ICC profiles: are we better off without them?

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Keyword(s):

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Before ICC profiles, a device-independent page description document would encode all color in a device independent CIE space like CIELAB. When the document was to be printed, the press person would measure a target and create a color transformation from the CIE coordinates to device coordinates. For office and consumer color printers, the color transformation for a standard paper would be hardwired in the printer driver or the printer firmware. This procedure had two disadvantages: the color transformations required deep expertise to produce and were hard to manage (the latter making them hard to share), and the image data was transformed twice (from input device to colorimetric and then to output device coordinates) introducing discretization errors twice. The first problem was solved with the ICC profile standard, and the last problem was solved by storing original the device dependent coordinates in the document, together with an input ICC profile, so the color management system could first collapse the two profiles and then perform a single color transformation. Unfortunately, there is a wide variety in the quality of ICC profiles. Even worse, the real nightmare is that quite frequently the incorrect ICC profiles are embedded in page description documents or the color management systems apply the wrong profiles. For consumer and office printers, the solution is to forgo ICC profiles and reduce everything to the single sRGB color space, so only one profile is required. However, the sRGB quality is insufficient for print solution providers. How can a modern print workflow solve the ICC profile nightmare?

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ABSTRACT

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1. INTRODUCTION

1.1 Color errors in printing

When color scientists apply their knowledge to color printing, they can get easily carried away by visual thresholds. The omnipresent just noticeable difference (JND) is their holy grail and they pursue the quest for the CIE 1976 $(L^*a^*b^*)$ $\Delta E < 1$ ideal. The reality is that this is not achievable in the real world, and fortunately it does not matter. For example, once upon a time a vendor put an Easter egg in the best high-end digital color printer at the time, which after a year would print a color chart and ask for it to be mailed back to the company. To everybody's surprise the result was $\Delta E \approx 14$, although the customers were perfectly happy with their prints.

One engineering approach is pragmatic and consists in first identifying all error sources, then working away at them in order of size, fixing first the largest error sources and then working down to the more cosmetic issues. Usually vendors do not divulge detailed information about the tolerances of their own products, so reliable information requires some sleuthing to discover. One good source is generously made freely available on the World Wide Web by Ing. Rainer Wagner of WagnerPrintConsult.[1] We can visualize his data in the polar diagram shown in Fig.1. The largest error source is the provenance of the ICC profiles.

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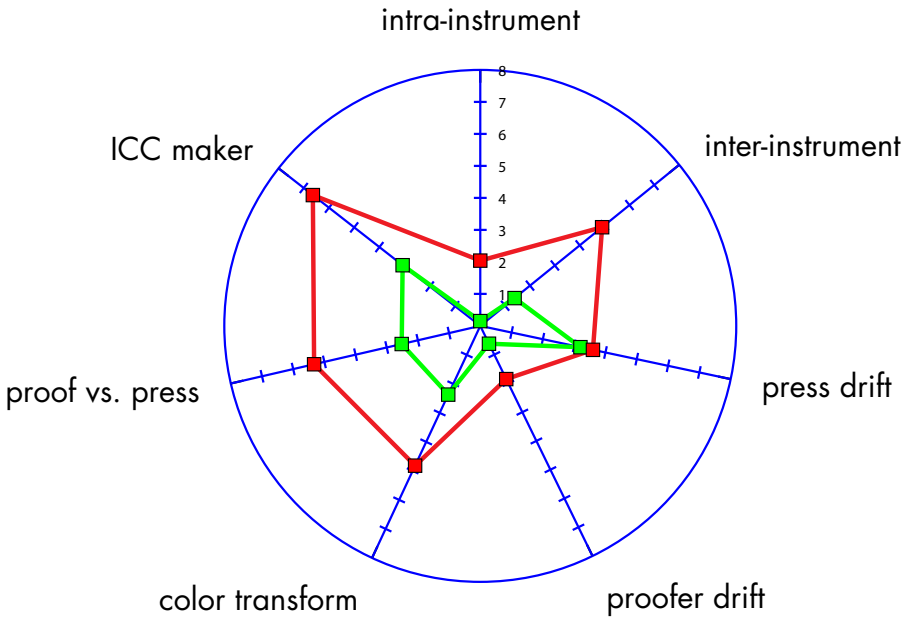

