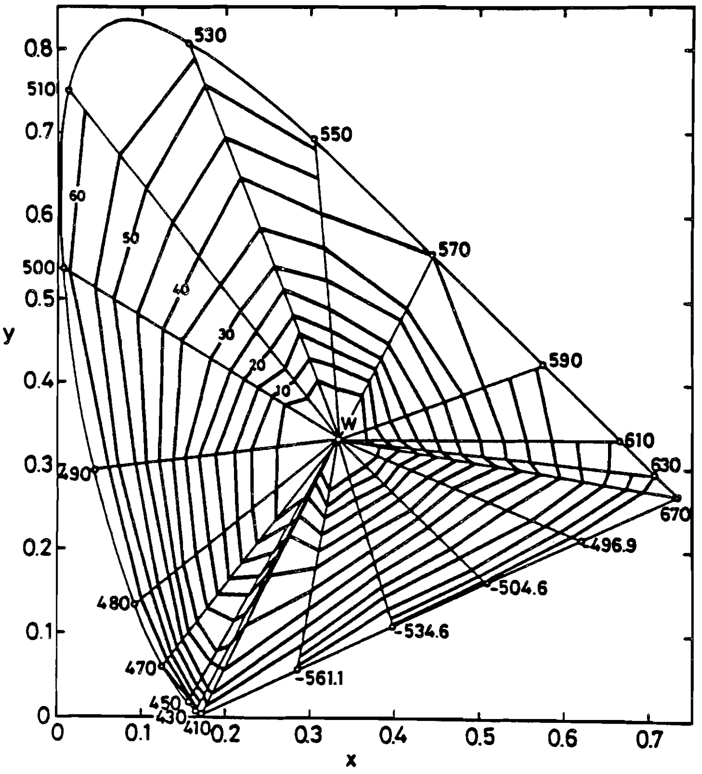

Fig. 2. Constant saturation loci in the 1931 CIE (x,y) chromaticity diagram in 5% saturation estimate steps. The numbers at each locus indicate saturation estimates of the loci.

The 1976 CIE (u', v') chromaticity diagrams has been recently developed by the CIE as one of the UCS diagrams. Constant saturation loci in a UCS diagram should plot as circles about the white point. The present results in Fig. 3, however, do not support the uniformity of this diagram.

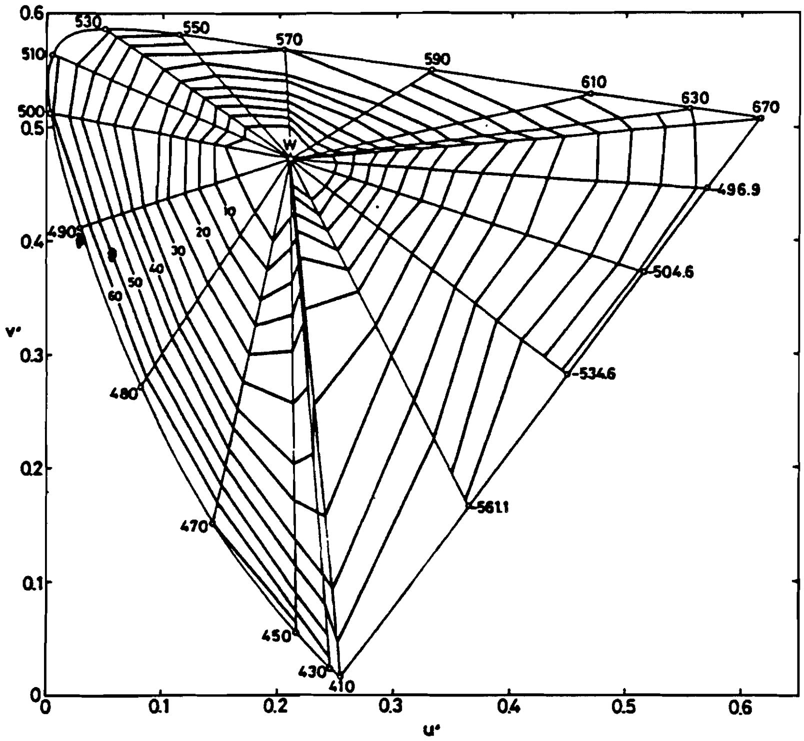

Fig. 3. Same as Fig. 2, but shown in the 1976 CIE (u', v') chromaticity diagram.

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SYSTEMATIC COLOUR ASSORTMENTS

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Very often you can hardly find traces of a plan behind the range on a colour card made for interior decorating or exterior paints. You get the impression that somebody has just picked up his own favourites. If those colours really sell it seems to be a bare miracle of coincidences.

Most people are able to discriminate about ten million colour shades. This could easily make us think that, from the customers point of view, the best offer of a colour assortment would be just ten million shades. From the producers point of view - and so the retailers - , which both are based on economics, the best offer would be just one single colour, probably white.

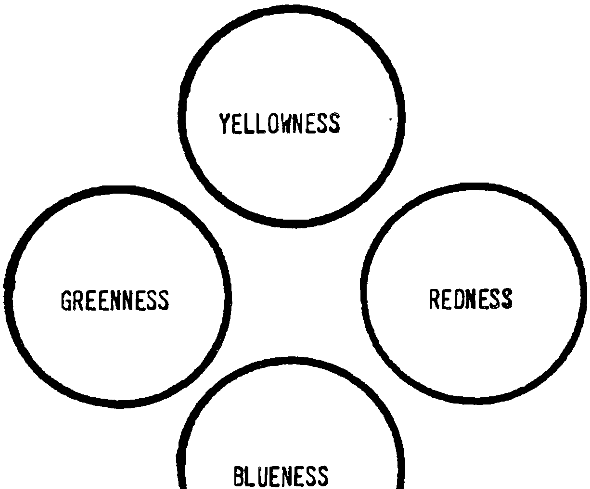
And so was the situation 30 years ago. The offer from the producers of paint was white, connected to a range of concentrated colorants or pigments, to shade the white paint. To find the wanted colour was mostly up to the customer, who in lack of experiences knew very little about colour planning. And the lack of any colour education made people even quite out of order to line up and to explain which colour they really wanted.

25 years ago the ready-mixed alkyd and latex paints were introduced, and in a modest range of some few pale pastel shades. With a growing sales success the assortments by and by increased to quite an offer. But was the offer reasonable ?

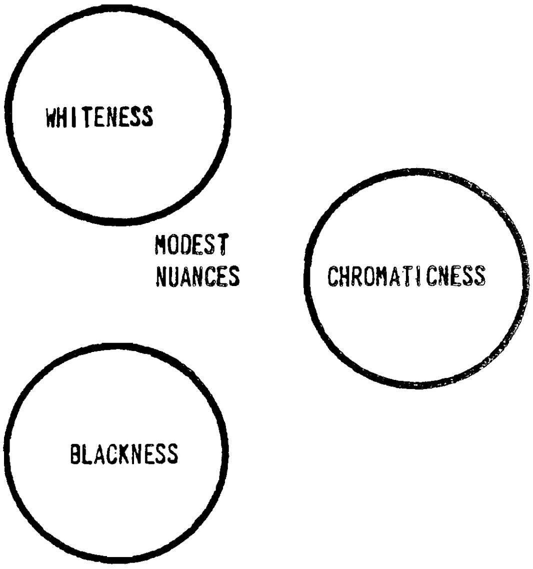
Looking back on the colour cards from the early sixties you get a feeling that the colour samples were brought together by some sort of gemmation, and without any trial to choose shades which in some way or another were connected to eachother. The shades seemed to be picked up one by one, and without a thought on "does this new shade make a good supplement to the already existing ones ?".

– – –

How do we use colours in our interior decorating, or exterior aswell ? First of all we make our choice between different hues. We want - for instance - yellow, or we want red, blue or green,and so on. But we also have vague ideas about bright colours, or darker shades, or perhaps high saturated nuances. And time to time we we might even look for some modest nuances, - in the middle of between.



Chromatic colours belong to one of these four groups, or between two neighbouring of them.



Every colour will belong somewhere between maximum WHITE, maximum BLACK and maximum CHROMATIC.

Mostly we are looking for good colour combinations. Interior decorating - very simplified - means putting colours together, which in some way or another have to interact, - planned or not. Exterior colorizing of a house frontage is of course very much the same.

The colours put together in such a constellation never appear independant of eachother. In some way, good or bad, they interact. If the colours in such a combination show some sort of relationship, like for instance perceptual similarities, the result very often will give an impression of rest, peace and toleration. The most important ways to figure colour similarities are:

a. equal hue
b. equal whiteness
c. equal blackness
d. equal chromaticness
e. equal lightness

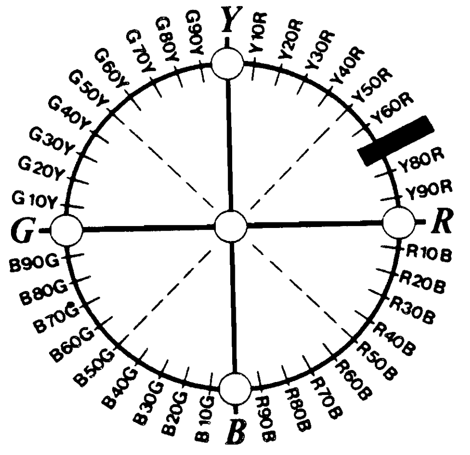
If the b, c, and d similarities are present at the same time the colours show different hues in the same nuance, which perceptual knit them very close together into unity and totality.

But to distinguish form, function and structure in an interior (or exterior) you have to underline and emphasize architectural details by the aid of colour contrasts, like:

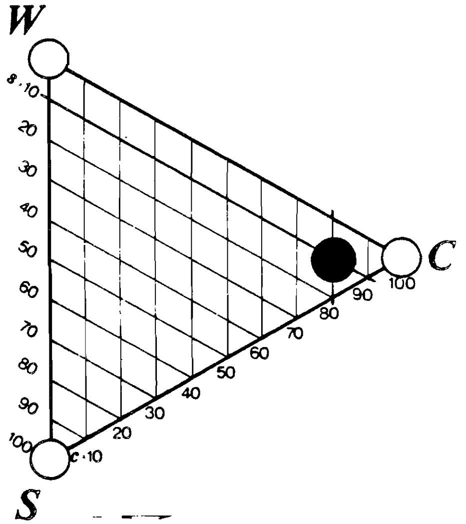
1. different lightness (light/dark)
2. different chromaticness (chromatic/nonchromatic)
3. different hues (ex. green/blue)

To gather all these important attributes of colour into the assortment of a colour card, we have to take care of an interesting game of colour logic, which lines out cross references to specific perceptual colour attributes.

The Natural Colour System (NCS) is a colour order system well fitted for describing and notating colours as they are perceived by man. Our models from last page we easily can translate to the NCS diagrams below, which give the references for the hue and the nuance of a colour.



THE NCS COLOUR CIRCLE
On the colour circle the hues are notated, percentual to the two related elementary colours. Y = YELLOW, R = RED, B = BLUE, G = GREEN. The marked case is between Y and R, and the actual hue notation is Y 70 R. The yellow-red colour is 70 % red.



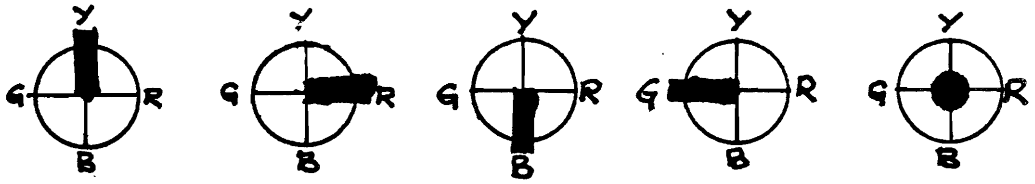
THE NCS COLOUR TRIANGLE
For each hue there is a colour triangle where the nuance is notated. W = whiteness, B = blackness, C = chromaticness. The actual example has the notation 10,80, which indicates 10 % blackish and 80 % chromatic (= 10 % whiteness).

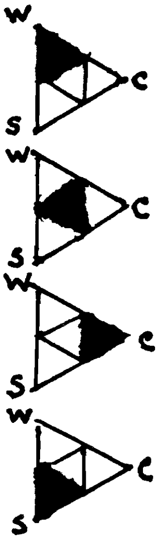
Total notation: 1080 Y70R

Designing a colour assortment is much like trawl-fishing. You choose the mesh size to catch the big fishes, and let the small ones pass through. To choose the right meshes in your colour card will be much safer by the aid of a perceptual colour order system, like the NCS, combined with sales statistics and some knowledge about colour combinations.

The offer must be spread over the most important hue areas, and all those areas have to be represented in a series of different nuances.

