Consistent[1] colour appearance

DR 8-13

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[1] Jack Holm (US) expressed concern about the term 'Common Colour Appearance' which he thought might be misleading for some people. Following extensive discussion in the Focus Group we agreed that it would be better to use the term 'Consistent Colour Appearance' and for that reason this report uses this term throughout except for existing publications where the term 'Common Colour Appearance' has been used.

As far as their usage in this report these terms have the same meaning.

The following members of DR 8-13, “Common Colour Appearance" took part in the preparation of this reportership report. The committee comes under Division 8 “Image Technology”.

Members: W Craig Revie (GB), Yasuki Yamauchi (JP)

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1 Terms of reference (CIE R8-13)

To study the topic of consistent colour appearance to determine whether people mean the same thing when they use this term. The report will collect examples of what people refer to as consistent colour appearance including for displays, printing systems and brand management in order to work toward a unified understanding of this term. The report will also identify some counter examples. Note: One aim of this work is to explore how we might conduct a series of tests to determine whether consistent colour appearance is a shared and quantifiable concept.

2 Consistent colour appearance (summary)

When a set of colour reproductions (photographic images or documents) are judged to have a high degree of similarity, they are often said to have a 'Consistent Colour Appearance'. The degree of similarity is generally judged by subjective assessment.

Although this term and similar terms are widely used it has no clear definition and there is currently no standard means of assessing whether a set of colour reproductions has consistent colour appearance. It has also been suggested that there may be a range of different colour transforms which maintain colour appearance.

In this report we describe some example cases where sets of images share a consistent colour appearance and propose assessment methods that could be used to test this concept and explore it further. One objective is to determine whether consistent colour appearance is a shared concept across observers and cultures, and if so, whether the degree of colour similarity of a set of colour reproductions can be measured.

Images that are colour matched have a 'consistent colour appearance'. Colour matching, including media-relative colour matching is widely used for print production today but has a serious limitation when reproductions are to be made across a range of printing systems with different gamut sizes and shapes. To achieve identical colour (a colorimetric match) the reproductions must be converted to the smallest colour gamut of all the output systems involved. The aim of this project is to explore ways of using the full colour gamut of all systems and at the same time retain consistent colour appearance.

2.1 Working definitions of Consistent Colour Appearance

The following have been proposed as definitions:

Po-Chieh Hung (JP): "[Consistent Colour Appearance is an] image attribute which gives a sense of identity among a set of images which have different tone and colour" [18].

Philipp Tröster (DE): "If an image, for example a company logo is shown on different devices the degree of colour consistency amongst this set of stimuli can be defined as consistent appearance" [6].

Yasunari Kishimoto (JP): "When colour reproductions show highest similarity between the display reference and each print, and across the set of prints, when viewed under a consistent viewing condition they have by definition a 'consistent colour appearance'. Similarity is judged by subjective assessment" [16].

Andreas Kraushaar (DE): "Consistent Colour Appearance reproduction aims to maintain the colour consistency of a document or image rendered on different printing systems or displays where one rendering serves as the reference". The main characteristic is that the output gamuts change significantly in size and shape, hence established types of colour reproduction can't be used.

3 Introduction

When reproducing images the objective is often just to produce a result that looks good (preference rendering). This results in reproductions that can look significantly different from each other. An example of a typical set of results is shown in Figure 1.

Figure 1 – Set of images with a low level of Consistent Colour Appearance

There are many cases where it is important that a set of reproductions share a consistent or consistent colour appearance. At present this is usually achieved using a process of trial-and improvement where manual colour adjustment is made to each of the reproductions and visual assessment made with further adjustments until the result is acceptable. An example of one such set of reproductions is shown in Figure 2.

Figure 2 – Set of images that share a Consistent Colour Appearance

Consistent colour appearance builds on the idea of gamut mapping and extends that concept to apply to a set of imaging systems with different colour gamuts. The objective is not simply to produce the best reproduction for each pair of reproductions (as is usually the case with gamut mapping) but to ensure that colour appearance of the set of all reproductions is consistent.

One question to be answered is whether, given a set of reproductions, observers agree the closeness of colour appearance across the set. In other words is there consistent agreement on the degree to which a range of prints or displayed pages share a consistent colour appearance?

If it can be demonstrated that observers agree, it may also be possible to develop an objective consistent colour appearance metric. Such a metric could be used to measure the degree of colour similarity of a set of reproductions and would be useful in a number of situations where this is the reproduction objective and where today ad-hoc methods are used.

The term may be less precise than other colour evaluation terms such as 'Colorimetric Match' and there may be more than one transform that can be applied to a set of colours that produces a result that most people will agree maintains Colour Appearance. If this is the case it may be useful to recommend a single transform that observers agree produces Consistent Colour Appearance.

3.1 Background

Attributes consistently used to describe the characteristics of images include colour balance, tone mapping, colour gamut mapping and colour rendering. Together these, possibly with other attributes, determine the colour appearance of an image reproduction. The effect of changing each of these attributes on its own has been studied and some rules for the way in which individual attributes should be changed in order to preserve colour appearance are already known. For example maintaining the neutral scale and hue are generally the most important factors in maintaining colour appearance. Most types of colour reproduction anticipate assessment of a pair of reproductions. Consistent Colour Appearance reproduction extends this concept to the simultaneous comparison of more than two reproductions.

Consistent colour appearance is related to gamut mapping. CIE TC 8-03 studied this topic and concluded that there is no single gamut mapping strategy that can be applied in all situations.

Our question is whether there is a single gamut mapping strategy that preserves colour appearance.