Figure 1. Color offset print tolerances. The green line denotes the minima tolerances, while the maxima are in red.[1]

The ICC standard covers the encoding of the data specifying the characterization of a device, i.e., the mapping of intrinsic device coordinates to device-independent colorimetric values, as shown in Fig. 2. This data can be a function when there is a model, or a table of various sizes when there is no model, and it can be colorimetric or spectral. Depending on a device's deviation from linearity, the choice of the method and the precision of the data quality can vary widely. Last but not least, the accuracy depends on the skills and tools of the profile's creator, which also vary widely.[2] Skilled printers will look at the ICC profiles provided with a job and in case of quality issues, will ask the client to provide better profiles. For the output profile they will use their own carefully prepared ICC profile.

1.2 Classical workflow

As detailed by Homann [3, Chapter 5], this approach worked well in the past when professionals controlled a rigid workflow and had full control over each step. They knew well their professional equipment and they produced high-quality profiles for the fixed machine park they used for their jobs.

Fig. 3 illustrates the old workflow. The client was typically a publisher or a corporate marketing representative. The job was coordinated by an art director, who interacted with copy editors for the text, and photographers and illustrators for the images. A graphic arts specialist then created the piece using a layout program, iterating until the art director and client were satisfied. A buyer form the purchasing department then shopped the job to printers. In the past, the next step was a separation or repro/litho house, but now this function is usually performed by the printer.

The buyer negotiated with the printer's sales representative on such parameters as fulfillment date, number of separations (ink), media, binding, etc. The job then went to pre-press, where a proof-print was created, based on the negotiated parameters. In the case of an offset or gravure press, a special proof-printer was used, while in the case of a digital press, the press itself could be used for proofing. This proof was then signed by the buyer and possibly actors farther up the workflow and became part of the contract.

The contract proof and the print job (plates or a PDF file, see Fig. 4) were given to the press person, who printed a run matching the contract proof. Eventually the job was passed to the bindery and to fulfillment. For the entire workflow, color could be reliably controlled through ICC-profiles.

1.3 Today's workflow

Nowadays the publishing and print industries are radically different. Today's young adults grew up with video games, email, and the Wikipedia—they did not receive an encyclopedia when they entered school. They are completely at ease