The following scheme (next page) shows a sort of minimum assortment, containing the four main hue areas: yellow, red, blue and green, and each of them in the four main nuance areas, white-dominated nuances, modest nuances, high chromatic nuances and finally blackdominated nuances. And there is even a further supplement of white, two greys and black. By the aid of 20 shades it will be possible to make colour combinations with sufficient regards to similarity-balance, and to structure-distinguishing contrasts.





Yellow	Red	Blue	Green	Non-chromatic
whitish yellow	whitish red	whitish blue	whitish green	White
modest yellow	modest red	modest blue	modest green	grey I
high chromatic yellow	high chromatic red	high chromatic blue	high chromatic green	grey II
blackish yellow	blackish red	blackish blue	blackish green	Black

A broad offer for the advanced and demanding customer, like architects, designers and colour planners, can be based on exactly the same reasonings. A supplementary number of shades just have to be added in each colour area.

Examples on a mini-assortment,and a maxi-assortment aswell (702 shades),can be studied at the poster-exhibition, as a supplement to this paper.

Every colour sample on these colour cards have got their notations refering to the NCS specifications. It means that even the notations tell about what the colours look like.

Klaus Witt, Berlin

Call for common colorimetric parameters in defining colour-charts.

Summary

The existence of different colour-systems, each with its own specific colour-coding and colour-chart, is puzzling for users. It would be very advantageous, if the coding of any colour-sample of a colour-chart could be transscribed into that of another colour-chart. Such a transscription is only possible, when a common basis of the description of all colour-charts is used. The only objective method for this approach is a colorimetric definition of codes, but it is necessary to agree on the choice of the colorimetric parameters illuminant, colorimetric observer and measuring geometry also. The colorimetric shifts for changing the measuring geometry depend strongly on lightness, saturation and gloss of the colour-samples and should not be neglected. The best way to find a transferable colorimetric description of colour-codes would be an international recommendation for the preferred or additional use of colorimetric parameters. These could be: 45/0 measuring geometry, standard illuminant D65, standard colorimetric observer.

Problem

Colour-systems are usually elaborated by visually scaling sets of coloured samples, finding a grid system of the wanted scales and producing colour-samples for grid points. Performing this procedure in an objective manner colorimetry should be used as it has been done in many cases. But there are different possible

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parameters of colorimetry, that introduce an element of noncomparability. If the shifts of tristimulus values due to the change of parameters would be smaller than normal tolerances for colour-charts, the parametric effect could be neglected. If on the other hand mathematical transformations of tristimulus values from one set of parameters to another one would be possible, comparability could be produced. The colorimetric shifts due to change of the colorimetric observer and to the change of the standard illuminant (C to D65) exceed normal tolerance limits of colour-charts, but the change from standard illuminant C to D65 may be calculable within certain limits[1].

While illuminant and colorimetric observer are elements of the colorimetric evaluation procedure, the measuring geometry influences the measured quantity, e.g. the spectral reflectance factor directly. Its effect on colorimetric shifts is rarely demonstrated (e.g.[2]) and will be shown in this paper.

Colorimetric shifts for change of measuring geometry

In order to find an estimate of the colorimetric shifts within critical regions of the colour-space and for different surfaces of colour-samples, some sets of colour-samples have been selected from different colour-charts and spectrometrically measured with 45/0 and 8/d (gloss excluded) measuring geometry. The colour-charts were: DIN colour-system matte and high-glossy finish, NCS semi-glossy finish, OSA-UCS glossy finish. The mean 20°-reflectometer (gloss) values are given in tab. 1. Colour-samples have been taken from neutral, desaturated light, saturated light and dark colours with closest possible similarity between colours of different colour-charts. The measurements have been done with a spectrometer (Zeiss DMC 25), the colorimetric evaluations calculated for standard illuminant D65 and the standard colorimetric observer CIE 1931.

Tab. 1 Reflectometer values and average colorimetric shifts for change of measuring geometry (45/0 - 8/d)

colour-chart	DIN matte	NCS semi-glossy	OSA-UCS glossy	DIN high-gloss
20°-reflectometer value	< 1	2.5	20	79
Number of colour-samples	30	37	37	32
$\Delta E^*_{ab} \pm \sigma$ (45/0-8/d)	1.4 ± 1.3	5.4 ± 3.9	3.8 ± 2.6	3.2 ± 2.2

Tab. 1 contains the average colorimetric shifts for changing the measuring geometry (45/0-8/d , gloss excluded) calculated with the colour-difference formula ΔE^*_{ab}. While for matte colour samples the average shift can be taken as tolerable, this is not the case for semi-glossy colour-samples and critical for glossy and high-glossy ones.

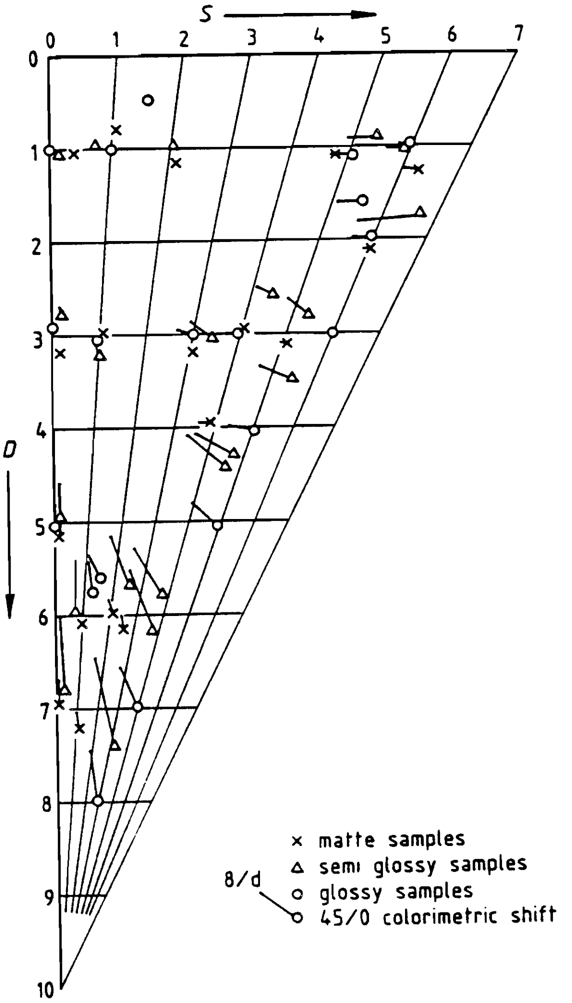

Fig. 1 Vertical cut through cone model of DIN colour-solid with colorimetric shifts for change of measuring geometry of colour-samples of different glossy appearance

Looking at a schematical hue plane of the DIN colour-solid[1] (see fig. 1) the critical colour regions are those of high saturation and of low lightness as expected. It can be concluded, that measuring geometry is an important factor for defining colour-charts and must not be neglected. So all three parameters are critical when chosing them for colorimetric definitions.

Need for a common colorimetric basis

Some of the existing colour-charts show a variety of different choices: Munsell[3], DIN[4], NCS[5], OSA-UCS[6]. Intercomparisons are difficult[1,7]. One way to solve the problem of colour-coding of colour-samples within different colour charts is a remeasurement and colorimetric evaluation according to the parameters used in each colour-chart[1,7]. This helps ordering of actual colour-samples within the system of different colour-charts, but for every new set of parameters the procedure has to be executed again. Moreover the exact positions of grid points of a colour-system within another one is difficult to evaluate because of deviations between grid points and their attached colour-samples.

The better way is to have a common colorimetric basis on which the individual codings of colour-systems rest. Every author of a colour-system should use such a basis for his own colour-coding either directly or additionally. The decision may be deduced from the mode of the visual task of elaborating a colour-system. Such a common colorimetric basis would greatly improve the clarity of intercomparisons of colour-charts for practical and scientific applications.

Proposal of a selection of parameters

1) Measuring geometry: The viewing conditions within a colour-matching booth are in favor of a 45/0 (0/45) measuring geometry. Colour-samples that show strong geometric metamerism for change of 45/0 to sphere geometry look much more alike, when colorimetric identity is given for 45/0, than when it is given for sphere-geometry.

2) Illuminant: The general trend favors standard illuminant D65 for use in daylight conditions.

3) Colorimetric observer: Both possible observers are used in different industries but the larger number of colour-charts is composed of small-sized colour-samples, which favor the standard colorimetric observer CIE 1931.

An international committee like the AIC-committee on colour-systems could be the right institution of elaborating a recommendation of the preferred use of colorimetric parameters for defining colour-systems.

Acknowledgements: Thanks are given to Mr. A. Knopf and Miss M. Koye for taking measurements and to Dr. G. Döring for fruitful discussions.

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Poster paper at the
Forsius Symposium on
COLOR ORDER SYSTEMS
KUNGÄLV 1983

Lars Sivik
Anders Hård

IS COLOR NAMING THE MOST NATURAL COLOR SYSTEM?

An abbreviated version of a forthcoming report:
Ord för färger - en kartläggning i NCS av våra vanligaste färgord.

It is often said that there is a considerable confusion as regards color names. This may be true, but not always and generally. Misunderstandings and controversies are often found between different groups of people who work with color, but who deal with different aspects of the problems. It is well known, for example, that printmakers, physicists, color-TV-technicians, painters, artists, and laymen have different opinions of which the "primaries" are. Hopefully the members within each professional group have the same inner image of their special words for colors (magenta, cyan, cobolt, and so on) - but "ordinary people" do not know what these color stimuli look like. If we go further to literature about art and art history and to the colorful world of fasion we find and abundance of color terms - but here perhaps the purpose is wider than to evoke an image of a particular color sensation.

"Ordinary people" - all over the world - are in their everyday speech satisfied with very few color names. First there are the six elementary colors (according to NCS): white, black, yellow, red, blue and green. (They are called "elementary" because they ar phenomenologically-perceptually undividable). Then we have brown, gray, orange, pink and purple/lilac/violet, which are comparatively unambiguous semantically but whose perceptual correlates also may be described in terms of the first six.

In a well known linguistic study of "Basic Color Names" (Berlin and Kay, 1969) was shown how this small number of color names is basic for almost all humans and that their equivalents between different languages correspond to about the same color sensations. Berlin & Kay compared a large number of different languages, primitive as well as highly developed, and they let representatives for each of the languages identify from a color chart (Munsell) the "focal points´ of each color word and also the borders for their validity. Their conclusions are that the basic color terms may be considered semantic universals and that people are comparatively concordant among each other about the meaning of the common color words; that is, which perception, or color sensation, the word in question signifies.

As regards the focal points there seemed to be a very convincing concordance between different languages and there appeared a hierarchical pattern, which is in agreement with Herings theories - as his elementary colors come first. Many researchers have confirmed and commented upon Berlin & Kay´s results (Heider 1973; Wattenwyl & Zolliger 1979). The latter have treated the relationships between the neurobiology of vision and the psycholinguistic colornames. Already Ewald Hering, who formulated his theory 1978 from what he could see with his eyes, predicted that the color structure he proposed necessarily must be found also in other languages than those he was aquainted with. Woodworth and Lukiech had noticed the mentioned hierarchy of color names already 1918, but at this time "the scientific world" was not yet mature to accept Hering´s elementary colors, because the physicists and the physiologists, who were able to measure radiation and receptivity of receptors, had another opinion at that time.

B&K found a considerable "universality" as concerns the "focal points", the colors that are the best representatives for each color name. But when the Ss on a color sample chart were supposed to point out the borders for the "area" covered by the color name, there was more of disagreement. But the differences between the languages were not bigger than those between individual subjects within each language (Lehrer, 1974). The larger dispersions among respondents when determining color name borders may, however, have various concurrent causes and this we will discuss further as it is of relevance for the present study.

If people have the same physiological structure for color vision it seems quite consequent that this is reflected in their languages. Even if all details of the visual process are far from completely understood it appears undisputable that what we **see** of various colors can be structured according to Herings modell of three pairs of elementary color qualities: black/white, yellow/blue and red/green.

And words for these colors do actually come first in the development of languages. But on the other hand, if these "elementary colors" had not come first, this would not **a priori** have contradicted the opponent color theory. Of great importance for color naming is namely the various **needs for having specific color names for specific color areas.**

One interesting observation is that variation within such color areas are described by the elementary color terms - yellowish brown, reddish brown.. Seldom one says orangeish brown.

Most languages have names for brown, purple (lilac), orange, etc. But some cultures have in addition (according to several but unspecified sources) a need to have several words for different shades within a color area, that may have no special word at all in other languages. There is the rumour, for example, of all the words for different shades of sand colors among some arabic tribes and we have heard of all the names for snow- and ice-colors among the eskimoes. It is also well known that it is possible to train oneself to detect very minute differences and deviations in color; in many industries this is an important profession. Examples of this kind may be relevant to explain that the borders of the various color names can vary between cultures, between groups and between individuals.

