Measuring the Quality of ICC Profiles and Color Management Software

By Abhay Sharma

The aim of this review is to establish some baseline assessment for ICC profiles, to assist user choice, raise the standard of profiling software and promote the wider acceptance of ICC color management.

The growth in color management means many software packages can make International Color Consortium (ICC) profiles. But how do we know which software is most accurate or represents the best value? Software vendors have not settled on a standard, and most users are unable to independently assess the quality of profiles.

This "consumer report" is an independent, objective assessment of current software products and ranks them according to their colorimetric accuracy. It follows up on a review last published as *Measuring the Quality of ICC Profiles and Color-Management Software* by Abhay Sharma and Paul D Fleming (Volume 2, Number 19, The Seybold Report, 2003) and has been updated to reflect new versions of products discussed earlier, as well as new products on the market.

The assessment of ICC profiles and color reproduction is complex, involving everything from color science, psychophysics and image analysis to "preferred" reproduction styles. Our approach is to evaluate the accuracy of profiles using the colorimetric intent, which is used in many workflows to print and re-purpose images and for soft and press proofing. Evaluations based on the colorimetric intent provide an indicative set of metric figures that can be used to make valid cross-vendor comparisons.

The accuracy of the colorimetric intent of a profile is analogous to quoting the miles per gallon of fuel consumed by a car. It is a good baseline comparative metric, but is not the full story. We stress that in the same way that you would not buy a car based solely on mpg, you should consider colorimetric numbers in conjunction with other parameters, such as cost, reproduction of real images, your overall workflow, hardware and software compatibility, etc.

It is important to have a quality measure for ICC profiles because this indicates how well a device has been characterized and, therefore, how accurate the color is likely to be in a color managed workflow. It is important for software vendors to publish a merit figure and for the industry to agree on how the figure is calculated. Some vendors quote a Delta E (ΔE) merit figure and programs often will write out a file with statistics. However, there is nothing to indicate how these figures are calculated and whether everybody is measuring the same thing in the same way.

What We Tested

In this version of the review, we tested profiles for the following types of devices: Umax Astra 4000u (low-end scanner), Apple 23-inch Cinema HD LCD Display and Epson Stylus Pro 4000 (CMYK inkjet printer with Ultrachrome inks and semi-matt proofing paper).

Products covered in this review are ColorSolutions basICColor, Digital Light & Color Profile Mechanic, Fujifilm ColourKit Profiler Suite, GretagMacbeth Eye-One Match, GretagMacbeth ProfileMaker, Heidelberg PrintOpen, Pantone ColorVision Spyder2PRO, QPI ColorBlind Pro, TGLC PerfX Color Management, X-Rite MonacoEZColor, X-Rite MonacoOPTIX and X-Rite MonacoProfiler. We also tested generic profiles and Apple's Display Calibrator utility. In this review we have expanded our coverage to include ICS RemoteDirector, which is not intended for stand-alone profiling, and GMG ColorProof, a proprietary, non-ICC proofing program. We also made a printer profile using a remote profiling service called ColorValet by Chromix.

All testing was done with Mac OS 10.3.6, Photoshop CS and the ACE CMM, except for Heidelberg PrintOpen and ColorBlind, which are Windows programs. Most users have placed little importance on version 4 ICC profiles, and while most vendors will make version 4 profiles, this is not the default, so in this work, version 4 profiles were not used.

We look at historical data for some scanner profiling products and we look at smoothness of the input profile by showing a 3-D gamut. The test procedure for each category of profile is described in the report. Enough detail is provided for a skilled user to replicate our results. For each product tested, we generally used default settings; no attempt was made to alter the vendor's starting recommendations. We used traditional CIELAB ΔE^*_{ab} in all cases.

It is inevitable in a survey of this type that some vendors fare better than others. However, this should not be taken as an endorsement of any product or manufacturer. Many other factors must be considered, including reproduction of images (very important) and price. Further, it must be noted that small differences in ΔE are usually insignificant and there are variances due to instrumental repeatability and device drift.