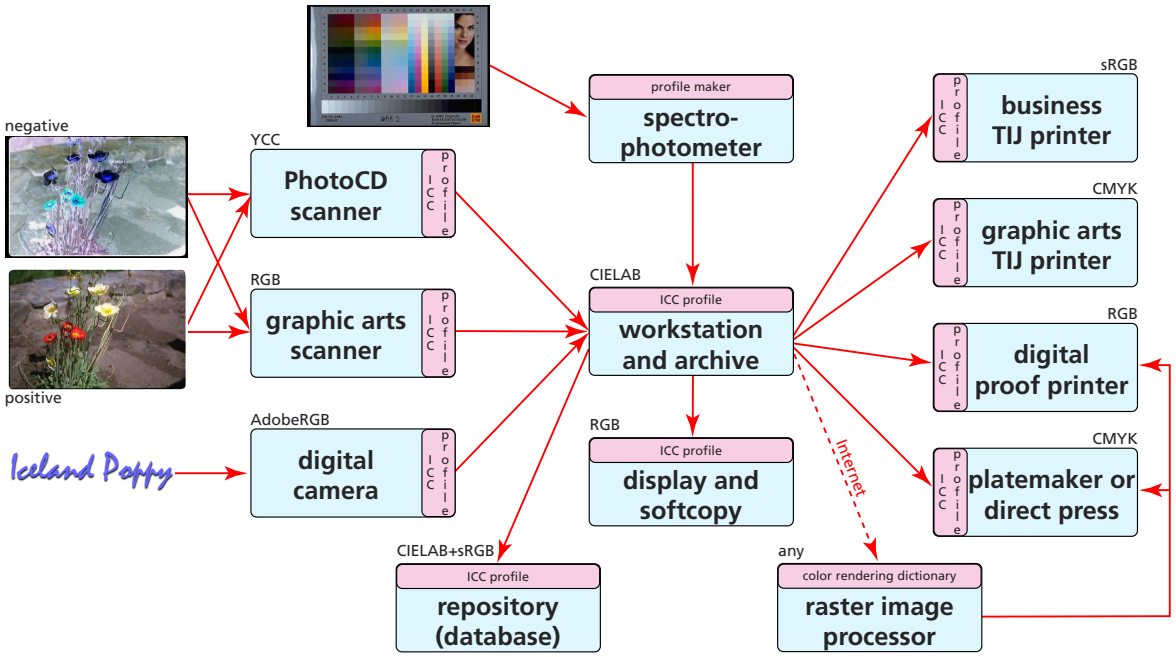

Figure 2. With ICC profiles, a workflow comprising n color devices only requires data for $O(n)$ color transformations instead of $O(n^2)$. (Photograph by William R. Hewlett used with permission)

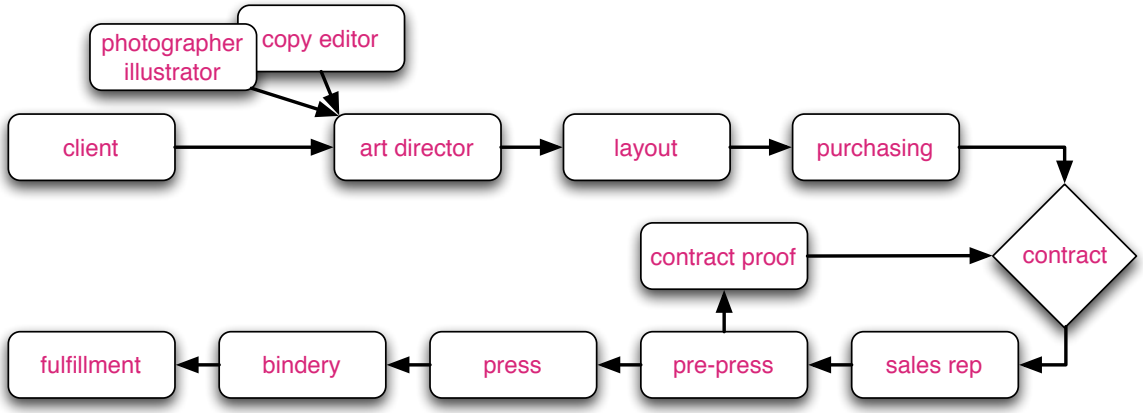

Figure 3. Classical workflow in use when the ICC standard was first defined.

with on-line manuals instead of printed books and like to read the information once printed in magazines on a slate, where it is hyperlinked to in-depth information available on the World Wide Web, and the text can be searched. This is true also for books, where a slate or an wireless reading device (ebook reader) can hold a person's entire library, always available to be consulted.

When company reports are downloaded, magazines are read online, and phone numbers are looked up on the Web, the demand for traditional print media vanishes. Technology allows everybody to do their own work, and print jobs like those illustrated in the workflow of Fig. 3 can now be produced by anybody using inexpensive, easy-to-use software. More precisely, anybody can now produce their own printed books, but the workflow is radically different.

In this contemporary model of self-publishing or vanity publishing, where people produce novels, text book and photo-books, a radically different workflow applies, as shown in Fig. 5. End-users receive free tools like HP MediaSmart Photo, for example, to collect and organize their photographs. The software allows end-users to upload the material for a photo-

Figure 4. Mik Lamming printed his technical report on *WYSIWYG Color* when digital color printing was being invented. Before the Internet became commercial, he had to drop off the plates at the print shop, then he checked the proof print against his original and signed the proof, making it the contract proof.

book to a Web service like Snapfish, which allows for the design of photobooks. In general, when a book is submitted for print, a print service aggregator collects the book materials from many end-users and distributes job batches to a number of print service providers, based on availability or geographic proximity. These batches can be as small as a single photobook.

