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Gravure Research Agenda: Predictable Color Methodology

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Abstract
Predictable color is simulation of spot color and pictorial color image using a proofer that resembles color appearance of a printing press. Color predictability begins with device calibration. This includes standardized Raster Image Processor settings for plates and cylinder engraving; standard colorants, substrate, and press settings. Color predictability also demands color repeatability. Although time-consuming and unglamorous, color repeatability must be ensured. Rochester Institute of Technology developed color measurement procedures and analysis tools to assist converters with verifying printing conformance. By applying color management tools in a repeatable color printing platform, color predictability from design-to-print, as well as in color proofing workflow, becomes easy.

Graphic Arts Workflow and Color Predictability

There are three stages in a design-to-print workflow: design, pre-media, and printing (Figure 1). Designers originate content in the design stage; pre-media specialists fit content into print-ready form, e.g., PDF/X files, and prepare image carriers (computer-to-plate or CTP and computer-to-cylinder) for a specific printing condition; printers and converters manage the print production process before the job reaches fulfillment.

![Design-to-print workflow](image)

Figure 1. Design-to-print workflow

To designers, predictable color means the realization of their creative intents, as evidenced by color proofs, without delay or frustration. To pre-media specialists, predictable color means the ability to manage content and color from designer’s color space to printer’s color space, and to communicate color expectations back to designers and print buyers with confidence. To printers, predictable color means the adherence to color repeatability, i.e., when printing conforms to specifications, color matches between print and proof as well as from one printing condition to the other.

Repeatable Color vs. Predictable Color
Color repeatability is defined as the measure of temporal variation in color from multiple samples randomly selected from a printing process. The standard deviation of density or
the $\Delta E$ distribution of CIELAB values to its average CIELAB values is often used as a measure of the color variation. A press run may be said to be repeatable when the variation in standard deviation or $\Delta E$ is small.

Color predictability is defined as a simulation or an imitation of a real thing, e.g., a synthetic diamond is an imitation of a real diamond. The act of simulating something generally entails representing certain key characteristics of an object with a different object, e.g., a color proof that bears the visual resemblance of a press sheet.

From a color management point of view, there are two distinct workflows: design-to-print and color proofing. The design-to-print workflow is production oriented and focuses on making color right. In order to predict the color consistency of design in printed color space using a number of printing platforms, both the color definition in the design stage and color printing platforms have to be repeatable.

The color proofing workflow is quality assurance oriented and focuses on making sure that predictable color is realized at all stages of color communication. In order to predict the color appearance of printed color reproduction, both the color proofer and the color printing press have to be repeatable. We will discuss the two color management workflows in relation to predictable color further in this paper.

**Meeting Color Challenges through the Years**

Print buyers have been demanding consistent color in high impact graphics. The expectations are only getting higher over the years. Print suppliers have been trying to meet these color challenges by utilizing resources they could find. If we take a look at how printers met these color challenges in the past 40 years, we can portray the technology transition in three eras:

1. The early days of photomechanical color reproduction
2. The era of scanners and CEPS
3. The era of digital color management

In the early days of photomechanical color reproduction, circa 1960s, color separation was done manually with the use of color filters, panchromatic films, and contact screens. Idiosyncrasies of photographic originals were not accounted for in the color separation process. Plates and engraved cylinders were made with the use of films and chemistry. Color repeatability of the printing process was unknown because little or no color measurement instrument was used in the pressroom. Color predictability was unheard of. In fact, color anarchy prevailed. Rework, in the form of dot etching and cylinder correction, was the norm. A customer’s presence to perform color checks by the press-side was essential because that was the last stage at which a job could be saved. Indeed, making color on press by craftsmanship until the job looked right and the psychology of color played significant roles in these days.

In the era of scanners and CEPS, circa 1980s, special-purpose mini-computers were used to process scanned signals that automated tone reproduction, gray balance, color correction, and screening in the pre-media stage. Printing industry associations recognized film-based proofing systems, e.g., Matchprint, as the ‘real thing’ where the press must print to match the proof. In a sense, color became predictable from scan-to-
proof. But color repeatability of the press remained unknown and color printing relied on craftsmanship. More often than not, the mismatch between proof and print was a major cause of customer complaints and job rejections.

The era of digital color management finally arrived in 1990s. Today, we use charge-coupled device (CCD) sensors to capture color; we use micro-computers to process color data. Color images are defined by means of International Color Consortium (ICC) profiles at the start of the design-to-print workflow. Color images are repurposed with the use of platform-neutral and vendor-neutral color management tools. Color became predictable from design to display in the design stage and from proof to press in the pre-media stage. Printing industry associations recognized the value of certified proofs to prevent false promises of ‘beauty comps.’ However, the need to certify a press run to improve color predictability between proof and press sheet remains as a challenge.