Scanner Profile

This section provides details for a range of tests that were done on three scanned IT8.7/2 targets on a low-end scanner.

Equipment Used. Agfa IT8.7/2 target (1999:03), Fujifilm IT8.7/2 target (2000:05), Kodak IT8.7/2 target (1997:04), Umax Astra 4000u, Photoshop CS (ACE CMM), GretagMacbeth MeasureTool 5, Mac OS 10.3.6.

Description of Test. We scanned Agfa, Fujifilm and Kodak IT8.7/2 reflection test targets on a Umax scanner and made profiles in different profiling packages using batch reference data. We tested the colorimetric accuracy of a number of profiling packages and averaged the result over the three target types.

We conducted the tests to measure the accuracy of the scanner profile as follows:

Following profile generation, we opened the raw RGB scan of each IT8.7/2 chart image in Photoshop. We selected each scanner profile in turn, using Image>Mode>Assign Profile, and processed the image to LAB using Image>Mode>Convert to Profile where the Destination Space was chosen as Lab Color. We chose Absolute Colorimetric rendering intent and used Adobe (ACE) CMM. We did not use dither. Next, we used a special program, written in our laboratory, to average the central part of each patch. We recorded the LAB value of each patch in the chart image in a text file. We used GretagMacbeth MeasureTool to compute the ΔE between this value and the original reference value used in profile generation. We noted a mean and maximum ΔE for all patches of the IT8.7/2 target. We repeated the test for each vendor on an Agfa, Fujifilm and Kodak target. We calculated an average of the mean ΔE for the different charts and used it to rank the products in the results table shown below.

Results. The accuracy of each vendor's program is shown in the table. A lower ΔE number is preferable. Manufacturers are ranked in order so that MonacoProfiler 4.7 provided the best overall result while the generic profile was the worst. Based on this table, we would expect good results from profiles that obtained a ΔE < 2; these are very accurate scanner profiles. In each case, the maximum ΔE should also be considered. The best program would ideally have a low mean and a low maximum ΔE. Further, it is important that each profiling package can make an acceptable profile with the Agfa, Fujifilm or Kodak targets. In a few cases, the results were different across the chart types. In these tests, Fujifilm ColourKit Profiler Suite 4.2, TGLC PerfX Color Management 1.2.8 and GretagMacbeth Eye-One Match 3.0 performed well, as they all had a low mean and a low maximum ΔE across all chart types. It is worth noting that PerfX Color Management uses artificial intelligence for data set training.

In color management circles, it is often asked how good the generic profile supplied by the manufacturer is. For this scanner, the generic profile with a ΔE of nearly 30 was very poor. A poor generic profile doesn't mean the Umax scanner is poor; in fact, the scanner is a remarkably good value. The ΔE value merely tells us how well the profile characterizes the scanner.

Though not shown in the table, the cost of the profiling packages should also be considered. Monaco EZColor and Profile Mechanic have a high ranking and a very competitive retail price.

The results suggest that some vendors might be using the same core for consumer and professional versions of their software. For example, note that MonacoEZColor and MonacoProfiler produce similar results and that GretagMacbeth's Eye-One Match and ProfileMaker are next to each other in the table. We could conclude that these companies are using the same code in both their products.

ICC profiles can contain different lookup tables for different rendering intents: A2B0 (perceptual), A2B1 (colorimetric) and A2B2 (saturation). However, this was not always the case. In the early ICC file format