Printing is manufacturing, so volume is important. While in the classical workflow all items in a run where the same, now each item is different—it is called mass-customization. To be able to handle a large number of different small jobs, the print quality and price must be negotiated by machine, using digital service license agreemenst, because at the required volume for profitability, in person negotiations are impossible. Note also, that there is no locus where a contract proof could be executed.

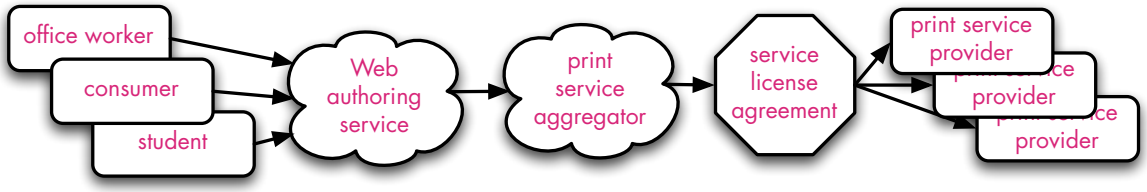

Figure 5. Contemporary workflow for self-publishing through Web services and print service providers. The end-users at the left perform all the steps in the upper half of Fig. 3, while the print service providers perform the steps in the lower half.

2. PAINS OF FLEXIBILITY

At first, the ICC profile technology shown in Fig. 2 would appear ideal for today's workflow shown in Fig. 5. However, there is a big caveat: while the workflow in Fig. 3 was static, there is no such thing in today's world depicted in Fig. 5: the workflow is dynamic and is not known a priori. The key for mass-customization is modularity and reconfigurability, where control theory is used to build cyber-physical systems for printing,[4] and actually even the presses themselves are parallel modular systems that can be reconfigured on the fly.[5]

The problem with ICC profiles is that the ICC specifications define in great detail how color profiles must be constructed and formulate some rough principles on how they are used, but they do not describe any detailed workflows or what is expected from ICC-compatible application programs so that an ICC profile based workflow can function. Worse, the ICC specifications lack references to processes and stages of control for quality assurance [3, p. 114]. Indeed, Homann titles the relevant section "ICC Standard, the Trouble Maker."

The regulars at this conference might remember the paper Johan Lammens gave in 1998, with the apt title "Night of the living color: horror scenarios in color management land."[6] In the case of photobooks, the images might have been taken with the camera set to sRGB mode and the transfer program could have embedded an Adobe RGB profile, or vice versa. The images could have been edited as Adobe RGB images but saved with the display monitor's profile, and the photobook layout program might have applied an Adobe RGB to sRGB transformation, all while the print driver could repeat this same transformation. But there are many possible scenarios that could even be worse.

3. THE UNVARNISHED TRUTH

Forty to thirty years ago, concepts like *High-Fidelity* and *Audiophile* became mainstream among young adults. People became obsessed with the linearity of frequency response, phase preservation, and distortions. The stereo equipment stores that opened in cities around the world to cater to this market began to disappear some 15 years ago, as people began to switch to good-enough equipment they bought in mass-merchandising stores. Today, people listen to music encoded with MP-3, with all kind of phase distortions, through ear-buds, etc. But they do care a lot about the social aspect of sharing their playlists and their music files with their friends, real or not. With this background, it is not surprising that yesterday's single lens reflex (SLR) amateurs today are happy with the good-enough color of a phone camera.

Such statements, however, are generalizations that can easily be based on urban myths; it is imperative to use hard data. The January 2010 issue of the Journal of Electronic Imaging has a very interesting article by Jonathan Phillips, Peter Bajorski, Peter Burns, Erin Fredericks, and Mitchell Rosen: *Comparing image quality of print-on-demand books and photobooks from web-based vendors*.[7] The article compares the image quality of several print service providers (PSP) catering to the self-publishing market, using all major digital presses.

