# Update on the INCITS W1.1 Standard for Evaluating the Color Rendition of Printing Systems

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## Abstract

The color rendition *ad hoc* team of INCITS W1.1 is working to address issues related to color and tone reproduction for printed output and its perceptual impact on color image quality. The scope of the work includes accuracy of specified colors with emphasis on memory colors, color gamut, and the effective use of tone levels, including issues related to contouring. The team has identified three sub-attributes of color rendition: 1) color quantization – defined as the ability to merge colors where needed, 2) color scale – defined as the ability to distinguish color where needed, and 3) color fidelity – defined as the ability to match colors. Visual definitions and descriptions of how these sub-attributes are perceived have been developed. The team is presently defining measurement methods for these, with the first of the sub-attributes under consideration being color quantization. This presentation will briefly describe the definitions and appearance of the proposed sub-attributes. The remainder of the discussion will focus on the progress to date of developing test targets and associated measurement methods to quantify the color quantization sub-attribute.

## Introduction

This paper addresses the work of the W1.1 Color Rendition *ad hoc* team of the INCITS W1 committee on the standardization of office equipment. In September 2000, INCITS W1 was chartered to develop an appearance-based image quality standard.[1,2] The resulting W1.1 project is based on a proposal[3] that perceived image quality could be described by a small set of broad-based attributes. Five *ad hoc* W1.1 teams were established to generate standards for one or more of these image quality attributes. Color rendition, one of the five *ad hoc* teams, is working to create a standard for evaluating color rendition of hard copy output generated from digital input.

When evaluating overall quality of color images in hard copy format, color appearance is an integral part of image quality. If the color does not look right, other image quality parameters may not matter; the print will be considered to be of low quality. What does it mean for the color to "look right," and how can the ability of any given printer to properly render color be measured? These are the questions that the color rendition *ad hoc* team of INCITS W1.1 is working to understand and answer. To date, the first of these issues has been addressed. Three important parameters or sub-attributes were identified as being necessary to describe what it means for color to be well-rendered: 1) color quantization – defined as the ability to merge colors where needed, 2) color scale – defined as the ability to distinguish color where needed, and 3) color fidelity – defined as the ability to match colors. Along with the definitions, descriptions of how these attributes are perceived have been developed. With the definition complete, work has begun to address the second question of how to measure color rendition. Plans are in place to develop a measurement methodology for each of the three sub-attributes, beginning with color quantization.

## Defining Color Rendition

Before a standard for measuring color rendition of printing systems could be established, definitions of color rendition and printing systems were necessary. Knowing what is and, just as importantly, what is not included in their definitions, when attempting to evaluate how well color is rendered, was considered essential to determining how color rendition would be measured. First, an understanding of what constituted "the printer" was needed. It was decided that the printer would be defined as "everything that occurred after hitting the 'print' button." As the definition of color rendition was discussed, it was decided that variations in color rendition across an image where a constant code value is specified, is not part of color rendition, but would come under the auspices of the macro-uniformity, micro-uniformity, or adjacency attribute *ad hoc* teams (depending on the nature of the variation). Conversely, tonal rendition was considered to be inextricably linked to color rendition and was, therefore, subsumed by the color rendition *ad hoc* team and included in evaluating color rendition. Finally, it was agreed that different metrics might be necessary for natural images and vector graphic images because of the adaptation effects and differences in the image content and intended use of vector graphic images.

With these considerations in place, the color rendition *ad hoc* team determined that "color rendition" could be defined in terms of three unique components or sub-attributes: color quantization, color scale, and color fidelity. A summary of these three sub-attributes of color rendition, their definitions, their correlations to classical color parameters, and examples are listed in Table 1. These sub-attributes are different from the traditional image quality color attributes; however, they do appear to form a complete perceptual set of attributes and were chosen because they emphasize the perceptual nature of the attributes.