It is not clear whether the idea of Consistent Colour Appearance is a concept which is shared by everyone or indeed whether there is a single colour mapping that preserves colour appearance. It is possible that each individual has a different idea of what is needed to preserve colour appearance for any given image. It is also possible that there is a range of colour renderings which most observers agree maintains colour appearance.

This seems to be a topic worth studying further and a number of projects have been, or are being, conducted in order to explore this area further. Research groups in Germany (Fogra), Japan (Yamagata University) and in Norway (Gjøvik) have current projects in this area with a US project (RIT) currently being considered. ISO TC130 and ISO/IEC JTC1/SC28 have a joint working group where this is one of the metrics being considered for standardisation.

4 Use cases for consistent colour appearance

There are a number of cases where having an objective metric for consistent colour appearance would be useful. In these cases there is usually an agreement, explicit or implicit, between the creator of a set of reproductions and the observer(s) of the set. In some cases it is important to be able to test whether the desired result has been achieved or at least the degree to which it has been achieved.

This section provides a brief introduction to a number of important examples and use cases. For each case the objective is identified, an initial assessment made and a number of key questions to be answered for each use case are listed.

4.1 Conventional printing

ISO/PAS 15339 defines a number of Characterised Reference Printing Conditions (CRPCs) developed by experts in the field of conventional printing. It has been claimed that these share consistent appearance across the range of printing processes. An example of the typical results for the reproduction of an image on the set of printing conditions is shown in Figure 3. In this case the same CMYK image (from ISO 12640-1, CMYK SCID) is printed on all CRPCs with identical CMYK values used for all cases. As can be seen from the result, these reproductions differ in both colour contrast and saturation due to the differences in colour gamut but there appears to be some colour consistency through the set. It is this colour consistency that we have called Consistent Colour Appearance and wish to explore further.

Figure 3 – ISO/PAS 15339 CRPC Example

For the set of reference printing systems the same combination of Cyan, Magenta and Yellow inks produce a neutral scale and the black scale has been adjusted to be approximately the same as the resulting neutral scale. This is designed to ensure that a CMYK image has a similar appearance on all systems. This result builds on many years of experience of printing systems where techniques have evolved that allow the same CMYK content to be printed across a range of printing systems with similar appearance.

It has long been a principle of RGB colour spaces that equal values of RGB should produce a neutral. ISO/PAS 15339 extends that principle to CMYK colour space, however in this case the additional constraint of ink hue may mean that although this works well for the set of printing systems included in the standard, it may not generalise to other CMYK colour spaces.

In this case, Consistent Colour Appearance has been achieved by ensuring that the colour of the solid Cyan, Magenta and Yellow inks have similar hue for each system and that the colour gamuts form a series in increasing size as shown in Figure 4.

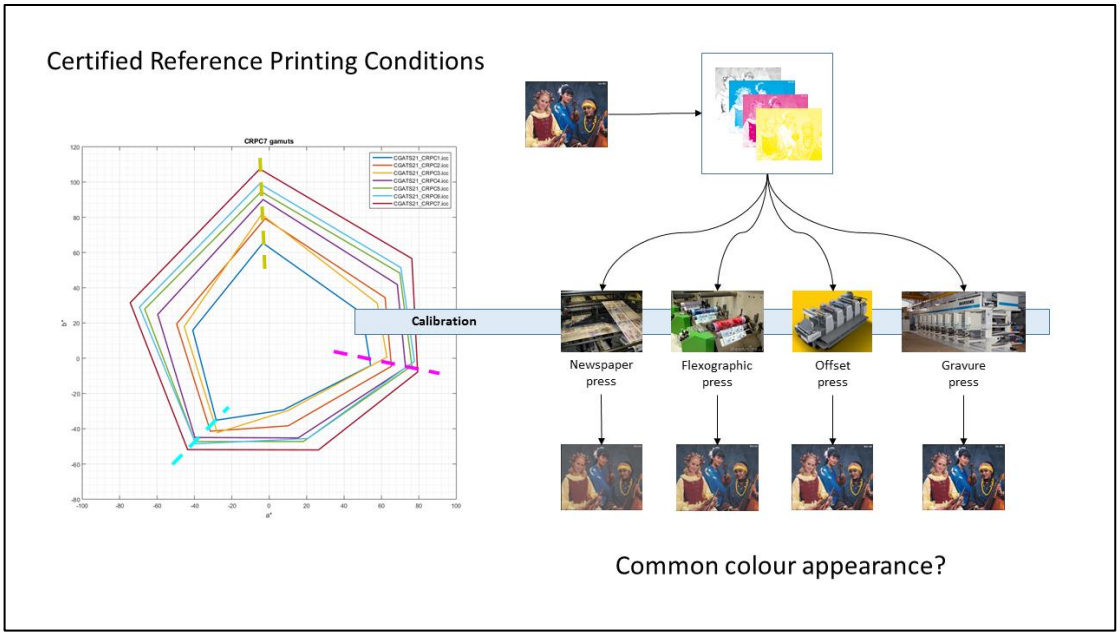

Figure 4 – ISO/PAS 15339 Certified Reference Printing Conditions

For these data sets the tone reproduction curves used are based on the procedures defined in CGATS TR015. Clause 5.1 of CGATS TR 015 says:

"The lightness aims for the 3-color near-neutral tone scale are based on the assumption that the substrate relative highlight lightness values should follow a consistent curve to the extent possible commensurate with variations in the three color minimum near-neutral lightness. To maintain optimum shared near-neutral tonality across printing conditions with different dynamic ranges a consistent near-neutral tone reproduction is maintained through the lightest approximate 30% of the tonal range while a controlled compression or expansion function is applied in the darker approximate 70%.