Scanner Profile Quality

Umax Astra 4000u	Agfa IT8.7/2 Chart	Fujifilm IT8.7/2 Chart	Kodak IT8.7/2 Chart	Final result
	Mean (Max) ΔE	Mean (Max) ΔE	Mean (Max) ΔE	Average ΔE
X-Rite Monaco Profiler 4.7	0.67 (9.66)	0.50 (3.87)	0.63 (6.17)	0.60
X-Rite Monaco EZColor 2.6.3	0.70 (8.63)	0.53 (4.51)	0.63 (6.11)	0.62
Fujifilm ColourKit Profiler Suite 4.2	0.99 (5.06)	0.87 (3.85)	0.83 (4.62)	0.90
TGLC PerfX Color Management 1.2.8	0.95 (4.11)	1.06 (4.01)	1.01 (4.77)	1.01
GretagMacbeth Eye-One Match 3.0	1.09 (3.94)	0.90 (5.80)	1.19 (5.33)	1.06
GretagMacbeth ProfileMaker 5.0.1[1]	1.08 (3.91)	1.15 (15.14)	1.20 (4.94)	1.14
Digital Light & Color ProfileMechanic 1.0[2]	1.09 (7.19)	1.00 (5.06)	1.37 (6.19)	1.15
QPI ColorBlind Pro 5.1 (Windows)	1.60 (6.94)	1.90 (9.49)	1.37 (8.16)	1.62
ColorSolutions basICColor scan+ 2.2	2.37 (9.29)	2.56 (7.99)	2.46 (10.78)	2.46
Generic Umax Scanner Profile[3]	29.76 (44.32)	28.85 (42.01)	29.33 (46.72)	29.31

1) It was necessary to override the default behavior and disable ProfileMaker 5 preferences for "Optimize image preview in Photoshop."

2) When we first tested this product, we calculated an average of 4.67 ΔE. The vendor investigated the product and sent us a new version of the code. The data shown here is based on re-testing using a new version of the program.

3) The generic profile was obtained as part of the Umax scanner driver, Umax VistaScan 3.5.4.

specification, scanner and monitor profiles had only one lookup table, which was called the A2B0 tag. The ICC mentioned the A2B1 and A2B2 tags for the scanner profile in the 1998 specification, but they were "undefined." Since the version 4 revision of the ICC specification (Specification ICC.1:2001-12, Version 4.0.0), the A2B0, A2B1 and A2B2 tags for all profiles are explicitly defined: *All profiles can now have the A2B0, A2B1 and A2B2 tags. Thus, there is no excuse for vendors to put colorimetric data (A2B1) in the perceptual (A2B0) tag, or vice versa.*

We were surprised to discover that the default behavior of GretagMacbeth ProfileMaker is to make a scanner profile in which the colorimetric lookup table tag contains the contents of the perceptual lookup table. We attained a ΔE of around 3 with ProfileMaker 5 in default mode. We had to repeat the test after we disabled the "Optimize image preview in Photoshop" item in ProfileMaker Preferences. To avoid this confusion, we recommend that vendors populate lookup tables in complete accordance with the ICC specification and that Adobe Photoshop is unambiguous in its use of rendering intents in all parts of the workflow.

Scanner Profile Evolution. Comparing our new research with data from the previous version of this review, we can conduct some historical analysis to determine if software is getting better and if there is any benefit in paying for an upgrade.

From the data in the table below, we could conclude that Fujifilm ColourKit was not changed between versions 2.2 and 2.3 but has been improved in version 3.0 and 4.2. GretagMacbeth's ProfileMaker remained the same between versions 3.1 and 4.0, and appears to be slightly less accurate in version 4.1, and has not changed much in version 5. We may conclude that the code for MonacoProfiler was greatly improved between versions 3.2 and 4.0, versions 4.0 and 4.5 were essentially the same, and version 4.7 shows improvements that reduce the ΔE error by 50%. Note that there may be improvements in these products that are not detected by our tests and that in scanner profiling it is possible to get a slightly different result each time the experiment is conducted as the IT8 chart may be cropped differently.