Color quantization is defined as "the ability to merge colors where needed." This attribute would manifest itself in images primarily as contouring. Images with adequate color quantization would be free of the contouring that can appear in gradient areas, such as sky, walls, or faces in pictorial images or backgrounds in graphic images.

Color scale was a term developed to be analogous to tone scale but which is meant to include not just changes in lightness, as might be thought of for tone scale, but changes in chroma and hue as well. With this in mind, color scale is defined as "the ability to distinguish colors where needed." Images having proper color scale would not suffer from loss of information in shadow or highlight regions but would have adequate separation of colors to provide contrast where needed.

The third attribute of color rendition, color fidelity, is defined as "the ability to match colors where needed, and colors must be reproduced in such a manner that the colors in an image look correct." Color fidelity is considered to include colorimetric accuracy (hue, lightness, and chroma), color balance, and memory color reproduction. This attribute will be a challenge and will likely require separate test targets and metrics to characterize images with text and graphical content, and others with pictorial content. Although the ability to match colors is included in color fidelity, it is not meant to imply that matching to a target or original is always necessary. While in graphical and text images, a colorimetric match will often be desirable, alternatively, in a pictorial image with good color fidelity, skin tones, grass, and sky areas should look realistic. Pictorial images, in general, should look natural.

## Measuring Color Rendition

With the definition of color rendition in place, the next step was to establish methodology for measuring the three sub-attributes of color rendition. While the measurement of color fidelity seemed fraught with potential hazards, agreement of a general approach for color scale and color quantization came more easily. It seemed that, because the colors in the case of color quantization, were related and inverted problems, they could both be evaluated using color sweeps. Establishing a test target and measurement methodology for one could very well be suitable for the other. However, while it was difficult to define exactly when a problem occurred in the case of color scale (What exactly is it *not* to have blocked shadows?), for color quantization it was clear that perceptible contours constituted a problem. It was, therefore, decided to: first, gain some experience and, next, work on the problem of measuring color quantization.

A strategy of first developing a test target, followed by a method of measuring the target, was adopted because of the difficulty of having any meaningful discussion without data or, at least, an attempt at obtaining data. After some discussion, it was decided that the test target should be comprised of color gradients or sweeps. Eight colors were chosen as candidates for the color sweeps: red, green, blue, cyan, magenta, yellow, blue sky, and skin tones. It was decided that the red, green, blue, cyan, magenta, and yellow gradients would sweep from black along the gamut to white, with the gamut being defined as "the locus of the maximum gamut points for monitors, laser printers, and ink jet printers." This is expected to lead to color mixing for dark colors, especially for the introduction of black. This color mixing can lead to contouring problems and, therefore, is considered an appropriate area for testing printer performance. The skin and sky gradients sweep from black to maximum realistic C* values, which are beyond preference, and then to white. The degree of maximum saturation for the blue sky was increased to approximately 40 C*, which took it beyond the preferred point to account for the fact that dark blue skies have higher chroma. For these two colors, we expect to work at constant hue.