The color aim for the 3-color near-neutral tone scale (a.k.a. gray balance) is defined as a function of substrate CIELAB a and b* values, reduced in proportion to the relative darkness of the scale."*

Figure 5 shows the 3 colour aim NPD of CRPC 1-7 based on the calculations of CGATS TR015 and the LAB values for the substrate and 3-color solids of the data sets VS the input Cyan TV. (NPD is simply the substrate relative colorimetric Y density which is approximately equal to the substrate relative ISO 5 visual status density).

Note because this is plotted vs input TV the output TV will include the effects of TVI (approx. 20% at the midtone) and the consistent area will be extended closer to a 70% input value.

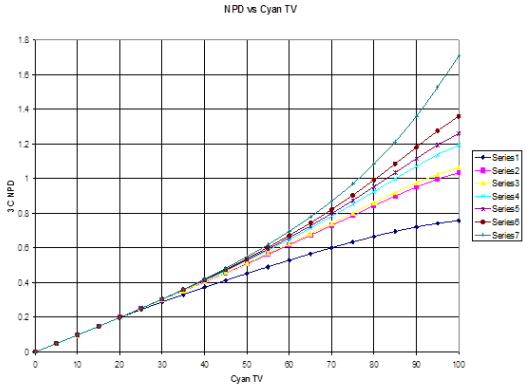

Figure 5: 3 colour aim NPD of CRPC 1-7 based on the calculations of CGATS TR015

If images printed to these CRPCs seem to have a 'consistent colour appearance', or a 'similar colour appearance', then one criteria might be to have a similar highlight to somewhat beyond mid-tone tone reproduction. Another way of saying this is that we seem to compare different reproductions of the same image based on their mid tone weight and their highlights. If these are similar and there is a similar grey balance, then we judge the reproductions to be similar. The dark end of the tone curve seems to be only important for some images - not the average image.

This approach works well for conventional offset printing systems where the primary inks can be selected with approximately the same hue angle but cannot be used directly for printing systems with non-standard ink sets or for digital printing systems where there are other constraints on the inks used. In these cases the CMYK separation data cannot be used for printing directly and a new set of colour separations must be created.

Can the principles on which this calibration method is based be extended to other printing systems and if so, what are the limitations? One approach to this is described in [5] which describes a CMYK re-rendering method that aims to achieve high output quality and consistency with offset printing while allowing digital devices to make optimal use of their native colour gamuts which is often larger than offset. This is achieved by assigning an ICC profile (SWOP) to determine the colorimetry of the CMYK image and applying a colour rendering transform that preserves hue and applies lightness and chroma mapping functions with special grey axis treatment.

There is a strong desire within the printing industry to move away from the creation of CMYK documents and instead to create documents that are independent of the printing system to be used. Colour separations optimised for each printing system can then be created at the time of printing. Notwithstanding this objective, it is very likely that the requirement to print CMYK documents across a range of printing systems with similar colour appearance will remain an important part of the printing industry and so this is an important use case.

4.2 RGB workflow

As has been noted, the workflow for digital print production is different from conventional offset print production in that a wide range of substrates and marking materials are used. One consequence of this is that different print providers are likely to produce prints using printers with significantly different colour gamuts. There is, however, a need for print buyers to be able to create and make 'proofs' of documents before they are printed and in many cases before the method of printing has been selected. This leads to a new model for proofing where a digital master document (incorporating RGB images) is created with the expectation that all print providers will produce prints that have a consistent colour appearance with the digital master document. This has become known as RGB workflow and has in part been standardised by ISO 16760:2014 (Preparation and visualization of RGB images to be used in RGB-based graphics arts workflows).

The basic concepts of RGB workflow are shown in Figure 6. A print contract is agreed between a print buyer and print service provider based on a reference which may be a print reference or

in some cases a displayed image. When printing on the selected print system(s) the printer should use the full gamut of each printing system and should achieve the colour appearance agreed with the print buyer. This is achieved by deferring rendering of the image until the system to be used for printing is known.

This is an area of significant activity, in particular for developers of digital printing systems and a number of proprietary RGB workflows exist. Since there is no objective assessment method it is difficult to resolve disputes between printers and print buyers and these workflow solutions have had limited success.