They prepared books containing a number of test targets to measure ICC profile use, gamut volume, color accuracy, modulation transfer function (MTF), etc. To assess noise related to perception, they developped a new quality metric for the PSP technology segment, called *W-rms* for eye-weighted root mean square L^*. In brief, they drew four conclusions:

1. ICC profiles are still a nightmare. Although with Version 4 profiles the technology has reached full maturity, there still is no reliable workflow for using ICC profiles and ICC profiles are used incorrectly
2. The color gamut volume is not a statistically significant correlate of book quality
3. Color accuracy is not a statistically significant correlate of book quality
4. Especially for photobooks, there is a lot of variability

Regarding ICC profiles, some vendors ignored ICC profiles altogether and simply assumed all color being encoded in sRGB. Others did use the ICC profiles, but did not check the version datum, thus interpreting the data incorrectly. Other vendors yet processed only one version for the profiles but not the other (the versions being 2 and 4).

At least the vendors ignoring the ICC profiles assumed sRGB, which is a safe bet for consumer images. Therefore, we can ask the question whether it is worthwhile to use ICC profiles at all, because in the modern scenario of PSP workflow it entails the smallest risk, and in the printing industry risk is where the cost is.

It could be argued, taking the risk is worthwhile, because ICC profiles allow the full exploitation of device gamuts and the reproduced images would be more vivid. Phillips et al.'s data indicates that gamut volume is not an optimal test for predicting perceived image quality, so this argument does not hold water.

A similar argument could be made for color accuracy, but again Phillips et al.'s data indicates that even for the best photobook vendor, whose mean CIEDE2000 is 3.99 and the maximum is 7.72, color accuracy is not an optimal test for predicting perceived image quality. Phillips et al. conclude:

> Analysis of the color gamut and color accuracy indicated that high overall image quality could be obtained from measurably different color performance.
>
> ...
>
> Finally, use of a target to test accuracy of ICC profile usage revealed that ICC profile handling was still inconsistently handled in the one-off print-on-demand and photobook markets at the time of printing; expansion beyond sRGB assumptions was still in process.

4. TOWARDS A SOLUTION

The ideal solution would be to extend the ICC standard to encompass workflows, noting that we write workflows in the plural. However, this will not happen in the next future and we need an approach to find an interim solution we can apply today.

For most consumers, the sRGB assumption is probably good enough. However, people who are willing to spend a lot of money on their own publications can have high expectations, because they not only spend a lot of money producing the book, but also a lot of time. The last thing you want to do to a photo amateur who spent hours tweaking an image taken in raw mode is assume it is encoded in sRGB.

We believe a PSP workflow dealing adequately with color should do an effort to analyze the book's contents. When there is no ICC profile, other metadata and the image contents can be consulted to guess if the image was taken with a simple device or a good camera and subsequently hand-tweaked. In the first case, the sRGB assumption might be sufficient, but in the second case, other possible encodings, like Adobe RGB and ProPhoto, should be considered based on the image data. Some things can be detected by looking at the picture histogram (tone curve manipulations), other could be detected by correlation, as when color by correlation is used for illuminant estimation.[8]

When there is an ICC profile, first of all it should be interpreted correctly. Second, a good guess should be made on the profile's quality. Is it based on a model or a lookup table, and in the latter case, how big is the table? Is it a generic profile or is it custom made? Which software was used, and what is its reputation? If necessary and possible, a better profile can be substituted, again possibly using heuristics like color by correlation to check for plausibility.

Maybe we can also learn from looking at other similar situations, like we did looking at illuminant estimation. An example that comes to mind is PhotoCD. This format developed for the high quality archival storage of photographs was abandoned by its legal owner without the format being made public, resulting in various reverse engineering efforts to save archived images (like was done for Fig. 4).