Another factor which may effect the borders is **the way the question is formulated.** Suppose we present a subject a typically pink color. I˜ we ask "What do you call this color?", the answer probably will be "pink" or some synononym), and if we ask "would you call this color red?", the S would probably say no. If, on the other hand, we ask the S if there is any redness in the color he/she would say "yes, of course".

So it seems as the question mark after the title of this paper has to remain there. Some of the color names may be used for systematic arrangement of colors, others just for grouping colors in more or less well-defined categories.

NCS-MAPPING OF COLOR WORDS

The investigation to be presented here has only partly the same goals as Berlin & Kay´s. The method is different, and it does not (yet) compare different languages. Instead it aims at mapping out the extension of "denotative meaning" of some common Swedish color words in the various parts of the "color world" - in this case defined by the NCS parameters.

Model for the method is our own earlier studies of color meaning (Hård, 1964; Sivik, 1970, 1974) where opposite-pairs like warm-cold, beautiful-ugly etc. literally were mapped in the color space as regards their color correlates. In the graphic symbol of NCS color triangle was drawn "iso-semantic lines" i.e. lines of equal meaning. These provide a very clear illustration of the relationships between the words and their associated meaning regarding colors. The lines can be interpreted in the same way as one reads a weather map with isoterms and isobars.

In the study of color meaning we studied words whose basic meaning are not primarily related to color, they only carry **connotations** to colors in varying degree. But in the present study we want to map out the **denotative** color words, i.e., whose basic meaning (at least nowadays) refer to images of color-sensations.

Method

Variables of meaning

The "scales" along which the Ss were asked to mark their opinion had the following design:

BROWN

not at all ☐ ☐ ☐ ☐ ☐ ☐ ☐ very well

The instruction was:

Your task is to mark how well the color of the sample corresponds with what you mean by the color word shown above each scale.

The choice of variables was a question of priority. First we wanted to see how the six names for the NCS elementaries BLACK WHITE YELLOW RED BLUE GREEN distribute their color correlates in the color space when the instruction given to the subject was as above - instead of the question behind the construction of the NCS model, where the coordinates of each point signify "the degree of resemblance with each of the (imaginary) elementary colors - which is something else.

Common color words (in Sweden) beside the six mentioned are (the assumed equivalents of) GRAY BROWN BEIGE LILAC ORANGE VIOLET PINK ROSE OLIVEGREEN and PURPLE. Some of the last ones are not too common for most Swedes, olivegreen was included to have one word more in the green area; purple was of interest because it has (by american expertise) received dignity of primary color.

Subjects were 168 and they were heterogenously sampled as to sex, age and occupation. Each color sample was judged by 24 Ss. (For further information of experimental conditions see original report).

Color samples. At the time this study was carried out the NCS atlas was not yet available and the 128 samples were chosen from Hesselgrens Färgatlas. This made that the colors were less evenly distributed in the NCS space than desired. The positions of the test samples are depicted in poster figure 1.

RESULTS

Each judgement (according to the scale and the instruction) was coded so that a mark in the scale position to the left "not at all" received the value 0; the next 1; and so on to 7 "for very well".

For each color for each of the 17 scales was calculated the mean - together 2434 mean values (N=24) making up the result matrix to be analysed and illustrated.

As each color sample has a certain position in the NCS it seems natural to illustrate the variations of the color word relevance for the different colors by a mapping (literally) in the NCS symbols of color triangle and color circle. At each color position we note the actual mean value and then it is possible to connect (after interpolation) points in the color triangle which have received the same mean values for the scale in question. In our earlier investigation of color meaning we named these lines "isosemantic" (with equal meaning) and this term is suitable also here.

The result of the study, transformed like this, is illustrated on the poster. There we also have demonstrated the isosemantic lines "seen through the NCS color solid from above". We would have preferred to present the results as "bubbles" in a three-dimensional color space. This is, however, hardly possible in a 2D medium and we have to appeal to the readers to imagine these bubbles of color-name representation in the color space.

In order to make the "maps" easier to read we omitted the means in the last version. Instead the increasing "loadings" are symbolized by increasing density of "graining". The first line always signifies the value 1, the nest 2, etc.

Reliability. One color sample (NCS 10 44 R10B) participated twice in the investigation and was judged by two groups of 24 Ss. The correlation between the two sets of values over the eight color-name scales, for which it had received mean values, was 0.984 - a satisfactory estimation of reliability.

DISCUSSION

(In the original report each color-name is treated more extensively but here the space allows only a few comments).

BLACK and WHITE. Contrary to the other four names of the elementary colors these two have high mean values only for a very little area. This does not mean that they are of different character than the others as regards the NCS-**definition.** But it is obviously so that the words yellow, red, blue and green are accepted as a description of far more colors with these elementary colors as **main attribute** than what is the case with black and white.

WHITE has the smallest area of all the color names investigated - perhaps because the stimulus was a piece of paper against a white background, making somewhat darker samples look even darker. Moreover, people of today have references for white paper - peasants 100 years ago had maybe been more generous with the denotation white.

YELLOW. Note how colors called yellow include nuances far up towards white. But a yellow must not be blackish, then it is called beige or brown. Also note how the yellow area is more narrow on the red side where we have the name orange for the yellow-red colors; yellow-greens have no corresponding name.

RED. Colors which without hesitation are called red cover - like the yellows - a relatively small "bubble". Blackish reds are called brown (or lilac if bluish) and white ones are rose or pink.

BLUE, on the other hand, covers a much larger part of the color space. Note that the word blue is an acceptable name for colors of very moderate blueness. They may be classified as blue and if needed they are specified as dark, light or grayish blues - but they are all blues. (One hardly speaks about a gray-red color in a corresponding nuance, it will be gray-brown).

GREEN has the largest extension in the NCS model among the elementary color words. Note how both blue-greens and yellow-greens can go in under the category green. An inconsequence we have often met and which is reflected here is how colors which people have NCS-determined to be mainly yellow with a little greeness by the same persons are categorized as greens.

BROWN is the name for colors in the yellow-red area with moderate or much blackness (30-80%). This color word comes as no 7 in Berlin and Kay's study on the development of color words; after the words for the elementaries. This means that most languages have a special word for this color area.

ORANGE comes thereafter in B&K's order. Without doubt orange is a commonly used word for yellow-red colors not too blackish. Orange covers about the same hue-area as brown. One has discussed where, between yellow and red, the "best orange" is situated; i i' a color which has the same redness as yellowness? Maximum orange for our group of subjects was significantly away from the midpoint towards yellow.

BEIGE is another of the colorwords with color correlates in the yellow-red sector; maximum around Y35R. Mainly whitish and grayish colors. Noteworthy is that many subjects have marked beige-values for colors far away in the green areas. It is obvious that the concept of beige for Swedish people is much less stringent than are the other words discussed above. Such an interpretation is probably relevant when large areas of the color space have received low mean values.

PINK and ROSE (skär & rosa) seem to be synonyms. Maybe not for the individuals but obviously for the group. The relatively low values indicate that many of the Ss had rather vague ideas about the "correct appearance" of these colors.

VIOLET and LILAC (violett & lila) is the next pair of synonyms. These words have their correlates somewhere in the middle between red and blue. "Violet" did not have any "unhesitant" areas at all. "Lila" was better known, but covered a considerable area of both dark, gray, light and strong colors.

PURPLE should be a third synonym to the previous ones. It is a common word in anglo-saxon color literature. We wonder if this is due to the large spreading of the Munsell Book of Color. Munsell happened to consider purple as a cornerstone of the color world and we are curious to see if ather English speaking people are of the same opinion. For our Swedish group was "purpur" the least known color word of the 17 presented. Many of the subjects had no marking at all and some had guessed that purple was up among the yellowreds.

GRAY and GRAYISH are good examples in a discussion of the importance of how the question is phrased, and this in turn is an example of how subtle and full of nuances man's relations are to colors.

In the main investigation we had the word gray with the question "How well does the color correspond with the word...". In another and comparable study we had formulated the question differently: "Mark on the scale how much of grayness you see in the color".

The difference between the diagrams for gray and grayness is considerable. In the first case it is a question of whether the word gray is a suitable name for the color and here we see how this word is reserved for - just gray colors, that is, with no or very little chromaticness. In the blue and green hues the word gray may pass also for colors with up to 10-15 NCS units of chromaticness, and this probably because there is no special word for these colors; on the red and yellow side the corresponding nuances are called beige and brown.

GRAYNESS on the other hand, it is possible to see and describe in a color - independently of hue and also if the colors have other names as well.

Gray is a **color notation or color classification term.**
Grayness is a **variable** , which people quite easily can make concious and quantify with a value on a scale.

This study was carried out with Swedish subjects. Corresponding data with English speaking subjects are collected and will be published in a near future.

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Diskussionsbeitrag

Thema: Ästhetische Farbsysteme, ihre gegenseitige Begründung und metrische Definition (auch mit ästhetischem Farbmaß).

1. Einheitliches internationales Bezugssystem und Bedingungen hierfür.

Die Vielfalt der Farbsysteme, Farbkarten und Farbkennzeichnungen erschwert zunehmend die gegenseitige Verständigung. Es entsteht der Wunsch eines einheitlichen Bezugssystemes, das zugleich eine Brücke zu den angewandten Farbkarten bedeutet.

So ist auch das AIC-Komitee Ungarns der Meinung, daß jetzt eine internationale Vereinbarung über ein "ästhetisch äqudistantes Farbensystem für Farbgestaltungszwecke" getroffen werden sollte.

Dazu werden drei Bedingungen zu erfüllen sein:

1. Zur Kennzeichnung dienen Empfindungskoordinaten Farbton, Sättigung, Helligkeit, also primäre Farbattribute.
2. Der Farbenraum soll ästhetisch äquidistant sein.
3. Das Farbensystem soll in einem Transformationsverhältnis zum CIE-X,Y,Z-System stehen.

Die Entwicklung in der DDR hat seit dem Vorschlag TGL 21 579 im Jahre 1966 die Richtigkeit und Zweckmäßigkeit dieser Bedingungen erwiesen.

Nach unseren Erfahrungen von etwa 17 Jahren möchten wir diese Bedingungen durch folgende Punkte ergänzen bzw. erweitern:

4. Es sollen in dem einheitlichen Bezugssystem beide Arten von Farbattributen (die primären und sekundären), die Folgerungen aus dem Farbsehen und die ästhetischen Funktionen Raum und Farbe sowie Licht und Farbe bei der Bildung von Komplexqualitäten (z.B. Wertgleichheit, Grauverhüllung) erfaßt werden.
5. Ein ästhetisches Farbensystem ist nicht nur durch Gleichabständigkeit, sondern auch durch Strukturen (aus den Elementen des Farbsehens), Komplexqualitäten (z.B. Wertgleichheit) und ästhetische Funktionen sowie chemisch-materielle Korrelationen (z.B. für Erscheinungsweisen) gekennzeichnet und bestimmt.

   Für die Praxis ist die Oberflächenerscheinung grundlegend. Die Gleichabständigkeit bedeutet z.B. Anwendung des ästhetischen Prinzips der Symmetrie.
   Es kommt nicht nur auf einfache ("primäre") Empfindung an, sondern wesentlich auf den Wahrnehmungscharakter der Farbe. D.h. Farbe ist nicht "optische" Erscheinungsweise.
6. Es soll eine Systematik der ästhetischen Farbsysteme und deren einheitliche Definition in einem ästhetischen Grundsystem er-

reicht werden. Dadurch wird es möglich, sich auf eine begrenzte Anzahl von ästhetischen Typen für praktische Farbkarten zu beschränken und die Farbsysteme einheitlich auf einander abzustimmen (eindeutige Korrelationen). Die bestehenden und eingeführten Farbkarten erhalten endgültige Verbesserungen (vgl. die Bestrebungen der Munsell-renotations). Für die Sonderfarbkarten und Auswahlfarbkarten gelten besondere zweckdienliche Regelungen (z.B.: Feinheit der Stufung, Kombinationstendenzen, "Metamorphosen" u.ä.).

7. Die Transformationen des CIE-x,y,Y-Farbenraumes in ästhetische Farbsysteme beziehen sich

7.1 auf ein valenzmetrisches Hilfssystem mit
Farbton (als λ_d-Korrelation),
Sättigung (als farbmetrische Reinheit),
Helligkeit (als Hellbezugswert,
das Ästhetisches Helmholtz-System genannt werden kann, da bereits eine empfindungsgemäße Gleichabständigkeit in den Koordinationsrichtungen zur Definition dient.