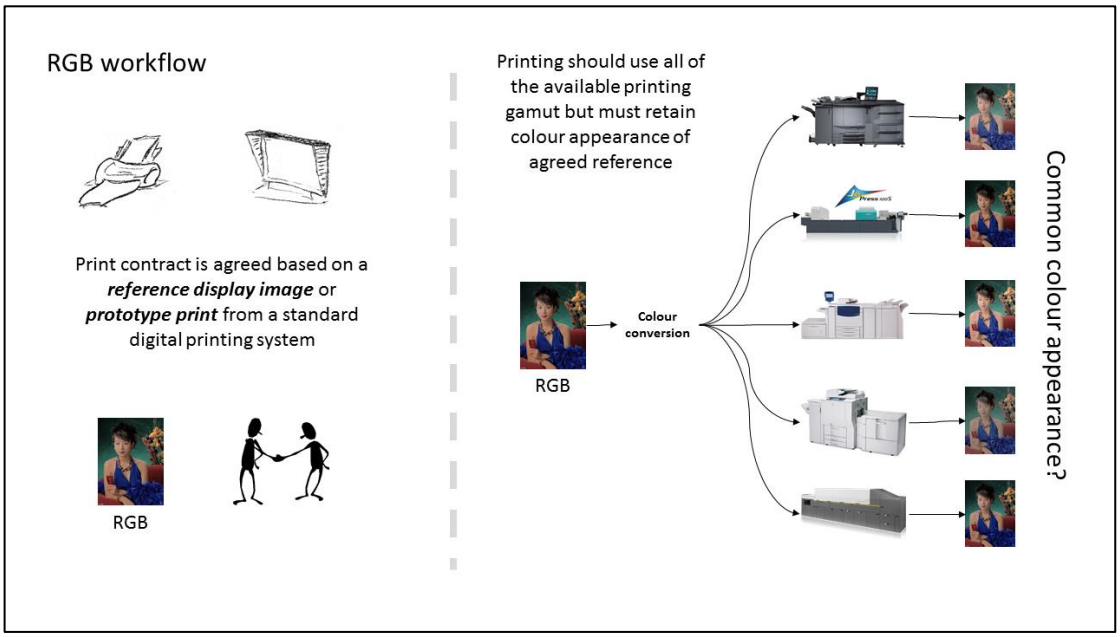

Figure 6 – RGB workflow

There is a pressing need within the print industry to develop a print assessment method to determine whether consistent colour appearance has been achieved. This has been identified by experts in ISO TC130 JWG14 as an area where a metric should be developed.

4.3 Consistency across print media

Manufacturers of printers often have a number of different printer classes with a number of printers in each category. In addition, a number of print substrates are usually available for each printer. This produces a huge range of possible print results and it is important in these cases that the prints made on each of these devices and substrates has a consistent colour appearance.

This case is a subset of the more general digital printing. It is included here as understanding this use case may provide important insight as to how the more general digital printing use case may be assessed.

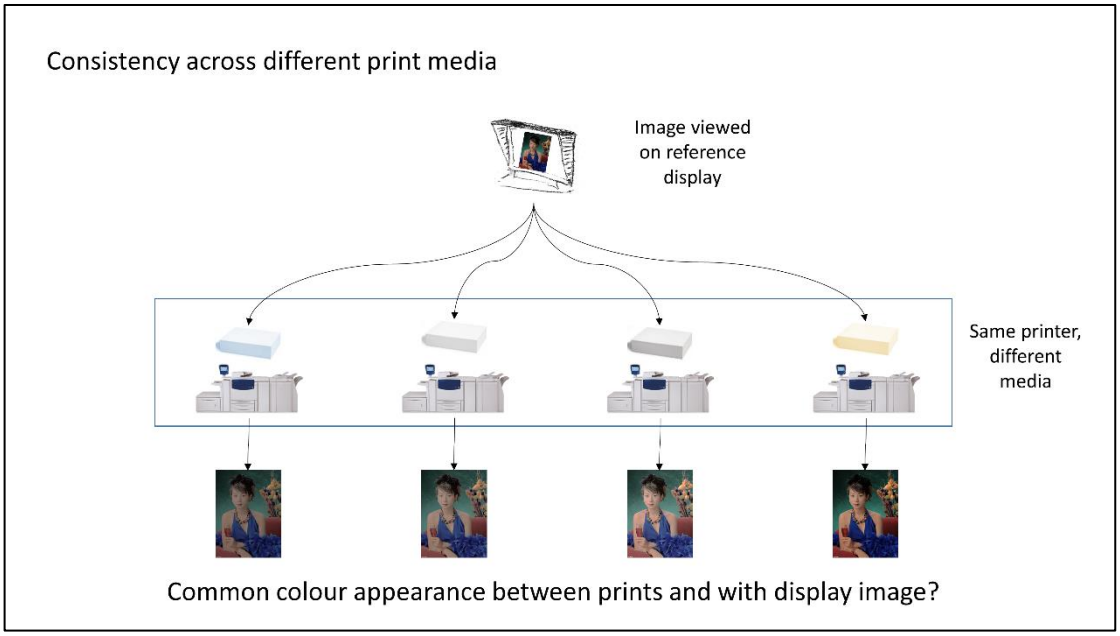

Figure 5 – Consistency across print media

The objective for this case is to ensure that reproduction of images maintains a consistent colour appearance across a range of print media used on a range of digital printers and that these all share a consistent colour appearance with these images when displayed on a reference display. There are examples where this is achieved by printer manufacturers across a range of printing systems.

It is likely that the assessment of consumables produced by printer manufacturers is of interest only to manufacturers themselves but there are many cases where specialty printing substrates are used and are provided by a third party. It would be useful to have some means to judge how closely the colour appearance on these substrates matches those provided by the printer manufacturer.

4.4 Brand management

One factor when selecting a product is the buyer's perception of 'brand identity'. It has been observed that brand identify is one of the most valuable assets on a company's balance sheet and one aspect of brand identity is colour. In many cases, colour is used to convey brand characteristics and values; the colours selected and the relationships between colours must be carefully maintained in order to maintain a good impression of the brand. Colours help consumers identify brands and recognise products and so influence buying decisions.

Colour appearance should always match expectations, but colour often can't be reproduced perfectly due to printing condition restrictions. In many cases brand colours are printed with different processes and on different substrates will only have a consistent appearance, if their colour data is carefully managed. The colours of a label on a bottle or can on the supermarket shelf can look different when compared to the colours on the same product or brand on a free-standing display at the end of the aisle or on the poster overhead. If those printed vouchers a consumer wants to spend, don't match the colours on the product label or package, they may hesitate and opt instead for another more reliable looking product. So colour variance can damage brand equity.