**Table 1. The Components or Sub-Attributes of Color Rendition.**

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| **Color Quantization** | |
| Definition | • The ability to merge colors where needed<br>• Colors that should be perceived as smoothly varying are free of contouring |
| Correlation with classical color sub-attributes | • This attribute would include contouring |
| Examples<br>(Appearance of sub-attribute in images) | • Freedom from contouring in smooth sweeps (human faces, sky, differentially lit backgrounds, walls, etc., in pictorial images or vignettes, fades, or gradated backgrounds, etc., in graphical images) |
| Physical measurement, test target | • Printed RGBCMYK sweeps; maybe skin tone and blue sky sweeps, and the $\Delta E(\Delta L^*, \Delta C^*, \Delta h^*)$ calculated from a digital scan of the sweep. Minimum slopes would have to be defined such that anything greater would result in contouring, but this is difficult because of image dependence<br>• Could be 2D sheets or simulated 3D objects |
| **Color Scale** | |
| Definition | • The ability to distinguish colors where needed<br>• Colors that should be perceived as separate are distinguishable |
| Correlation with classical color sub-attributes | • **This attribute would include tone scale (lightness, contrast, shadow and highlight detail, and tonal clipping), hue "scale," and color saturation (chroma)**<br>• The equivalent of "tone scale," but extended to cover C* and h* in addition to L* |
| Examples<br>(Appearance of sub-attribute in images) | • Distinguish between dark colors to avoid blocked shadows<br>• Distinguish between light or pale colors to avoid blown highlights<br>• Adequate separation of colors to provide contrast in pictorial images and colors that are perceptually distinguishable in graphics<br>• Are there enough colors and are they distinct where they should be?<br>• Contrast, color saturation, tonal detail in light and dark colors, detail in saturated colors, ability to distinguish hues |
| Physical measurement, test target | • Printed RGBCMYK sweeps; maybe skin tone and blue sky sweeps. Minimum slopes would have to be defined such that anything less would result in colors that are blocked, etc. |
| **Color Fidelity** | |
| Definition | • The ability to match colors where needed<br>• Colors look correct<br>• Does not require matching to an original or target print but can include matching to target colors. |
| Correlation with classical color sub-attributes | • This attribute would include hue accuracy ( lightness and chroma accuracy as well), color balance, and memory color reproduction |
| Examples<br>(Appearance of sub-attribute in images) | • Skin tones, grass, sky look realistic<br>• Image is not too saturated or too washed out or too dark, etc.<br>• Image looks natural, color rendition meets expectations<br>• Color match a target image when needed |
| Physical measurement, test target | • To be determined |

Two iterations of red, green, blue, cyan, magenta, yellow, blue sky, and skin tone sweeps were generated, and scans of prints of these targets, rendered on photographic, electrophotographic, and inkjet printers, were evaluated. Initial results indicate that it is possible to perceive contours that, with our current procedures, cannot be reliably measured. The noise in the prints was higher than the signal. Two further attempts at developing this measure are under consideration. One involves a serpentine test target and the other follows the protocol of Mizes.[4]

Because the use of sweeps as test targets required the use of scanners as a convenient and ubiquitous means of evaluating printed targets, the team evaluated scanner characterization work underway in the macro-uniformity *ad hoc* team to determine its suitability to the color rendition test target requirements. Discussions with other *ad hoc* teams in INCITS W1.1 indicated similar concerns existed in their teams, as well, precipitating a digression to answer these questions. W. Kress reported the results of this work earlier in his paper, "Digitization and Metric Conversion for Image Quality Test Targets."[5]

## Next Steps

Having worked through the issues associated with test targets for the color quantization sub-attribute, the team is in the process of evaluating our learnings from that exercise and reconsidering what can now be applied to the other two sub-attributes. Because the color fidelity and color scale sub-attributes are considered to be more difficult to address, it is anticipated that some fundamental research will be needed. The team plans to define this work so that the research can be planned and initiated.

## Conclusion

A method of quantifying the perceived image quality of the color rendition of a printer has been defined as being comprised of three basic components: color fidelity, color scale, and color quantization. These sub-attributes have been defined, related to classic color components, and descriptions of how these attributes might be perceived in images have been developed. Measurement methodology for the color quantization sub-attribute has been initiated. Potential test targets are in the process of being designed and generated. Prints made of these targets on photographic, electrophotographic, and inkjet printers, and initial attempts at measuring contours have been made. Further work is underway and will be reported in the formal presentation, as it is available. Also planned is a review of future work, including planning for fundamental research that will be needed to fully answer the question regarding measuring the ability of a printer to render color.

## References

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## Biography

**Susan Farnand** is a graduate of Cornell University and the Rochester Institute of Technology's Masters of Imaging Science program. She has worked for Eastman Kodak Company on assignments involving electrophotography and imaging science. She has also taught color science to a variety of audiences. Currently, she is working in the area of image quality metric development. She has participated with the INCITS W1.1 ad hoc team charged with developing a standard for color rendition for printing systems since its inception.