Dieses System soll die Brücke bilden zwischen den CIE-Farbmaßen x,y,Y und den möglichen Typen der ästhetischen Farbsysteme. Es besteht eine einfache farbmetrische Handhabung und die Möglichkeit zu mathematisch einfachen Abbildungen.
Der Vorschlag des Ungarischen AIC-Komitees bezieht sich im wesentlichen auf diese neue Form der Helmholtz-Koordinaten.

7.2 auf ein "technisch-ästhetisches Grundsystem", aus dem sich alle ästhetischen Farbsysteme als Typen entwickeln und einheitlich ableiten lassen.
Es ist ein konsequentes Farbwahrnehmungssystem vorgesehen, das die funktionellen Beziehungen zwischen den möglichen Systemen schritteise verwirklicht.

Aus dem technisch-ästhetischen Grundsystem wird eine Folge

von Systemtypen entwickelt und

ein einheitliches ästhetisches Bezugssystem als Synthese der Farbattribute abgeleitet.

7.3 Die Transformationen sind in einem

"Funktionellen Farbkörper"

durchzuführen; es ergibt sich eine systematische Folge VOM CIE-Farbsystem x,y,Y bis zu den ästhetischen Farbsystemen. D.h. aus dem Ästhetischen Helmholtz-System bzw. dem technisch-ästhetischen Grundsystem erfolgen nach und nach Abbildungen auf spezielle Farbkörper, die den Typen "angemessen" sind.

Oder: Es gibt im valenzmetrischen Grundsystem bzw. dem technisch-ästhetischen Grundsystem verschiedene Farbmannigfaltigkeiten ästhetischer Art, die wir nach Transformationsregeln erhalten. Diese Regeln folgen aus Seh- und Wahrnehmungsfunktionen und können nicht "formal-mathematisch" sein.
Es entstehen verschiedenartige geometrische~~n~~ Gebilde, die graphisch definiert werden; z.B. der Doppelkegel Ostwalds für das Weiß-Schwarz-Vollfarbe-System. Das Ästhetische Helmholtz-System wird durch einen geraden Kreis-Zylinder dargestellt, dessen Oberfläche von den spektralen Optimalfarben gebildet wird.

Zur Übersicht wird die Diagrammfolge der farbtongleichen Flächen sowie die CIE-Farbtafel R/L (nach TGL 21579) beigefügt:

2.5 Attribut-System L/S/T mit Farbton, Sättigung, Farbtiefe
als Synthese der primären und sekundären Farbattribute.

Diagramm farbtongleiche Fläche L/T/K mit Sättigungsgleichen S_N und Weißgleichen T_N (gleiche Farbtiefe T). (Ausführung bis zur Pigment-Vollfarbe und bis zum Weißpunkt H 10.2 für Titanweiß).

Beide Systemarten (Typ Munsell-System und Typ Ostwald-System) haben durch die gemeinsame Systemfolge (Farbkörper-Modell) dieselbe Farbtonstruktur L_N (d.h. denselben definierenden Farbtonkreis), dieselbe metrische Grundlage x,y,Y und dieselbe Gleichabständigkeit (mit Verbesserungen der TGL 21579).

Vom System der primären Farbattribute wird die Sättigungskoordinate S_N, vom Weiß-Schwarz-Vollfarbe-System die Farbtiefekoordinate T_N (als Weißlichkeit) gewählt. Dies kann auch als ein selbständiges, rechtwinkliges Diagramm S_N/T_N für den praktischen Gebrauch konstruiert werden.

Gründe für die Kombination der Farbattribute:

Die visuell richtige Sättigung ist für die Farbgestaltung grundlegend und ästhetisch interessanter als die Dinghaftigkeit mit ihrer Schattierung (die seit Lionardo da Vinci bekannt ist). Mit helligkeitsgleichen Farben wird in der Gestaltung selten operiert, da die Kontraste den dynamischen Charakter und die Gestaltbildung garantieren müssen.

Der Farbkennzeichnung wird H_K für den Helligkeitskontrast beigefügt.

Die Wertgleichheit als Grauverhüllung wurde durch das Weiß-Schwarz-System eingeführt und bedeutet die Anwendung von Komplexqualitäten.

Es ist aber wichtig, die Pigmentkonzentration und ihr Korrelat zu den T_N-Stufen für die Mischarbeit (ästhetisch zielsichere Pigmentmischung) zu kennen und zu gebrauchen. Wenn ästhetische Koordinaten (Farbattribute, Grauverhüllungen und Licht-Raum-Beziehungen) verlangt werden, müssen sie technisch einfach realisierbar sein. Das ist mit "reinen Rohstoffen" nicht möglich. Nötig sind mindestens wertgleiche Grundpigmente (z.B. T 6/K 10 bzw. T x/K 10).

Das definierende Diagramm L/S/T ist das gleichseitige Dreieck T/K, in dem die Sättigungsgleichen S 0.1; S 0.5; S 1 bis S 7 eingezeichnet sind. Für alle Farbtöne hat man das gleiche Dreiecksformular. Man braucht für Entwurfsarbeiten nur ein Formular und kann darin veränderliche, verschiedene Farbtöne der geplanten Farbgestalt eintragen, also die Gesamtplanung fixieren und übersehen (besonders in den Beziehungen Sättigungskontrast und Grauverhüllung). Wegen des Helligkeitskontrastes sind die Helligkeitsstufen H_N auf den Farbmustern angegeben. Es kann also auch für die Farbgestalt das Helligkeitsbild angelegt werden.

Aus diesen Gründen (ästhetischen Vorteilen, Planungsmöglichkeiten, ästhetischer Mischtechnik, Entwurfstechnik) ist das L/S/T-System dem L/S/H-System als allgemeines Bezugssystem vorzuziehen.

In der DDR ist eine L/S/T-Farbkarte aus dem "neuen Baumann-Prase-System L/GK/T = Farbton, Grundpigment, Weißlichkeit" entwickelt worden. Diese Realisierung kann als Entwurf "Farbmappen 2. Aufl." und als Auswahl-Kartei L/S/T in der Ausstellung geprüft werden. Es wurden also für die Herstellung und Anwendung einer einheitlichen internationalen Bezugs-Farbkarte schon Erfahrungen gesammelt. Für die Farbmappen 2.Aufl. gibt es eine Broschüre, die in die Systematik und metrische Grundlage einführt.

Die Synthese der beiden Arten von Farbattributen befreit also von einer gleichzeitigen Verwendung von zwei ästhetischen Farbkarten Munsell und Ostwald. Es wird also eine technische und ästhetische Vereinfachung bei gleicher "Mannigfaltigkeit" geboten.

Die Anwendung der L/S/T-Farbkarte ist besonders neu und interessant, wenn man zur"ästhetischen Pigmentmischung" die Farborgeln I und II mit einem Pigmentsortiment (aus Organischen Verschnittpigmenten) zugrunde legt.

In der DDR ist mit der Herstellung von "funktionellen Farborgeln", besonders der weißen Stammfarben als Farborgel I, begonnen worden. Schon ein "ästhetisches Pigmentsortiment" mit wertgleichen Pigmenten T 6/K 10 bietet besondere Vorteile, die bisher für Farbmischungen ungewohnt sind.

Der Gedanke von Wilhelm Ostwald: die vollständige "System-Orgel" ist teils vereinfacht worden (jetzt 90 Pigmentnuancen statt früher 680 "Normfarben"), teils aber auf mehrere Farbsysteme erweitert worden, da man funktional und praktisch alle wichtigen ästhetischen Farbsysteme: Munsell, Ostwald, Prase, DIN 6164, Hering (als Grauverhüllung), Runge (als Fernenverhüllung) beherrscht, d.h. rasch selbst ermischt. Die Ostwaldsche Farborgel blieb auf das Weiß-Schwarz-Vollfarbe-System beschränkt.

Die Diagrammfolge vom Helmholtz-System bis zum L/S/T-System ist mittels gleichseitigem Dreieck einheitlich dargestellt worden. Damit sind alle Farbmannigfaltigkeiten (Systemtypen) in einem Farbkörper dargestellt und auf einander bezogen.

Das Diagramm Vektorsystem L/R/H
mit Darstellung des S/T-Systems (vgl. Ausstellung)

zeigt die analytisch und äathetisch richtige Darstellung der Reinheitsgleichen (Schattenreihen) als Strahlenbüschel des Schwarzpunktes. Hier werden die Farbreihen anschaulich adäquater, d.h. sinngemäßer gezeigt. Die Sättigungsgleichen sind nicht völlig parallel zur Grauachse; die Weißgleichen haben eine sich wandelnde Krümmung.

Es läßt sich ohne weiteres auch ein L/S/H-System ablesen, wobei die Helligkeitsgleichen in allen farbtongleichen Flächen dieselbe Struktur aufweisen. Es kommt also für die Praxis darauf an, diese farbtongleichen Flächen der Vektoren R und H als farbige Diagramme zur Verfügung zu stellen.

Für den Farbgestalter ist es wichtig, zur Beherrschung der ästhetischen Farbkombinationen die günstigste "Auswahlordnung" zu finden. Denn erst dann kann der Entwurf der Farbgestalt ästhetisch-konstruktiv werden.

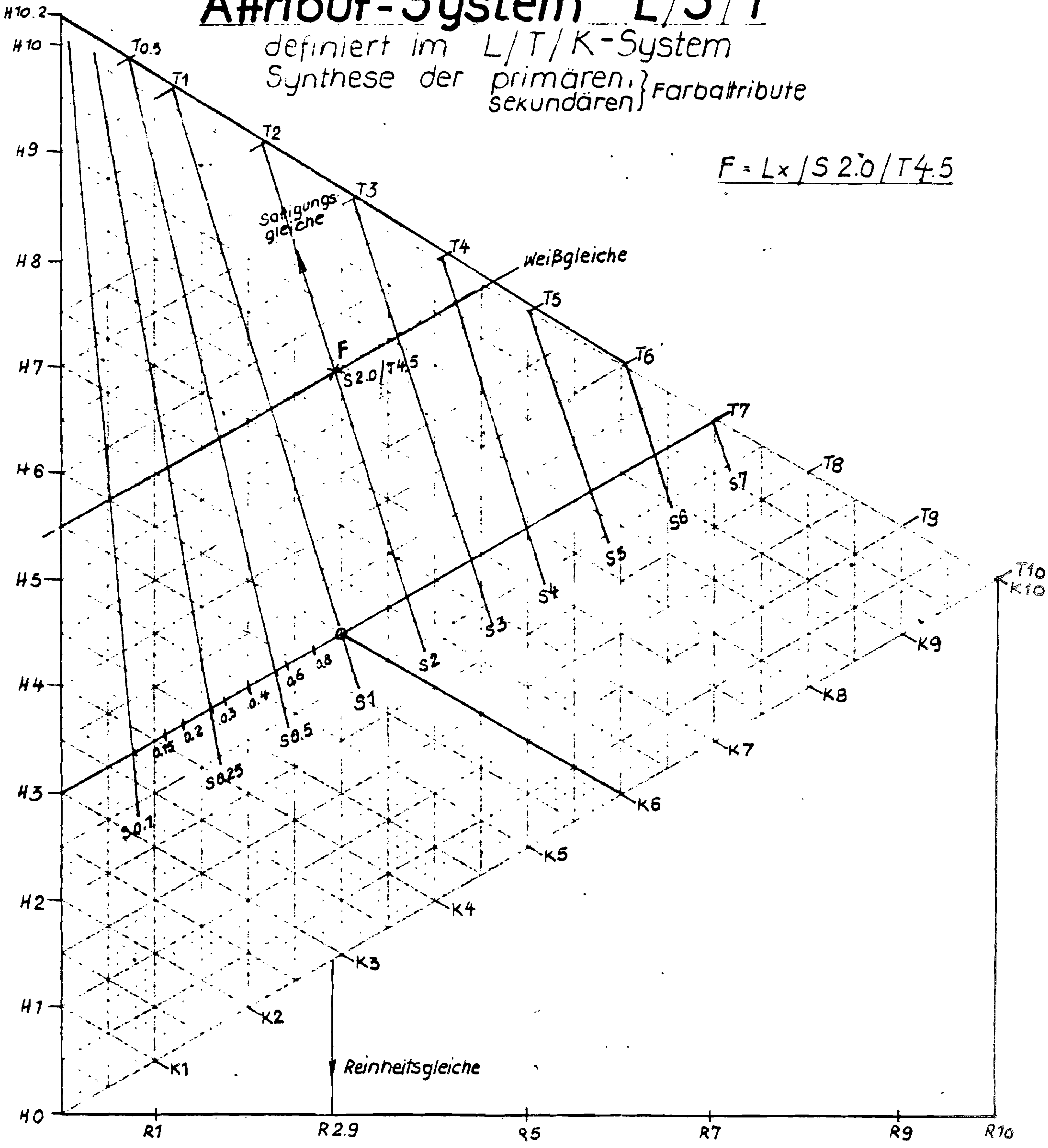
Abb. 7.3.5

Attribut-System L/S/T

definiert im L/T/K-System

Synthese der primären, sekundären } Farbattribute

F = Lx / S 2.0 / T 4.5



Small Color Difference Samples and Color Order Systems

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Color Order Systems provide various methods of specifying color. A system's object color samples form a color map that allows the user to locate non-reference color samples which will be related to, but not identical to, the standards of that system.