Like ICC profiles, PhotoCD also lacked provisions for workflow. Like other color encoding standards before PostScript Level 2, PhotoCD chose a device independent device. However, instead of using a CIE color space like CIE 1976 $(L^*a^*b^*)$, PhotoCD invented their own space based on YCC and used an algorithm—known as SBA for Scene Balance Algorithm—to perform the color transformation, and this algorithm was often fooled.

Moreover, SBA required information on the scanner and the film densities, in the form of profiles. The vendor released profiles for three films combined with two scanners, for a total of six profiles. Often operators chose the incorrect profile. Moreover, the profiles should have depended on the film age and storage conditions, which it did not. Finally, when PhotoCD images were imported in an application, it was necessary to specify the profile, which lets one doubt on the veracity of device independent storage. Since the technology is secret, we may never know.

How then do archivists crack this problem? It helps to read the related scientific papers of the company's scientists of the time to see what was going through their mind. With this knowledge, the data could be reconstructed to a reasonable degree and stored for example in the DNG format, since that vendor has a better track record in keeping de facto standards alive. The encoding is a linear RGB color space known as ProPhoto and for which there are ICC profiles. ProPhoto was called ROMM RGB by the PhotoCD owner. It has a very large gamut, so it requires working with 16-bit color depth per channel.

Is there a better way than this kind of sleuthing?

5. CONCLUSIONS

From the release of PostScript Level 2, lazy evaluation has been ruling color workflows. The disadvantage is that the color encoding of an image might be incorrect or missing. Because the ICC standard has not provisions for workflow, in practice these problems happen more frequently than than one might think. This problem has become worse in today's age of print service providers using dynamic workflows for mass producing single copy runs.

Although the assumption that all color is encoded in sRGB works in a large number of cases, there are self-publishers who care about their printed colors, requiring printers to do a better effort in correctly decoding color. Some heuristics learned estimating illuminants or rescuing PhotoCD archives might be useful, but a more systematic approach would be preferred. We look forward to a solution of this conundrum.

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REFERENCES

[1] Wagner, R., "Tolerancias en las mediciones espectrofotométricas." World Wide Web page (1999). `http://wpc.4t.com/wpcinfo10.html`, last checked 30 September 2010.

[2] Beretta, G. B., "Spectrophotometer calibration and certification," External HPL-1999-2, HP Laboratories (January 1999). `http://www.hpl.hp.com/techreports/1999/HPL-1999-2.html`.

[3] Homann, J.-P., [*Digital Color Management: Principles and Strategies for the Standardized Print Production*], Springer-Verlag (2009). `http://www.colormanagement.de/`.

[4] Hindi, H. and Crawford, L. S., "Control in modern printing systems: Modular reconfigurable media paths, color consistency, fuser process, and registration," in [*American Control Conference, 2009. ACC '09*], 34–34 (June 2009).

[5] Biegelsen, D. K., Crawford, L. S., Duff, D. G., Eldershaw, C., Fromherz, M. P. J., Kott, G., Larner, D. L., Mandel, B., Moore, S., Preas, B. T., Schmitz, G. P., and Swartz, L.-E., "Hypermodular parallel printing systems," in [*Proceedings of NIP25: International Conference on Digital Printing Technologies and Digital Fabrication 2009*], 184–187, IS&T, Springfield, VA (September 20 2009).

[6] Lammens, J. M. G., "Night of the living color: horror scenarios in color management land," in [*Color Imaging: Device-Independent Color, Color Hardcopy, and Graphic Arts IV*], Beretta, G. B. and Eschbach, R., eds., **3648**, 197–205, SPIE (December 1998).

[7] Phillips, J., Bajorski, P., Burns, P., Fredericks, E., and Rosen, M., "Comparing image quality of print-on-demand books and photobooks from web-based vendors," *Journal of Electronic Imaging* **19**, 011013 (January 2010).

[8] Finlayson, G. D., Hordley, S. D., and HubeL, P. M., "Color by correlation: a simple, unifying framework for color constancy," *Pattern Analysis and Machine Intelligence, IEEE Transactions on* **23**, 1209 –1221 (November 2001).