Figure 6 shows the many different contexts in which a single brand design must be displayed. In order to retain brand integrity it is important that the colours of the logo and other colours associated with the brand should be displayed in a consistent way.

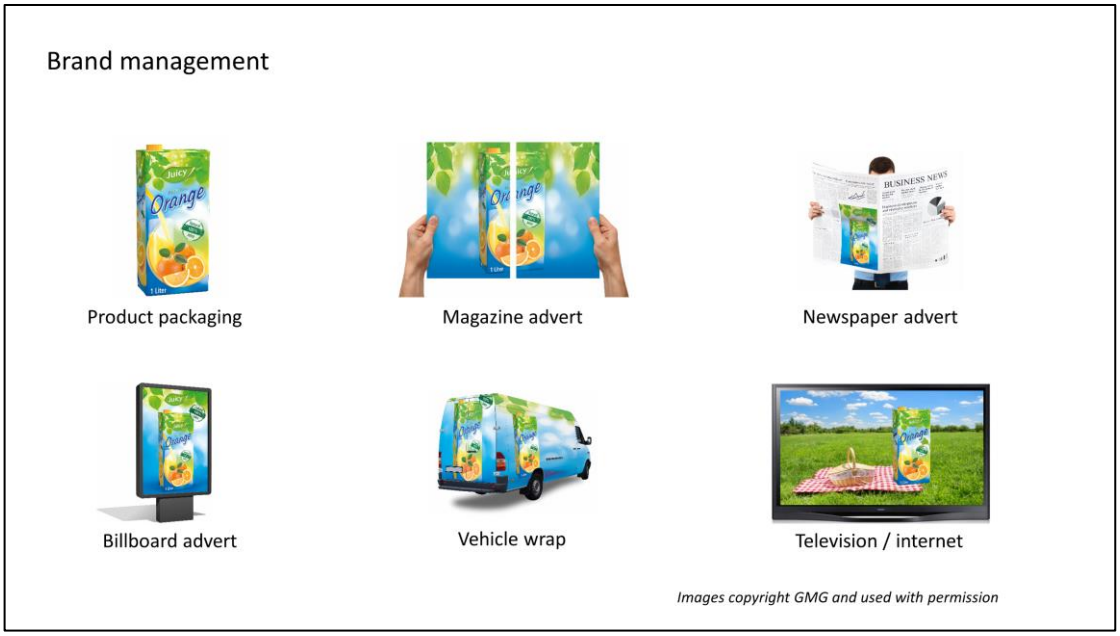

Figure 6 – Brand Management Example (images: GMG GmbH & Co KG)

The objective in this case is to ensure that brand colours are reproduced in a consistent way to ensure that brand integrity is maintained and that the brand is perceived as having high quality. Today, a collection of ad-hoc tools are used by brand managers who use visual assessment of reproductions to maintain colour appearance.

Ideally we would develop a metric to measure closeness of colour appearance between reproductions. Finding a general solution for this case will be challenging as there are many variables including viewing conditions, variations in illumination and in the colour devices used, however a number of these aspects have already been addressed in other CIE work, for example iCAM and metamerism index and where possible work in this area should build on these existing metrics.

4.5 Consistency across displays

With the advent of new display technologies such as LCD, LED, AMOLED, laser display and others, there is now a huge variety of possible colour gamut achievable. The ITU recommendation Rec. 2020 (BT.2020) defines a standard for a large gamut transmission of broadcast television. The potential colour gamut (or colour encoding range) of the transmitted signal is very much larger than the typical consumer display and so some kind of colour mapping must be performed in order to display these broadcast images. It is important to the broadcaster that these images are reproduced in a way that achieves a consistent colour appearance.

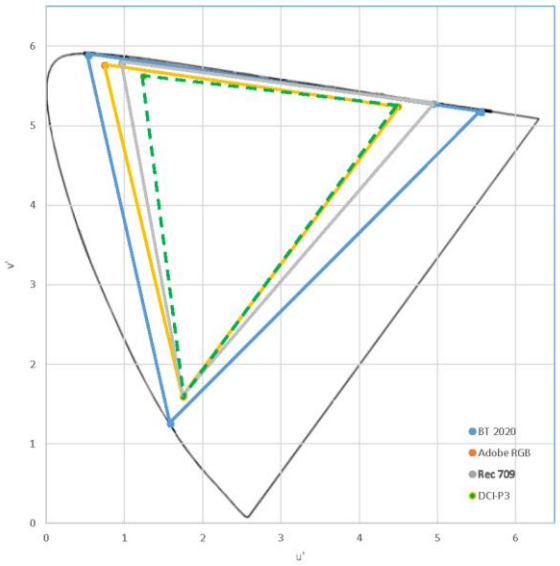

Figure 7 – BT.2020, Rec. 709, Adobe RGB and, DCI-P3 RGB chromaticities

When receiving UHDTV broadcast, content must be displayed on a range of devices with substantially different colour gamuts in a way that retains the colour appearance of the original and produces consistent colour appearance with the reference.

When transmitting legacy images (for example Rec. 709) these images need to be prepared for UHDTV transmission. There are two possible options: communicate the colour encoding with these images and allow the receiver to perform an optimal colour conversion or to map the colour to the UHDTV gamut prior to transmission. It isn't yet clear which of these options will be used but for both cases there is a need to be able to transform images in a way which maintains their colour appearance.