The production of small color difference samples that show the relationship of a non-reference color to the related standards of a particular system will become increasingly important as color science progresses. Precision and adherence to a selected systems object standards is required. Careful selection of a system that facilitates the production of small color difference samples will prove to be a more practical path to new color applications.

When a series of color samples are produced that record the pathway of color changes in the evolution of a color phenomenon, as may occur in agricultural product maturation, small color difference samples are particularly useful. Object colors that are identified steps in the development of an agricultural produce are not the object colors of a standard color order system. Their specificity derives from the characterized changes in the evolution of the product in question. When produced, they are specified object colors and are part of a visual measurement system applied to the control of that agricultural product. Their instrumental measurement assigns the identity of those object colors and permits location within another color order system.

Small color difference samples representing the steps in the ripening process of an agricultural produce provide a finer series of measurement steps to allow a more carefully selected tolerance and an improved color control system.

Because of the equal visual spacing advantages offered by the system, CIE LAB particularly lends itself to close color tolerance work. Presently there is an absence of a comprehensive collection of standard object colors for CIE LAB color space. Nevertheless, CIE LAB is a logical color space to employ to organize small color difference samples.

Small color difference samples produced for the L*-50 level of CIE LAB color space illustrates the concept. When producing samples between a*-30 to a*+30, samples show the spacing in 6 steps, 12 steps, 60 steps, 240 steps, and 600 steps. Selection of color tolerance steps are difficult at 6 steps and 12 steps, but selection is greatly improved at 60 and 240 steps.

When we increase the number of steps until there appears to be a continuation of color without any visual change from one step to another, and determination of change can still be made by instrument, the instrument becomes the observer and the data to determine tolerance becomes more finite. Smaller and smaller differences indicate greater promise in product control.

Poster paper at
the Forsius Symposium
on Color Order Systems
Kungälv SWEDEN 1983

Anders Hård
Lars Sivik

BASIC CONCEPT OF THE NCS AND ITS USE FOR STUDIES OF COLOR RENDERING

(Abbreviation of a forthcoming report on color and lighting).

The NCS color order and notation system is based on the experimentally confirmed fact that a "naive" observer is able to determine an arbitrary color in terms of degree of resemblance to the six imaginary color sensations called elementary colors; the two achromatic: white (W) and black (S), and the four chromatic: yellow (Y), red (R), blue (B) and green (G).

The psychometric definition "degree of resemblance to each of the elementary colors" represents the basic perceptual variables called **elementary color attributes:** whiteness (w) and blackness (s); yellowness (y), redness (r), blueness (b) and greenness (g).

But y-b and r-g, respectively, are mutually exclusive and the corollary is that a given color can have maximally four attributes.

By giving the elementary attributes metric scale values from 0 to 100 we have also established the psychometry of the NCS COLOR SPACE, viz.

$$\text{the color } F = s + w + (y \text{ or } b) + (r \text{ or } g) = 100 \qquad (1)$$

In studies with magnitude scaling using the definitions above we have found a very good accuracy of the judgements. For a group of 20-30 "naive" observers the confidence-interval at the 0.05-level is usually less than 5 NCS units.

From the space-defining equation (1) we have developed a three dimensional NCS color model by deriving two additional parameters: the sum of two chromatic attributes gives the chromaticness c

$$c = (y \text{ or } b) + (r \text{ or } g) \qquad (2)$$

and the ratio between the two chromatic attributes, expressed as one of them in percentage of the sum(= the chromaticness), gives the hue φ

$$\varphi_r = (r/c)100; \quad \varphi_b = (b/c)100; \quad \varphi_g = (g/c)100; \quad \varphi_y = (y/c)100 \qquad (3)$$

From (1) and (2) we find that

$$F = s + w + c = 100 \qquad (4)$$

which geometrically is an equilateral triangle. Rotated over all hues it forms a three dimensional solid shaped as a double-cone. This is usually illustrated by its two projections, the NCS color triangle and the NCS color circle (see figure 1).

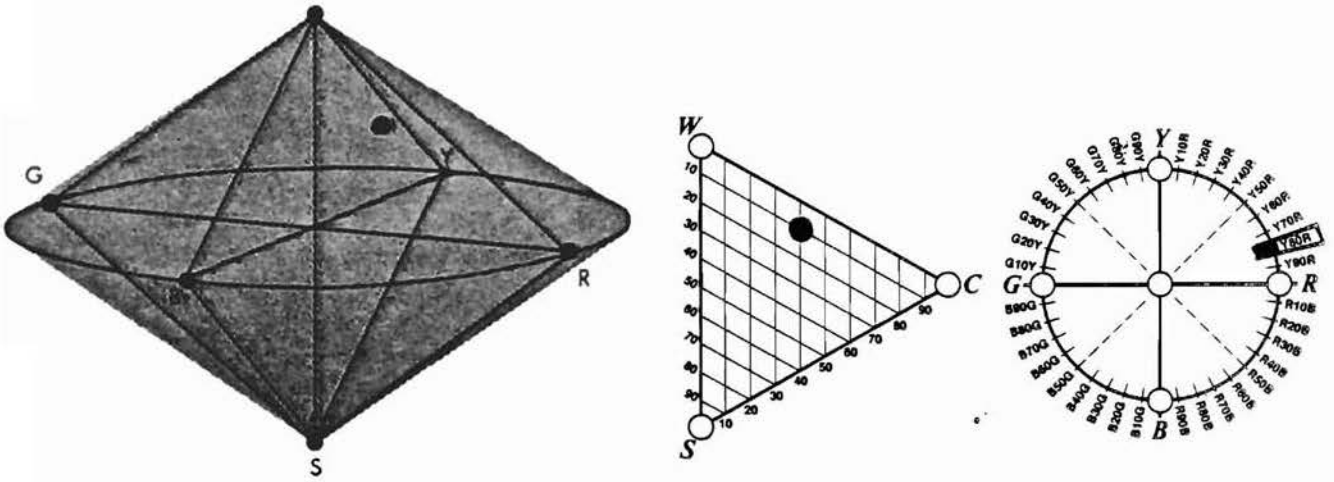

Figure 1. NCS color space and its two projections, the triangle and the circle.

We can now define a given color simply by marking it in the geometric symbols. In addition these also provide the possibility to derive a DESCRIPTIVE COLOR NOTATION. The NCS notation from (4) $s + c = 100 - w$, and (3)

$$s;\ c;\ -\varphi; \qquad (5)$$

tells us what the color looks like by giving the perceptual blackness, chromaticness and hue. In this notation we use the term hue (Sw. kulörton) for φ, and nuance (nyans) for s; c;, the latter in accordance with the terminology used by Hering. (   ).

Example: The colour marked in figure 1 will have the NCS notation 1040-Y80R, which means $s=10$, $r=32+$ $y=8$ makes $c=40$, $w=50$.

It has also been shown by experiments that the accuracy of color judgements have increased when the observers have been asked to make them in two steps; first the hue then the nuance (or reverse).

Another advantage of the geometric symbols is that it is easy to show how a given color may be dominated by one attribute or another, as in figure 2 where

$$w > c\ (y > r) > s \qquad (6)$$

This determination of what was called **main and secondary attributes** is one of the basic concepts in the first outline of our **theory of color combinations.** (Hård & Sivik, 1975).

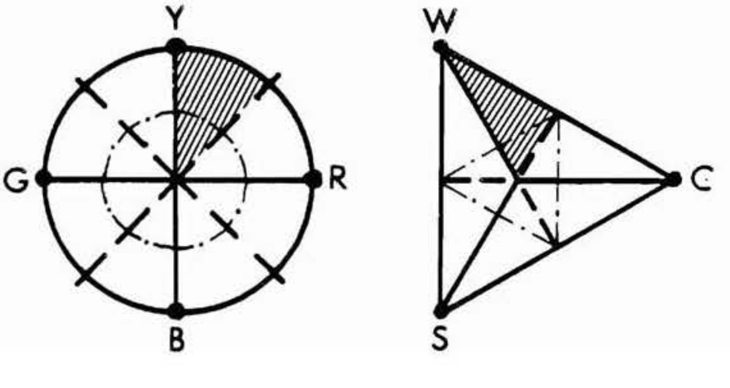

Figure 2. Characteristic areas in the NCS color space.

Color Rendering Experiments

During the development of the NCS it was convincingly proved how the color of an arbitrary color object can be judged and determined without any comparison with physical reference color samples. As the NCS is a method for direct psychometric color scaling of this kind it constitutes a unique tool for for studies of color changes which cannot be measured by physical instruments - for example due to various outer conditions like illumination, size of objects, viewing distance, etc.

We have just finished a first series of studies on the change of object color appearance in different illuminations.

20 observers were instructed to give their NCS judgements of 68 color samples (evenly spread over the color space) under three different light conditions:

a) daylight (simulated according to CIE and the same as in the basic NCS experiments);
b) incandescent light;
c) warm-white fluorescent tubes;

The observers had to adapt to the actual light before they started the judgements.

The "daylight" was taken as the reference light and for each observer and for each color sample was calculated the NCS difference in s, c, and between the reference light and the test light. Thereafter was computed the mean of changes over the observers and the confidence interval as a measure of the significance.

Although the color differences were small and significant in not more than about 25% of the cases they could, however, be plotted in the NCS diagrams. And here it was possible to interpret more general results and demonstrate significant trends.

In the poster is shown how such data of color changes can be illustrated in NCS diagrams; they give a relatively good idea of what happens when object colors are seen under different light conditions.

On the poster is also illustrated by a number of samples the color changes between two illuminations (when the observer is adapted to each of the conditions). The examples are taken from figure 3 which summarizes the differences in color appearance between warm-white tubes (c) and incandescent light (b).

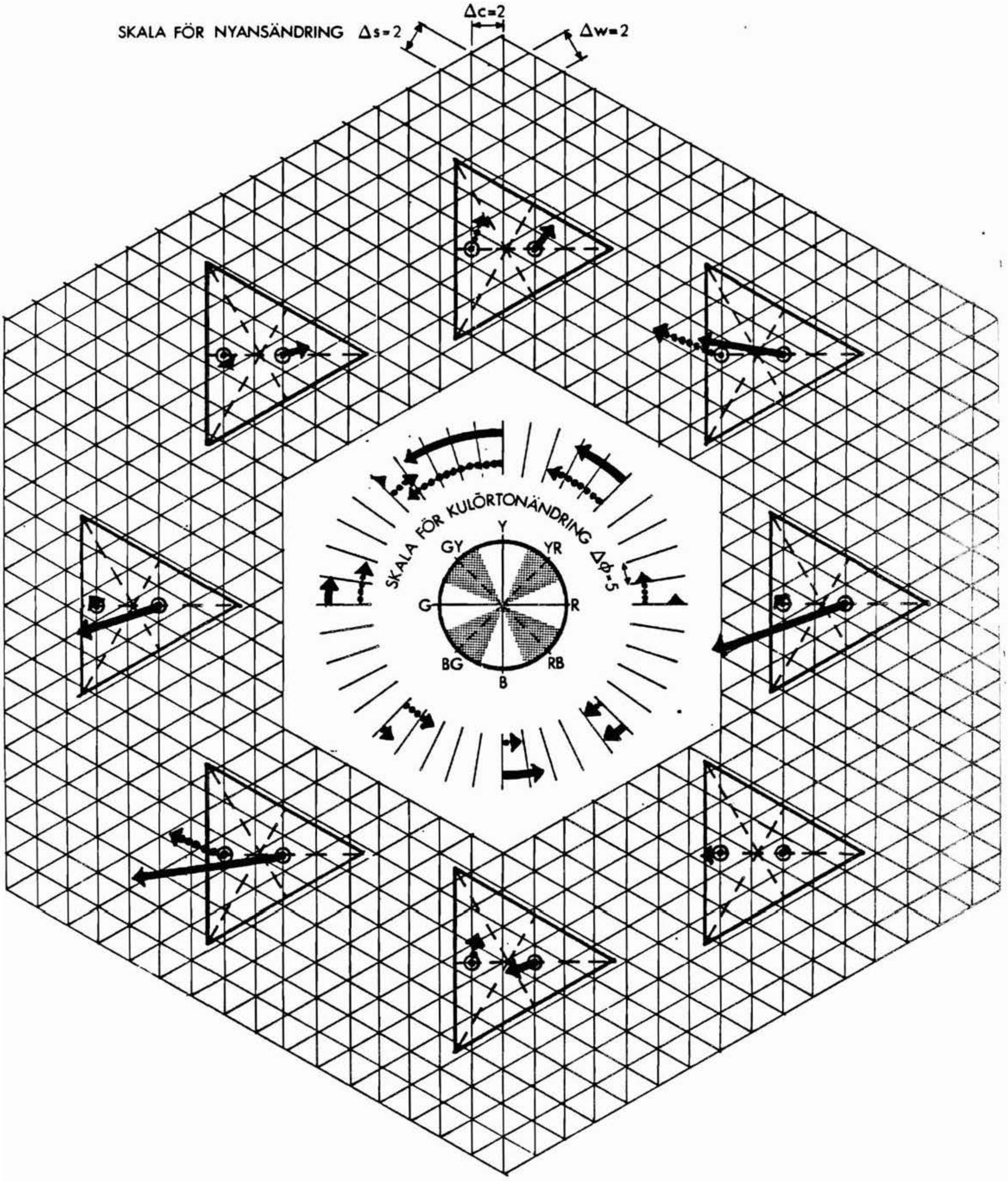

Figure 3. Color changes from b) incandescent light ~~to~~ c) warm-white tubes. Average for colors of less than c=10 ····> and above c=15 ⟶ Observe the scale factors!