Making Color Predictable from Design-to-Print

The ability to simulate printed color in the design stage is the power of color management. Figure 2 illustrates the color management concept in a simple manner. Key points of color management include:

1. Source images are converted to their destination via a source ICC source profile and a destination ICC profile.
2. Because ICC profiles are look-up tables between the device color space (also known as ‘A space’) and the profile connection space (PCS or ‘B space’), we can say that the conversion goes through PCS (or B space).
3. The color management module (CMM) is a math processor that performs pixel-to-pixel color conversion in an application programming interface (API).

Design-to-print workflow addresses color conversion for color images in a red-green-blue (RGB) source space to a destination cyan-magenta-yellow-black (CMYK) space. The conversion is also known as A-to-B-to-A conversion. Converting RGB images to any number of printing presses via their prospective press profiles enables color predictability among different printing conditions. For additional information about the basics of color management and how one implements predictable color from design to print, please consult the textbook, *Real World Color Management* (Bruce Fraser, Fred Bunting, and Chris Murphy, 2005).

Figure 2 is used to explain how color images are converted from RGB to CMYK in a color management paradigm. It’s possible that data files from the input side are already in CMYK spaces and converted data files, or output, are also in CMYK spaces.
Graphic arts technology standards development groups, e.g., CGATS, ECI, ISO, etc., argue that there is no need to have a custom profile for every ink-substrate-press combination because the task of managing all press profiles can be daunting. Based on all combinations of ink-paper interactions, only a handful of color characterization data sets, or ICC profiles, are needed to serve color management needs. For example, when publishers demand that all magazine ads must look alike regardless of where the magazine is printed, the publication printing industry basically needs only one set of color characterization data, thus, one press profile. Such a standardized printing condition is also known as a reference printing condition (Dave McDowell, 1999). In other words, reference printing conditions are the outcome of the graphic arts technology standards development that addresses two common needs of a given industry: standard printing conditions and standard ICC profile.

One way to increase the flexibility of the pre-media workflow is to decouple the conversion from the design (or RGB) color space directly to the press CMYK color space. The first step is to convert source RGB images to a CMYK reference printing condition (Figure 3). Converted images in the reference CMYK color space may be proofed without the need for a specific press profile (see the next section for the proofing workflow). A press that has been calibrated to the reference printing condition can use the same CMYK file to print the job. In case that the production press prints differently than the reference printing condition, the need for a custom press profile and the subsequent CMYK-to-CMYK conversion becomes necessary.

![Figure 3. The use of reference color space in the design-to-print workflow](image)

CMYK-to-CMYK conversion, particularly going through the PCS, can be cumbersome and has some drawbacks in preserving the black printer integrity. A work-around is to adjust gradation curves in the CtP stage such that the gray balance of the press conforms to a known printing standard (IDEAlliance, 2006).

**Making Color Predictable in a Proofing Workflow**

The terms predictability and simulation involve the relationship between two things: one that simulates or predicts the other. Managing source color images so that printed colors agree with their source has been discussed in the previous section. Now, we focus on the simulation or prediction of printed colors with the use of color proofs.

There is more than one way to configure a proofing system. A color proofer may be calibrated to conform to the printing conditions. Thus, press CMYK files are output directly to the proofer without color management. The Kodak Approval color proofing system implements this strategy with success in the printing industry.
RIT researchers developed color measurement procedures and analysis tools to compare device characteristics between a proofer and a press. Figure 4 compares colorimetric properties of the Kodak Approval to a sheet-fed press sheet in terms of a*b* plots. In this case, the press sheet is the reference (gray dash lines) and the Approval is the sample (solid black line).

![Figure 4. Gamut (or a*b*) comparison between Kodak Approval proof and a press sheet.](image)

The fact that the size and shape of the two-dimensional gamut of the Approval is similar to the press sheet suggests that material selections and calibration can help achieve color predictability.

Figure 5 shows the comparison of the Kodak Approval to a sheet-fed press sheet in terms of L* C* hue slices of cyan, magenta, and their overprint (blue). Notice that the primaries (cyan and magenta) may be adjusted closely between the proof and the press sheet, but it does not guarantee that their overprint, in this case, blue, will conform automatically.

![Figure 5. L* C* slices of cyan, magenta, and their overprint blue.](image)

When it comes to color predictability between a proof and a press sheet, we need to pay attention to not only primary colorant (C, M, Y) responses and their two-color overprints (R, G, B), but also chromatic gray responses. Using the standard IT8.7/3 (basic) color block, we can measure three-color gray patches and compare the gray balance between the simulation (proof) and the real thing (press sheet), as shown in Figure 6.
The left-hand-side of Figure 5 compares how black channels compare between the Kodak Approval and a sheet-fed press sheet. In this case, both are quite neutral as indicated by low C* values throughout the tonal scale. The right-hand-side of Figure 5 compares gray balance from a set of fixed CMY dot area combinations, as defined in the IT8.7/3 (basic) color block. In this case, the press sheet (gray dash line) is more neutral than the Approval (solid black line). This evidence, alone, suggests that achieving color predictability by means of gradation adjustment between a proof and a press sheet is not sufficient. More research and testing are necessary to find out if gradation adjustments that satisfy gray balance requirements will achieve color predictability between two printing devices.