5 Survey of related work

5.1 Determination of constant Hue Loci for a CRT gamut and their predictions using color appearance spaces

This work [10] was conducted at RIT by Po-Chieh Hung in 1995. This work is included here as there seems to be some similarity between this work and consistent colour appearance. The abstract is in the following paragraph.

A colorimetrically characterized computer-controlled CRT display was used to determine 24 loci of constant perceived hue for pseudo-object related stimuli, sampling the display's interior color gamut at constant lightness and the edge of its gamut at variable lightness. Nine observers performed three replications generating matching data at 132 positions. The constant hue loci were used to evaluate the correlation between perceived hue and hue angle of CIELAB, CIELUV, Hunt, and Nayatani color appearance spaces. The CIELAB, CIELUV, and Hunt spaces exhibited large errors in the region of the blue CRT primary, while the Nayatani and CIELUV spaces produced large errors in the region of the red primary for constant lightness stimuli. Along the edge of the CRT's color gamut (variable lightness stimuli), all the spaces had a similar trend, large errors in the cyan region. The differences in performance between the four spaces were not statistically significant for the constant lightness stimuli. For the variable lightness stimuli, CIELAB and CIELUV had statistically superior performance in comparison with the Nayatani space and equal performance in comparison with the Hunt space. It was concluded that for imaging applications, a new color appearance space needs to be developed that will produce small hue error artefacts when used for gamut mapping along loci of constant hue angle.

5.2 Color Gamut Mapping in a Hue-Linearized CIELAB Color Space

This work [11] was conducted at RIT by Braun, Fairchild and Ebner and builds on Hung's work on constant hue locus [10]. The abstract is reproduced in the following paragraph.

Color gamut mapping plays a crucial role in color management. Depending on the application, it is sometimes desirable to perform color gamut mapping by shifting the lightness and compressing the chroma of an out-of-gamut color while preserving the perceived hue of the color. The term “perceived hue” is used to distinguish between the visual sensation of hue and metric hue angle (e.g., CIELAB hue angle (hab)). If a gamut-mapping task constrains CIELAB metric hue angle in the "blue" region of CIELAB, a perceived-hue shift will result. Due to these nonlinearities, two hue-linearized versions of the CIELAB color space were generated, one from the Hung and Berns visual data (1995) and one from the Ebner and Fairchild data set (1998). Both data sets consist of visually mapped hue data to planes of constant visual hue. These modified versions of the CIELAB color space were psychophysically tested for their hue-linearity characteristics against the CIELAB color space. The results of these experiments show that, in the "blue" region of CIELAB, the hue-corrected color spaces are more visually uniform and perform better than CIELAB in gamut mapping situations with respect to perceived hue. However, the CIELAB color space performed as good as or better than either hue-corrected spaces outside of the blue region.

5.3 CIE 156:2004 Guidelines for the Evaluation of Gamut Mapping Algorithms

CIE TC8-03 (Chair: Jan Morovic, UK) was established to study, develop and recommend an optimal solution for cross-device and cross-media image reproduction. This solution was expected to provide a standard procedure to calculate the colour gamut of an image, an imaging system, or its components, and either one algorithm, or a set of algorithms and rules for use in specific applications. The TC concluded that it would not be possible to recommend a single gamut mapping strategy that would satisfy all use cases and instead released CIE 156:2004 [17].

This technical report provides guidelines for the evaluation of the cross-device and cross-media colour image reproduction performance of gamut mapping algorithms (GMAs). The guidelines cover numerous aspects of GMA evaluation including test images, media, viewing conditions, measurement, gamut boundary calculation, gamut mapping algorithms, colour spaces and experimental method. Also provided are example workflows that show how the general principles are applied and a checklist for determining compliance with the guidelines. The results of GMA evaluation carried out in accordance with these guidelines will then serve as the basis for recommending either one gamut mapping algorithm, or a set of algorithms and rules for use in specific applications.

The guidelines may provide useful input towards the assessment of consistent colour appearance.

5.4 Colour trend-line for evaluating colour consistency

This work, reported in [8] was supervised by one of the authors of this report (Yasuki Yamauchi, JP) and was conducted at Yamagata University in Japan.

In order to reproduce an image on different colour reproduction output device, it is important to match the colour appearance according to its gamut size [8] and an appropriate evaluation method is required. In addition to the direct comparison of the apparent colour distance we might be able to judge the closeness of two colours via some intervening colour. We define a trend-line of a colour which expresses the consistent colour appearance locus. Two colours on the same trend-line provide a consistent colour impression. Thus, we may be able to assess the apparent colour distance between two different colours via the closest intervening colour on the trend-line. Although the experimental results showed that the trend-line projected onto the CIELab a*-b* plane shows a similar tendency with the constant hue locus [10], the trend-line also includes some changes in lightness so the lightness component should be taken into consideration for defining the trend-lines.

In the experiment described in this paper, both the method for finding the trend-lines of the reference colours and the apparent colour distance between the colours were assessed. A

subsequent experiment has been conducted to determine how to find the intervening colour which gives the closest impression of a given colour on the trend-line.

5.5 A pilot study on evaluating common appearance and a colour naming approach to measure it

This work reported in [9] was conducted at Fogra by Philipp Tröster (DE) and others.

In order to find a new scientific evaluation method of common appearance, the use of colour naming, or colour categorization, was tested [9]. In the experiment which used several gamut mapping strategies and different colour gamuts, sets of colour patches were reproduced for evaluation. Results showed that there were several trends which indicated that common appearance could be obtained through rank order experiment and a pair comparison experiment.