ABSOLUTE COLOUR ESTIMATION BY THE NCS-METHOD

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The Natural Colour System NCS

NCS is a colour notation system, by which one can describe every imaginable surface-colour. It is strictly based on how colours appear to human beings with normal colour-vision, and is therefore independent of chemical and physical characteristics of the estimated object, and independent of viewing conditions.

This means, that a person trained in NCS can, without comparing with any colour samples, notate which colour he observes on an object in an arbitrary situation. The estimation is made by judging the degree of recemblance to the six elementary colours, pure white (W), pure black (S), pure yellow (Y), pure red (R), pure blue (B) and pure green (G), which are built into the human mind.

Graphic NCS colour notations

The NCS colour space can be illustrated in a three-dimensional solid, a regular double cone with white at the top, black at the bottom and the chromatic elementary colours yellow, red, blue and green round the equator.

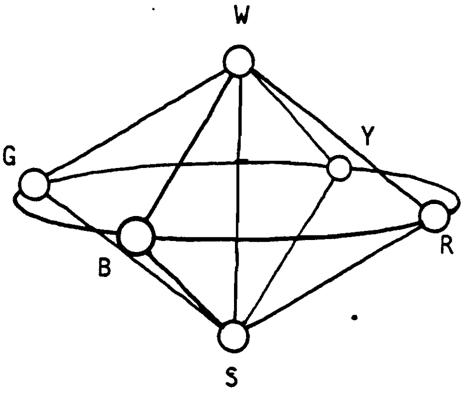


Fig 1 The NCS colour solid

When notating a colour perception one uses two two-dimensional projections of the NCS colour solid; 1. the colour circle where the chromatic elementary attributes and the ratio of them are notated (the hue of the colour). 2. the colour triangle where the resemblance to black, white and the pure chromatic colour of the hue in question is notated (the nuance of the colour).

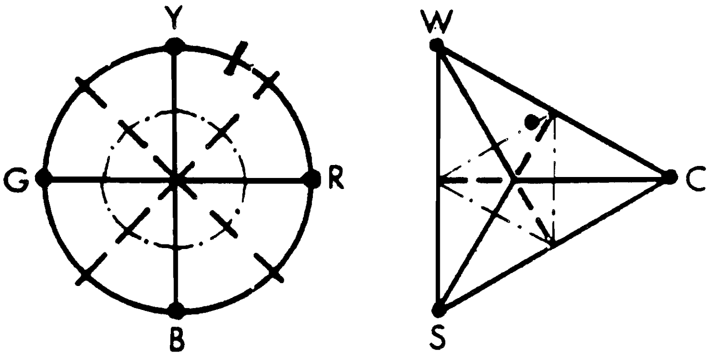


Fig 2 The NCS colour circle and the NCS colour triangle with an example of a graphically notated colour

This method of absolute colour estimations has been taught in colour education in Sweden since NCS was introduced in its present form in the late 60th. It has shown to be a surprisingly accurate method, also compared to e.g. absolute estimation of a distance without any measuringtool.

After only a few hours education in NCS, a group of persons with normal colour vision are capable to notate their colour perceptions with quite small deviations.

This possibility to make absolute colour estimations has been our foundation in many studies on how colours of objects changes in varying conditions, as surrounding, distance and illumination.

Numerical NCS colour notations

The colour attributes graphically notated in the colour circle and the colour triangle can also be expressed by numbers, where the sum of the elementary colour attributes whiteness (w), blackness (s), yellowness (y), redness (r), blueness (b), greenness (g) is 100.

$$w + s + y + r + b + g = 100$$

From this the numeric NCS notation is derived.

The colour graphically notated in fig 2 becomes the numeric NCS notation 1040-Y30R. 10 is the blackness (s), and 40 the chromaticness (c) (the sum of the chromatic attributes).

Blackness, chromaticness together with whiteness is the nuance of the colour and the sum of these attributes is always 100.

Y30R expresses the hue, i.e. the two chromatic attributes involved and the ratio of them, in this case a reddish yellow hue. (There are 100 steps between Y and R.)

These numeric colour notations are also used in statistical work up of colour estimation tests.

A colour notation test

Here I will present the result of a colour estimation exercise made on a 5-days colour course in 1979.

Observers. The observers in the test were of two categories. 10 were teachers or assistant teachers well accustomed to the NCS-method. 24 were participants of the course. They were adults who had chosen this course because they, in one way or another, came in touch with colour questions in their profession. The test was made on the second day of the course after only a few hours training in the NCS-method of colour designation.

Colour samples. The 9 colour samples presented to the observers were of size A4 (210 x 297 mm) with a glossy surface. The samples had been given their "objective" NCS-coordinates through transformation of measured CIE-coordinates.

Viewing conditions. The observers were sitting in a lecture room spread out between 3 and 8 metres from the wall where the colour samples were presented. The room was illuminated by daylight from both sidewalls. The samples were presented on a white screen with extra illumination from a projector lamp.

The test. The observers were asked to notate the colour of the presented colour sample by a mark on the arc of the colour circle (notation of the hue) and by a dot in the colour triangle (notation of the nuance), see fig 2!

Each sample was presented for about one minute, so that all observers should have plenty of time to make their notations.

The result. The result is presented both in NCS diagrams (colour circle and colour triangle) and in calculated average values. Course attenders and teachers are presented separately.

Key to the signs: NCS notation = the NCS coordinates transformed from measured CIE-data

Colour estimation = results from the test

s = blackness
c = chromaticness
w = whiteness
ϕ = hue
av = average value
σ = standard deviation
ci = confidence interval at a level of 95%
● = the "NCS notation" in the NCS diagram
★ = the average of the colour estimations in the NCS diagram

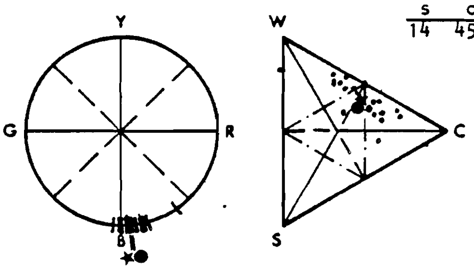
Course attenders

Teachers

SAMPLE No. 1

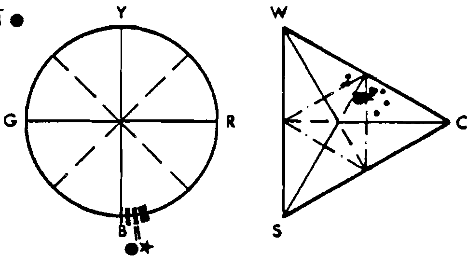
NCS notation

s	c	Φ	
14	45	R91B	●



Colour estimation

	s	c	(w)	Φ	
av	10	48	(42)	R92B	★
σ	7	11	(14)	9	
ci	±3	±5	±6	±4	



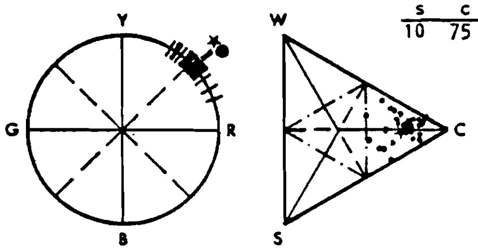
Colour estimation

	s	c	(w)	Φ	
av	10	49	(41)	R90B	★
σ	4	9	(9)	5	
ci	±3	±7	(±7)	±4	

SAMPLE No. 2

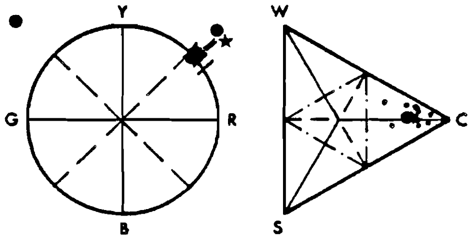
NCS notation

s	c	Φ	
10	75	Y54R	●



Colour estimation

	s	c	(w)	Φ	
av	14	71	(15)	Y53R	★
σ	10	11	(9)	11	
ci	±4	±5	(±4)	±5	



Colour estimation

	s	c	(w)	Φ	
av	9	77	(14)	Y55R	★
σ	5	9	(8)	5	
ci	±4	±7	(±6)	±4	

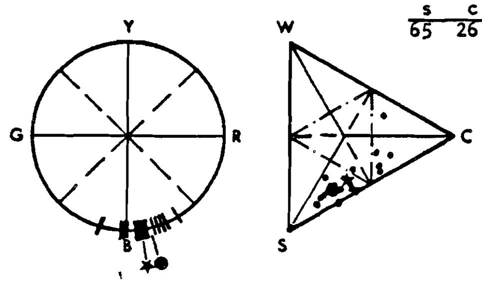
Course attenders

Teachers

SAMPLE No. 3

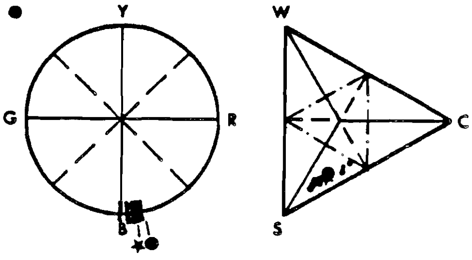
NCS notation

s	c	Φ	
65	26	R84B	●



Colour estimation

	s	c	(w)	Φ	
av	56	35	(9)	R90B	★
σ	17	14	(7)	12	
ci	±7	±6	(±3)	±5	



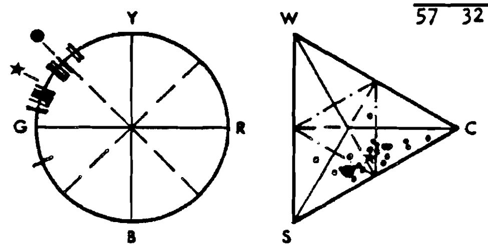
Colour estimation

	s	c	(w)	Φ	
av	68	25	(7)	R90B	★
σ	10	9	(2)	5	
ci	±7	±7	(±1)	±4	

SAMPLE No. 4

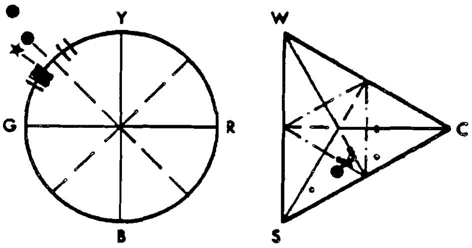
NCS notation

s	c	Φ	
57	32	G49Y	●



Colour estimation

	s	c	(w)	Φ	
av	40	46	(14)	G30Y	★
σ	15	18	(9)	18	
ci	±7	±8	(±4)	±8	



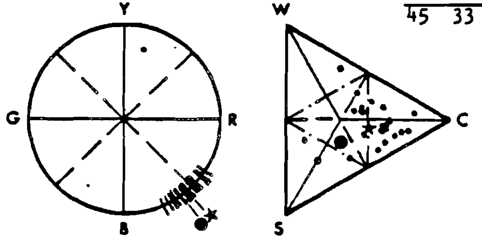
Colour estimation

	s	c	(w)	Φ	
av	47	39	(14)	G40Y	★
σ	13	11	(5)	12	
ci	±10	±8	(±4)	±9	

SAMPLE No. 5

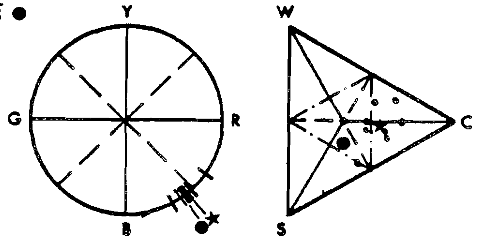
NCS notation

s	c	Φ	
45	33	R60B	●



Colour estimation

	s	c	(w)	Φ	
av	29	51	(20)	R55B	★
σ	14	16	(13)	10	
ci	±6	±7	(±6)	±4	



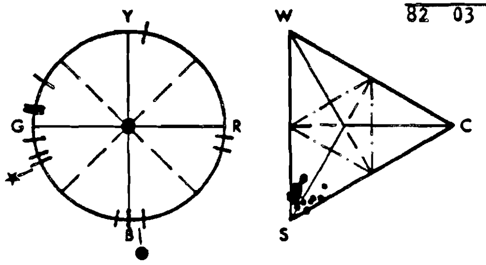
Colour estimation

	s	c	(w)	Φ	
av	24	56	(20)	R55B	★
σ	10	13	(9)	8	
ci	±7	±10	(±6)	±6	

SAMPLE No. 6

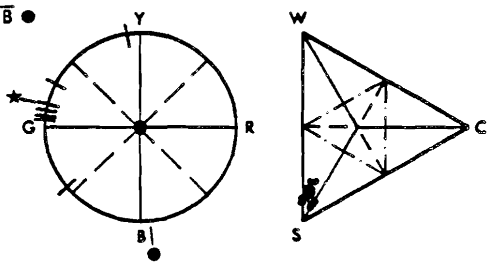
NCS notation

s	c	Φ	
82	03	R93B	●



Colour estimation

	s	c	(w)	Φ	
av	85	03	(12)	B72G	★
σ	5	7	(7)		
ci	±2	±3	(±3)		