A color proofer often has a larger color gamut that uses a brighter substrate and a different marking engine than a press, e.g., an ink jet printer. In this case, color management is used to convert the file from the press color space to the proofer color space. Examples of such an approach are evidenced in many certified SWOP proofing systems listed in the IDEAlliance web site at http://www.idealliance.org/.

Color rendering intent impacts color predictability in design-to-print and in color proofing workflows. Perceptual color rendering intent is typically used for RGB-to-CMYK conversion. Absolute colorimetric rendering is used in the press-to-proof workflow if the white point of the proof is whiter than that of the print; otherwise, relative colorimetric rendering is used if the white point of the proof is the same as that of the print.

**Evaluating Color Predictability**

The evaluation of color predictability is complex by two factors: (1) color imaging constraints, and (2) human vision and psychology. Below offers some explanations.

We use color imaging tools, e.g., digital cameras and scanners, to capture color from the scene or photographic materials. We use printing presses to render these color images in high volume. Due to the fact that the color gamut of the press is smaller than that of the real-life scene, we use color management tools to come up with compromises. The
compromises are usually in the form of a reduced lightness range, which reduces the colorfulness due to constraints in color printing. We then use the color proof to communicate what is to be expected to designers or print buyers.

Print buyers usually don’t know such things as color reproduction constraints. Color, being a visual sensation, is hardwired into the brain. Everybody can see color. However, the perception of color is subjective. When there are differences in opinions, print buyers will always have the final say, thus making the evaluation of color predictability complex. Below are recommended practices when evaluating color predictability for spot color and for pictorial color images.

• In order to make spot color predictable from press run to press run, the key control point is in color measurement and ink formulation. This means that the action is in the ink mixing stage and not in the pressroom.

• In order to make spot color predictable in a color proofing workflow, this author recommends the following: (1) recognize how critical the color match should be for spot colors, e.g., logo and brand colors, from the customer; (2) establish visual tolerances when possible; (3) use ΔE as a key measure of color matching performance; ΔE(2000) is a better metric than ΔE(ab) because it correlates closer to visual perception (see a demonstration on page 59 of the Test Targets 5.0 publication from RIT); (4) some spot colors can be matched by four-color proofers; more spot colors can be matched by six- or seven-color proofers provided that color management practices are based on repeatable color platforms; and (5) there are some spot colors and metallic colors that a color proof cannot predict.

• In order to make pictorial color images predictable from press run to press run, we need to ensure color repeatability within the press run. In order to make pictorial color images predictable between two different printing platforms, we can calibrate one device to conform to the reference without altering the data file. Alternatively, we can color manage the data file to reconcile color differences between the two different printing conditions.

• In order to make pictorial color images predictable in a color proofing workflow, the author recommends the following: (1) visual match of pictorial images is the key measure of performance; (2) standard viewing condition and the color normality of the ‘judge’ must be verified; (3) only use the color proofing system that has been certified; and (4) insist that the reference press sheet is also certified. To learn more about how to certify a press run, read the article, “Gravure Research Agenda: Achieving Repeatable Color in Packaging Printing” (Chung, 2006).

Summary

Achieving color predictability hinges on our ability to answer two questions: “When do things become predictable?” and “When do things become unpredictable?” The answer to the first question is, “Doing the right thing all the time.” Specifically, we need to (a) calibrate imaging devices, including input, display, proofer, and press, (b) print by numbers to demonstrate device repeatability, and (c) enable color management
technology to preserve color as contents are passed from device to device in a digital workflow. In addition, we need to communicate with the customer regarding his color requirements.

The answer to the second question is, “Leaving process and workflow unattended will make things unpredictable.” Color anarchy, the opposite of predictable color, is an interpretation of Murphy’s Law -- if color can go wrong, it will. Similar to seeing through many glass windows, the clarity of the view diminishes if only one window is dirty. This also points out the importance of process control and verification of conformance as defined by the customer.

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Literature Cited


Test Targets 5.0, School of Print Media, Rochester Institute of Technology, 2005 (available as a PDF from www.rit.edu/~rycppr).


Calibrating, Printing and Proofing by the G7™ Method, Version 6, IDEAlliance, August 2006 (available as a PDF from www.IDEAlliance.org).

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Bob Chung is a professor in the School of Print Media, Rochester Institute of Technology. Chung was named the RIT Gravure Research Professor in 2004 with the mandate to develop a gravure research agenda and curriculum to help students understand the gravure process and explore career opportunities in the gravure industry. Chung was the recipient of the Michael H. Bruno Award, given by the Technical Association of the Graphic Arts in 2006. He is interested in your comment regarding this article and any suggestion that you may have to further gravure research and scholarship. Visit his web site at www.rit.edu/~gravure or email him at rycppr@rit.edu.