Also the results were compared with colour-naming experiments. The colour fields of a reference and that of the other gamut were connected, and the colour names closer to the connection of those two colour field than a certain value of threshold were counted as crossed colour names. The comparison of the crossed colour names and the results of pair comparison showed a good correlation.

5.6 Model of common colour appearance

Greg High is a PhD student at the Norwegian University of Science and Technology (NO) (previously Gjøvik University College) and has selected the topic of Common Colour Appearance for his research topic. Greg has described his proposed research project in the following paragraphs.

The project objective is to build a model of common colour appearance for graphic arts and colour display applications. The aim is to facilitate colour reproductions across different output media that create, as closely as possible, an appearance match relative to the context and viewing conditions of each medium. The scope of the project is limited to colour appearance; other appearance attributes are excluded.

The project seeks to build metrics of ‘dissimilarity’ (a measure of colour appearance difference between two or more reproductions) for the key attributes of lightness, partial adaptation, colourfulness and hue that are derived from psychophysical category judgement and scaling experiments. The metrics, together with media-specific parameters, are used to build predictive models for optimized reproductions.

A combined metric of colour appearance dissimilarity is proposed, together with applied models of common colour appearance for print and display uses. Potential applications include re-targeting for digital print and gamut mapping for UHD Television.

5.7 A Basic Sample Database for Modelling Common Colour Appearance

This work was conducted by Yuan JiangPing as part of a master's degree at the Norwegian University of Science and Technology (NO) (previously Gjøvik University College) and is described by Yuan in the following paragraphs.

In this project, CRPCs data from ISO/PAS 15339 standard were selected as the standard data source. Ten colour centres were selected from CRPC4 as primary references. The corresponding colour centres with the same CMYK values in CRPCs 1, 2, 3, 5, 6 and 7 were selected as the secondary references. In each CRPC gamut, twenty samples were generated by small adjustments of attributes including different combinations of lightness, colourfulness and hue angle. Similarity scaling values were obtained from a category judgment experiment under a standard viewing conditions and colour patch samples with the highest similarity were summarised by analysing mean opinion scores and z-scores.

The results showed that the similarity between the colour patch set and the common colour appearance set was achieved with a 95% confidence interval. The adaptability and scalability of the proposed common colour appearance data were verified to provide basic data references for common colour appearance metrics.

5.8 Achieving common colour appearance on different substrates

This work was conducted by Theresa Deschner as part of a master's degree at the Norwegian University of Science and Technology (NO) (previously Gjøvik University College) and is described by Theresa in the following paragraphs.

Five images from ISO 12640-1 were converted to CIELAB and adjusted in hue, lightness and chroma and observers were asked to judge the similarity to a reference (unedited) image in a pair comparison experiment with the images viewed on a display.

The experiment was unable to determine what direction of adjustments had the strongest impact on common colour appearance. The results did show that there is a connection between the impact of the adjustment and the type of the image, because the impact of the adjustments varies strongly between the different images.

5.9 CIECAM02

CIE TC8-01 was established in 1998, with Nathan Moroney (US) as chair, to study, develop and recommend methods for the application of a colour appearance model based on CIECAM97s.

The research work described in 5.1 and 5.2 was conducted under a D65 (or E) white point. CIECAM02 extended this work to incorporate initially partial adaptation and subsequently full adaptation of human visual perception and confirmed hue consistency under typical CIE illumination.

CIECAM02 primarily deals with matching of a single colour stimulus across different illumination and viewing conditions. Some of the principles that underpin CIECAM02 may be helpful in understanding Consistent Colour Appearance whose primary consideration is the reproduction of images. At first it will be important to understand how Consistent Colour Appearance can be achieved on similar media in a single viewing environment. When that aspect has been fully understood it may be extended to the appearance across different media and different viewing conditions at which point the role of CIECAM02 is likely to be more significant.

6 Recommendation for future work

Some work has been started in this area but much more remains to be done. In order to ensure broad participation from all regions and to give the project a sufficiently high profile we recommend establishing a CIE Technical Committee. We have also provided some initial ideas of the kinds of activities suggested for such a TC. Note that these are just suggestions and should not be interpreted as activities currently planned by CIE. Refer to later CIE documents for any planned work.

6.1 Recommendation for CIE Technical Committee in Division 8

As has been mention in various sections of this report, there is an interest in this topic in a number of regions. Our proposal is to establish a CIE Technical Committee whose scope is to study a subset of the general problem of maintaining colour appearance. A useful subset would be to develop a metric whereby colour rendering for RGB workflow (4.2) can be assessed. Although challenging, this seems like an achievable goal. The TC may wish to consider restricting the scope further to consider only printed images on isotropic media and viewed simultaneously in the same viewing environment. This is an important subset of the general consistent colour appearance problem.

6.2 Relationship to ICC activities

Consistent Colour Appearance is an area of interest to ICC members since ensuring consistent colour reproduction of images is very important within ICC workflows. The ICC objective is to determine whether standard ICC rendering intents produce consistent colour appearance. This work is separate from that of the CIE and we should continue to ensure clear separation between the work of each group. The tests proposed within the ICC are reported here but since ICC members are best placed to conduct such testing we do not expect this to be part of the CIE TC activity. The proposed tests are, however, described briefly here for the sake of completeness and to inform CIE experts who do not participate in the ICC. Testing of ICC

rendering intents could provide some insight into what is required to maintain colour appearance and the results of testing by ICC members may help to inform the work of a CIE Technical Committee.

6.2.1 Absolute Colorimetric rendering

In this case images and printing gamuts are selected so that when images are converted for print using ICC Absolute Colorimetric rendering intent no clipping of image colours occurs. For all printing processes the same substrate colour should be used.