Colour estimation

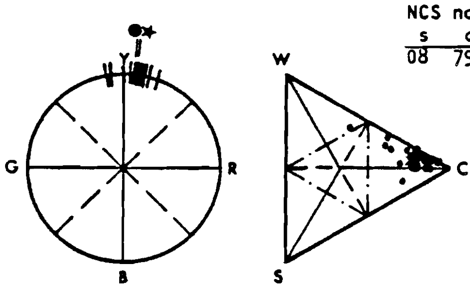
	s	c	(w)	Φ	
av	86	03	(11)	G14Y	★
σ	5	3	(4)	43	
ci	±4	±2	(±3)	±32	

Course attenders   Teachers

SAMPLE No. 7

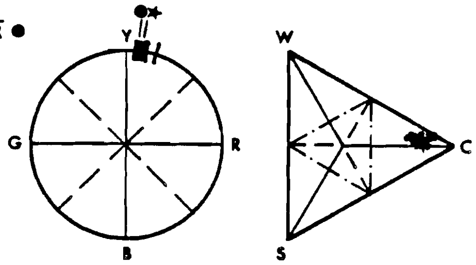
NCS notation

s	c	Φ	
08	79	Y07R	●



Colour estimation

	s	c	(w)	Φ	
av	07	76	(17)	Y08R	★
σ	5	12	(11)	7	
ci	±2	±5	(±5)	±3	



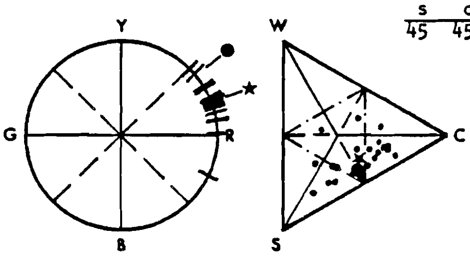
Colour estimation

	s	c	(w)	Φ	
av	07	80	(13)	Y10R	★
σ	3	5	(4)	4	
ci	±2	±4	(±3)	±3	

SAMPLE No. 8

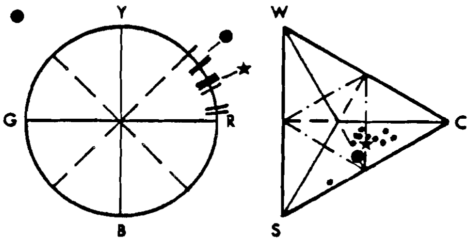
NCS notation

s	c	Φ	
45	45	Y57R	●



Colour estimation

	s	c	(w)	Φ	
av	39	46	(15)	R78B	★
σ	16	15	(9)	17	
ci	±7	±7	(±4)	±8	



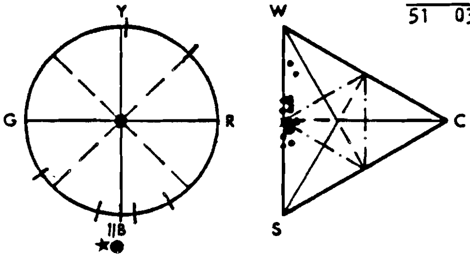
Colour estimation

	s	c	(w)	Φ	
av	36	50	(14)	Y74R	★
σ	12	11	(6)	14	
ci	±9	±8	(±5)	±11	

SAMPLE No. 9

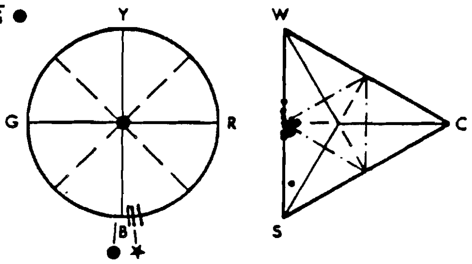
NCS notation

s	c	Φ	
51	03	B03G	●



Colour estimation

	s	c	(w)	Φ	
av	49	01	(50)	B06G	★
σ	12	3	(10)		
ci	±5	±1	(±5)		



Colour estimation

	s	c	(w)	Φ	
av	52	02	(46)	R92B	★
σ	11	3	(12)	5	
ci	±9	±2	(±9)	±4	

Comments

One must keep in mind that the viewing conditions were not in accordance with the standardized conditions for estimating NCS colour samples, and therefore the result of the estimations is not directly comparable with the NCS notations transformed from measured CIE-values. In spite of this and of the various viewing conditions for the observers, the results are astonishingly accurate. This is probable an example of colour constancy.

In the well controlled conditions under which the NCS R&D work was carried out, the confidence intervall (on 95% level) had a size of up to ±5 NCS units. The size of the confidence intervalls in this estimation test is not much bigger, which shows that a novice observer-group of about 25 persons or a well-trained observer-group of about 15 persons is sufficient for an accurate NCS designation.

Colour reproduction from a NCS notation

Another test showing the accuracy of the NCS notations as colour communication is presented as a poster on the symposium.

After a few days, on a colour course, the course attenders were given the task to paint a colour in opac gouache paint from a graphic NCS notation. In spite of problems of paint-mixing and predicting colour changes, when the paint dried, the deviations from the given NCS notation is surprisingly small. The average deviation was only about ±10 NCS units, which can be illustrated as the difference between two adjacent colours in the NCS colour atlas.

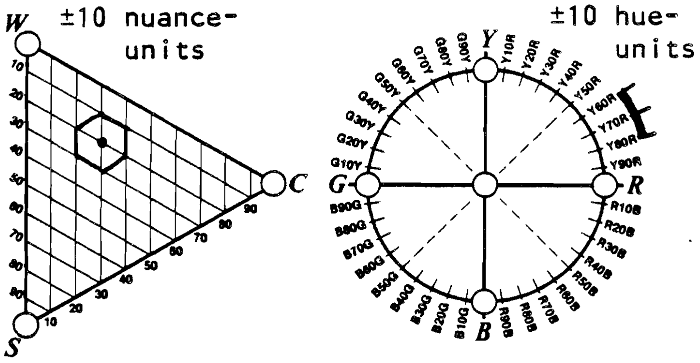


Fig 3 Deviation of 10 NCS units in the NCS colour space

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NCS - Natural Color System: A Swedish standard for colour notation, Anders Hård & Lars Sivik, Color Research and Application, issue 3, Sept 1981.

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NCS COLOUR SAMPLES AND COLLECTIONS - WORKING TOOLS FOR ENVIRONMENTAL COLOUR DESIGN

Poster to be presented at the Forsius symposium on Colour order systems

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The NCS system is independent of the existence of physical colour samples in the same sence as the meter system is independent of rulers. But for many reasons one needs this kind of aids partly to illustrate and make clear the structure of the NCS arrangement of colours, but mainly in order to give all who work within environmental design working tools in their daily. work. The kind of people we think of are architects, designers, decorators, colour consultants, interior architects and also all teachers involved in education of these cathegories. But also in all communication between the prescribers and the industry or workmen like paint contractors and naturally within colour-research it is a good help with colour samples.

To present the general NCS idea structure and the NCS colour notation system we have the Swedish standard SS 01 91 00 Colour notation system completed with a NCS Colour atlas SS 01 91 02 published by the Swedish standards institution. There are also the standards giving the colour samples' CIE-specifications.

But for the more practical daily need a range of colour samples and sample collections have been developed in order to cover different needs.

These kinds of products will be presented at the symposium,but as a brief idea a four-colour print illustrating the NCS working tools is enclosed here.

Our general idea is, that when working with colour you need survey collections with smaller samples to make your primary colour choise. The final choise and the illustration of your choise,however, must be done with larger separate samples.

To cover different needs we have produced and stock different sizes of complete sets of the NCS samples, but also stock for direct delivery all the 1,412 colours in four different sizes (A9, A6, A4 and A2).

As the basic idea is that these colour samples should be practical tools, we have also tried to keep costs as low as possible. (For instance the price for a single A4 (210x297 mm) colour sample is approx one US$.) That is to say that the NCS samples should firstly be seen as industrial mass-products, where every separate colour sample is not controlled. If there is a need for NCS-calibrated samples for scientific purposes or precision handling the Scandinavian Colour Institute is prepared to supply them including accurate CIE and NCS specifications at an extra cost.

Today, three years after the introduction of NCS, we can evaluate our basic ideas. In Sweden the "NCS colour language" is used in almost all education on all levels. The NCS colour samples are spread out and used by almost every architect and designer working with colour. The largest paint companies have parts of the 1,412 NCS colours as their tinting system, and all other paint companies will follow. Many companies within the building industry

NCS-notate their products, which also goes for many other big companies. The NCS tends to be used within all sectors of society,and during some years we have seen Swedish fashion and textile industry using NCS for their colour communication.

The Scandinavian Colour Institute controls and supplies the NCS colour samples. Last year, the second after introduction of NCS, we delivered to the Swedish market about 17,000 A9 booklets, which means over 80,000 colour samples of just this size, and this year the figures probably will reach about 150,000 A9 samples.

We have confidence in our basic ideas that the colour system that will be used must be based on logical and natural principles - a "langugae for colour", and that illustrating material must be practical and possible to use to reasonable low costs.

1983 05 31 TH/EL

INTERNATIONAL BUILDING COLOUR STANDARDS:

SYSTEMS AND STRATEGIES.

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ENGLAND.

Preliminary moves have been made through the International Standards Organisation to develop international standards for the colouring of building materials. These will function to provide greater compatability between the colour ranges of different building materials in different countries. In addition, these should provide an agreed system for specifying colour appearance. This will provide much needed international uniformity in the area of industrial and architectural colour specification.

A research programme has been sponsored by the Science and Engineering Research Council, Great Britain to investigate (1) the strategies that can be employed in compiling colour standards (2) the nature of the colour specification system that will underlie them. Part of this work consists of a major survey of architects' attitudes to the use of colour in buildings. It is intended that the paper offered at the A.I.C. Symposium will outline the results of this survey.

THE YCM SYSTEM

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Background

Two means have been used in solving problems in object color measurement: one is through spectrophotometry and the other through colorimetry. When spectrophotometry is used, some analytical function is appliead to relate the measured quantity---reflectance, transmittance, or radiance factor--to the amount of colorant(s) present in a colored material. With the colorimetric approach, a measurement is made in terms that parallel the three-stimulus function of the human eye. The latter data can be obtained directly from a tristimulus colorimeter with suitable light source, filters, and detectors or indirectly through spectrophotometric measurement followed by computation with a suitable set of weighting factors.

Recently we have questioned the fundamental assumptions behind the recommended use of the CIE x,y chromaticity diagram to display the relationships among colorants. These same principles underlie the practice of colorant formulation which is based on colorimetry (*1*). There is no *a priori* reason why these should be regarded as strictly colorimetric techniques when in fact they are analytical problems requiring colorimetry only for the evaluation of results but not necessarily for the solution of the problem. With these questions in mind, we have taken a third approach to solving problems in dealing with colorants in object color measurement which is a hybrid of colorimetry and spectrophotometry. We term the method YCM, and it is described below.

Principles of YCM

The idea of YCM stems from the concept of using three ideal colorants, Yellow, Cyan, and Magenta, as stimuli for a system which can define any object color unequivocally in terms of the relative amount of each ideal colorant. This is analogous to the CIE system of colorimetry where the product of reflectance and the visual response to mixtures of three colored lights (color matching functions---(*2*)) has been replaced by an analytical colorant concentration function.

Consequently, the idea of a color space was evolved for object color mixing based on first principles that do not depend on conventional colorimetry (*3*). To preserve the three-dimensionality of color, the visible spectrum is arbitrarily divided into three equal sections and named according to commonplace terms: yellow is that section between 400 and 500nm; between 500 and 600 is called magenta; and cyan is between 600 and 700 nm. These are the three stimuli of the system. The other fundamental used to complete the YCM concept is the Kubelka-Munk relationship between reflectance and concentration.

Mathematically the stimuli are:

$$Y = 1/n \sum_{\lambda=400}^{\lambda=500} f(\beta)\ P\ \Delta\lambda$$

$$M = 1/n \sum_{\lambda=500}^{\lambda=600} f(\beta)\ P\ \Delta\lambda$$

$$C = 1/n \sum_{\lambda=600}^{\lambda=700} f(\beta)\ P\ \Delta\lambda$$

where,
β, is the reflectance of the object, range 1 to 100%
λ, is the wavelength, 400 to 700 nm
n, number of integrating intervals
$f(\beta) = [(1-\beta-b)^2/2(\beta-b)]^x$
P, is the spectral power distribution of an illuminant
b,x are determinable constants

A set of chromaticity coordinates, y and c , are calculated from the relationships $y = Y/(Y + C + M)$; $c = C/(Y + C + M)$. A derived quantity, S, strength, is also calculated as the simple sum of Y + C + M. This is the third variable used with y and c to describe the position of any color in this color space.

Several useful concepts are obtained from the y,c chromaticity diagram, as follows:

1. All mixtures of colorants lie on straight lines joining the y,c coordinate points for the individual colorants.

2. The concentration of the individual colorants in a mixture line can be calculated by center-of-gravity methods.

3. When the chromaticities of three colorants are plotted on the same diagram, the triangle formed by the line joining the points describes the gamut of all colors that can be produced by combinations of the three colorants. This gamut can be altered with inclusion of other colorants having different chromaticities and outside the triangle formed by the points for the original colorants.

4. Colorants of different strengths will plot on parallel y,c chromaticity planes.

5. The coordinates of the ideal yellow, cyan, and magenta plot at the points 1,0; 0,1; and 0,0; respectively, which describes the limit of all real colors.

Applications of YCM

Research was done at Clemson (4) to test the practise of using YCM colorimetry. Instrumental color formulation was deemed as a suitable demonstration of the validity of the method. However, a substantial amount of background investigation had to be done as a preliminary to achieving the final result. It was shown that a y,c diagram gave a useful display showing the gamut of colors produced by any group of colorants. Furthermore, linearity of binary mixtures in a y,c chart provided an unambiguous method to select colorants to match colors when a field of many colorants was present.

The actual formulation trials that were part of this work were based on center-of-gravity calculations and then compared to the conventional tristimulus match prediction. The tristimulus method gave slightly better results than the YCM method until a special adjustment was made to the concentration function itself and then quite good results were obtained. The adjustment was developed after the thesis was completed and involved optimizing b and x in the concentration function, $f(\beta)$, given above.

It was concluded from this research that the YCM concept is useful in efficient selection of viable combinations from a field of colorants. It was also shown that center-of-gravity method is appropriate at least as a first approximation in computer match prediction if not an alternate to the present tristimulus method.

One advantage of this type of color system has been in teaching. Demonstration in the classroom using YCM has been found ideal to convey to the uninitiated how colorants relate to each other and how they can be mixed to achieve other than self-colors. No mathematics is needed in the simplest approach other than an initial set of y,c chromaticity coordinate values for the demonstration colorants. Any mixture of the component colorants is located by center-of-gravity giving a precise position on the YCM diagram. This position can be closely approached intuitively even by novices in color mixing.

Conclusion

YCM is a color order system quite different from conventional systems. It is not ordered in terms of any specific colorant but embraces all colorants and retains a concentration functionality in a special chromaticity diagram. This system has worked with pigments in paint and with several types of dyes. It is, therefore, presumed that it could be the basis of a general approach to another and unique form of colorimetry.

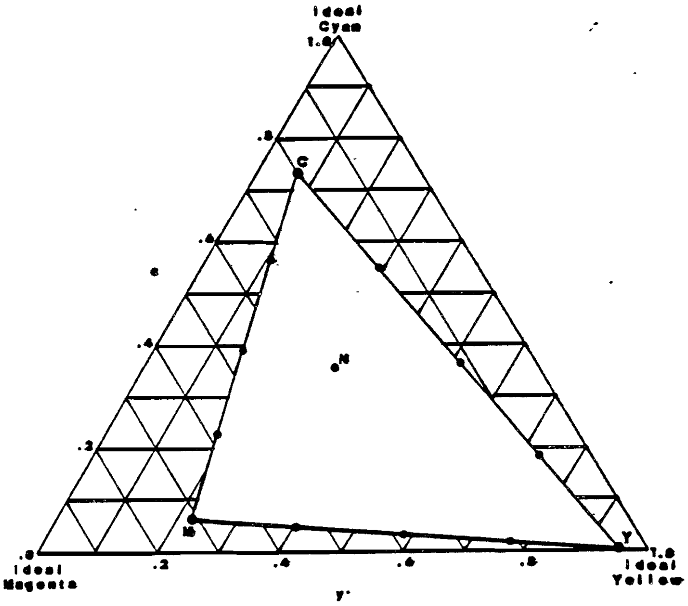
References

1. Park, R.H. and Stearns, E.I. (1944) *J. Opt. Soc. Am.* 34, 112
2. CIE (1971) "Colorimetry", Publ. 15, Bureau Central CIE, Paris
3. Ganz, E. (1965) *Text. Rundsch.* 20(9), 255
   Note---- the Ciba-Q method described in this reference uses tristimulus calculations by summation of the product of the CIE color matching function, illuminant, and reflectance function. This preculudes the unique stimuli of ideal yellow, ideal cyan, and ideal magenta.
4. Lucas, J.M. (1983) "The YCM Color System for Color Formulation" a Master of Science thesis, School of Textiles, Clemson University, Clemson, SC 29631

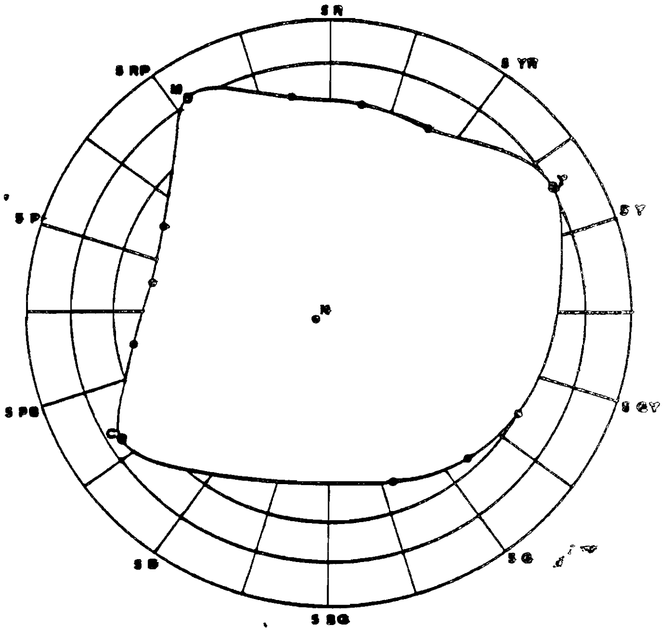
YELLOW, CYAN, AND MAGENTA PIGMENTS

Primaries and 25:75, 50:50, 75:25 binary mixtures

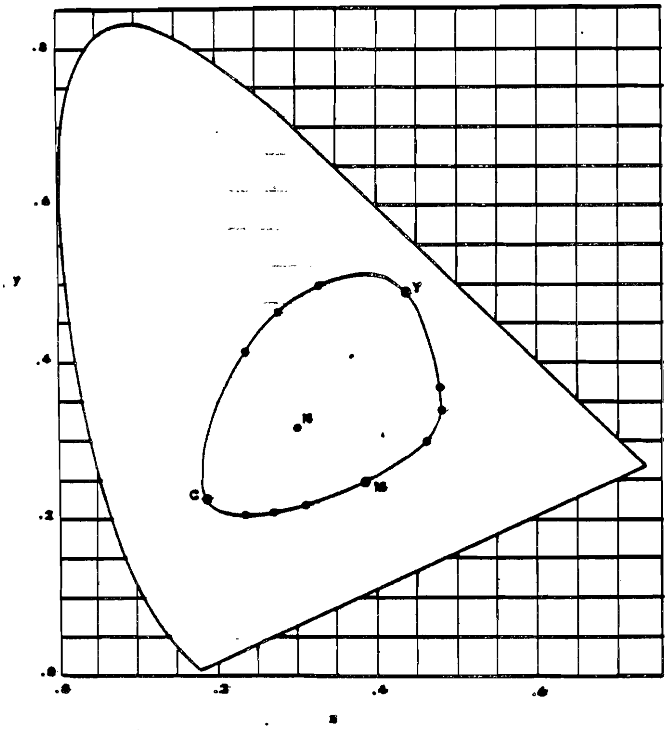
shown in several colorimetric systems



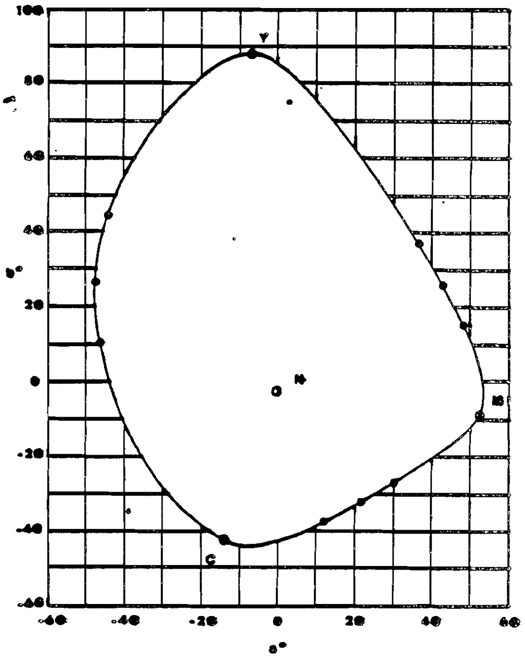
YCM y,c



Munsell Hue,Chroma



CIE x,y



CIELAB a*,b*

Illumination Dependence of Object-color Ordering.
Experimental Considerations.

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The Natural Color System is related to Hering's opponent-color theory. Hurvich and Jameson characterized Hering's opponent-colors by spectral maxima. Three of these maxima, near 450 nm, 540 nm, 610nm, have appeared in visual experiments for many years. It has recently been shown that the three corresponding spectral colors, when present in white-light illumination, stabilize the colors of perceived objects. If a practical color order system, composed of object-colors, is to remain usefully stable under change of illuminant, either the composition of any new illuminant must not deemphasize the three essential spectral constituents (this will be demonstrated), or the spectral reflectance curves of the objects themselves must peak strongly at the three wavelengths.

Natural Color System®

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1 SIS Färgatlas NCS
2 NCS Index
3 NCS Färgblock
4 NCS Färgregister
5 NCS Färgalbum
6 NCS A4-pärmar

7 NCS Ljushetsmätare
Separata färgprover
8 A2-prover
9 A4-prover
10 A6-prover
11 A9-häften (5 prover)

1 NCS Colour atlas
2 NCS Index
3 NCS Colour block
4 NCS Colour register
5 NCS Colour album
6 NCS Colour binders

7 NCS Lightness meter
Separate colour samples
8 A2 samples
9 A4 samples
10 A6 samples
11 A9 booklets (5 samples)

1 NCS-Farbatlas
2 NCS-Index
3 NCS-Farbblöcke
4 NCS-Farbregister
5 NCS-Farbalbum
6 NCS-Farbordner

7 NCS-Helligkeitsmesser
Separate Farbmuster
8 A2-Muster
9 A4-Muster
10 A6-Muster
11 A9-Hefte (5 Muster)

1 Atlas des couleurs NCS
2 Index NCS
3 Blocs-couleurs NCS
4 Fichier des couleurs NCS
5 Album des couleurs NCS
6 Classeurs des couleurs NCS

7 Indicateur de clarté NCS
Échantillons de couleur séparés
8 Échantillons A2
9 Échantillons A4
10 Échantillons A6
11 Carnets A9 (5 échantillons)