The hypothesis is that if the substrate colour is the same for all prints, and the image colours are within the gamut of all of the prints, ICC Absolute Colorimetric rendering will produce consistent colour appearance.

A metric already exists (ISO 12647-7) and could be used for conformity assessment for this case.

6.2.2 Relative Colorimetric rendering

In this case images are selected such that when they are converted for print using ICC Relative Colorimetric rendering no clipping of image colours occurs. The main difference from the previous test is that different substrate colours should be used.

The hypothesis is that where the substrates are different ICC Relative Colorimetric rendering can be used as long as no clipping of image colours is required. A likely limitation is that this holds only where the maximum colour difference between the substrates is less than 8 CIEDE2000.

A metric for conformance already exists (ISO 12647-7) and could be used for conformity assessment for this case.

6.2.3 Relative Colorimetric Rendering with BlackPoint Compensation

In this case images are selected such that when they are converted for print using ICC Relative Colorimetric rendering with BlackPoint compensation no clipping of image colours occurs. In this case different substrate colour and printer black points should be used.

The hypothesis is that where the substrates and / or the black points of the production printers are different, ICC Relative Colorimetric rendering with BlackPoint Compensation can be used as long as no clipping of image colours is performed.

A metric for assessing this condition is currently being developed in ISO TC130 JWG14 and this could be used to provide an objective measure of conformance for this case.

6.3 Plan for CIE activities

6.3.1 Psychophysical assessment

Conducting psychophysical experiments is usually very time consuming and so before any activity is started a clear definition of its scope and limitations should be developed and reviewed as widely as possible. Appendix A provides some suggestions about a possible assessment method.

6.3.2 Quantitative assessment

Since our ultimate goal is to develop a metric it is important to think about what we might measure and how. One possible direction would be to identify dominant image colours for a set of images that observers agree share a consistent colour appearance. The relationship between these colours can then be examined to determine whether there is an underlying pattern and that underlying pattern can be used to develop a metric.

6.3.3 Consistent colour appearance metric

The ultimate goal for the Technical Committee should be to develop a consistent colour appearance metric or to explore ideas as to how such a metric could be developed.

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Appendix A Some initial suggestions for CIE TC consideration

This annex describes some initial ideas for consideration within the proposed CIE TC. Please be aware that subsequent documents created by the CIE Technical Committee may be quite different to what is described here.

A.1 Scope (tentative)

There are many factors affecting appearance such as resolution, texture, fluorescence, illumination, gloss etc. and determining the relative contribution of each factor is at least very difficult and may be impossible.

In order to set an achievable goal for a CIE Technical Committee we propose to limit the scope to the assessment of printed images on substrates with approximately similar characteristics in a fixed viewing environment. The objective should be to identify a colour conversion algorithm or algorithms which preserve colour appearance when images are reproduced on devices with different colour gamuts.

Although this scope is limited it will allow the most pressing use case of reproduction of images in a graphic arts environment to be addressed. There are other possible ways in which the scope for this TC could be limited and yet produce a useful result and these options should be considered carefully by those participating in the Technical Committee.

A.2 Relation to and Impact on Existing Work

It seems that this work is significantly different from other work being conducted in CIE at present and so is unlikely to have an impact on any current work.

One topic identified as having strategic importance for the CIE is that of the development of a uniform colour space and our project would benefit from this work.

A.3 Affected Stakeholders

The stakeholders who are most likely to benefit from work done in this area are graphic arts professionals. A successful outcome for this project is expected to result in the improvement of printed and displayed image fidelity.

Given the level of interest we have seen in this topic to date we expect to see the development of many tools for processing and assessing images.

A.4 Scientific and Technical Objectives

The first objective of the Technical Committee should be to identify suitable colour conversion algorithms. Since this is an area where companies may be reluctant to make a full disclosure of their algorithms the work should be framed in such a way that disclosure of the algorithms used is not necessary. It must however be possible to have the algorithm assessed independently. Image-specific algorithms may also be considered but should be identified as such.

A second objective should be to develop an objective measure for the degree of similarity of a set of reproductions. We recognise that such a metric may not be achievable in the time frame permitted by the CIE for a Technical Committee and this work may be deferred.

A.5 Impact Metrics

The best way to measure the effectiveness of our work would be through the number of standards (de facto or de jure) that build on it. This work has already been requested by ISO TC130 and ISO/IEC JTC1 SC28 as JWG14 would like to develop a standard based on this work.

A.6 Some initial ideas

The following ideas have been identified in discussion with various groups and are offered as suggestions to the TC:

Reference images: identify a set of reference images which are available to everyone and encourage their use so that different assessment results can be compared easily. Ensure that images have well defined colour characteristics and include typical content including a variety of skin tones, neutral images, natural scenes, food, saturated colours and pastel colours.

Reference print gamuts: identify a set of reference print gamuts whose colorimetry is well defined (for example by means of characterisation data). Ensure that these are representative of the colour gamuts in consistent use.

Image and image sets preparation: the way in which the images are prepared may have an impact on their assessment and guidelines on this aspect should be prepared in order to ensure consistent presentation to observers. This should include at least the border size, the background colour and the spacing of images being compared.

Viewing conditions: the viewing conditions should be specified and should be limited to one or two options.

Assessment on a display (soft proof): the most efficient assessment method would use a wide gamut, calibrated colour display and the TC should consider whether such an assessment method can be used reliably and if so to provide guidelines for its use.