Scanner Profile Evolution

	Agfa IT8.7/2 Chart	Fujifilm IT8.7/2 Chart	Kodak IT8.7/2 Chart	Final result
	Mean (Max) ΔE	Mean (Max) ΔE	Mean (Max) ΔE	Average ΔE
Fujifilm ColourKit 2.2	1.17 (3.98)	1.25 (4.53)	1.42 (3.66)	1.28
Fujifilm ColourKit 2.3	1.15 (3.72)	1.23 (4.53)	1.43 (3.53)	1.27
Fujifilm ColourKit 3.0	1.11 (4.36)	0.90 (3.52)	0.88 (4.47)	0.96
Fujifilm ColourKit 4.2	0.99 (5.06)	0.87 (3.85)	0.83 (4.62)	0.90
Gretag ProfileMaker 3.1	0.85 (2.59)	0.97 (3.21)	1.16 (3.30)	0.99
Gretag ProfileMaker 4.0	0.85 (2.87)	0.99 (10.13)	1.23 (4.12)	1.02
Gretag ProfileMaker 4.1	1.15 (3.59)	1.12 (2.86)	1.22 (4.91)	1.16
Gretag ProfileMaker 5.0	1.08 (3.91)	1.15 (15.14)	1.20 (4.94)	1.14
Monaco Profiler 3.2	4.39(15.00)	5.04 (8.25)	4.79 (11.35)	4.74
Monaco Profiler 4.0	1.19 (9.95)	0.92 (4.70)	1.19 (7.10)	1.10
Monaco Profiler 4.5	1.25 (11.31)	0.91 (4.40)	1.19 (9.02)	1.12
Monaco Profiler 4.7	0.67 (9.66)	0.50 (3.87)	0.63 (6.17)	0.60

3-Dimensional Gamuts. For any profile, accuracy needs to be accompanied by adequate smoothness. In this section, we look at the gamut of each input profile. The graphs are shown on the next page. The gamut shown is for the profile made with the Kodak IT8 target. Also shown on the same scale is the reference data that was provided to each vendor to generate this profile. It is generally necessary to have a smooth gamut surface with the least strange behavior inside and outside the training set region. The plots were generated in Chromix ColorThink.

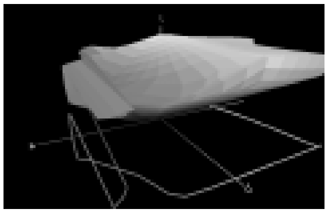
Monitor Profile

LCD panels are becoming increasingly important in color management. Are profiling instruments and profiling packages able to accurately characterize these devices? This section provides details of a range of tests that were done using an Apple 23-inch Cinema Display. CRT displays are no longer evaluated as part of the review process.

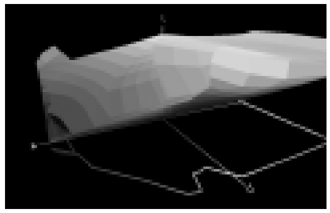
Equipment Used. Apple 23-inch Cinema HD LCD Display (M8536), measuring instruments as listed, Photo Research PR-650 SpectraScan spot spectroradiometer, Digital Macbeth ColorChecker chart, Photoshop CS (ACE CMM), Mac OS 10.3.6.

Description of Test. We tested a number of profiling packages to see if they were able to achieve a requested gamma and a requested white point, and accurately reproduce 24 colors that approximately represent a Macbeth ColorChecker chart. We made monitor profiles using different measuring instruments as shown in the table. Where offered, the user requested a gamma of 1.8 and white point of D_{50}.

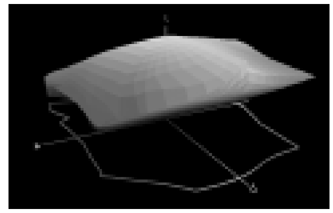
After each profile was made, it was selected as the system profile. Using Photoshop, a grayscale ramp was displayed on the monitor consisting of RGB (0,0,0), (15,15,15) … (255,255,255). The luminance (Y) was measured using the PR-650 SpectraScan and we used a log-log plot to determine the gamma of the display by fitting a straight line to the data and noting the slope as the gamma value. Next, a white patch of RGB 255,255,255 was displayed and the XYZ values of this patch were measured. The measured XYZ values were normalized to Y=100 (the color temperature is unchanged by a uniform rescaling of the XYZ values). The measured XYZ was converted to LAB for the cho-



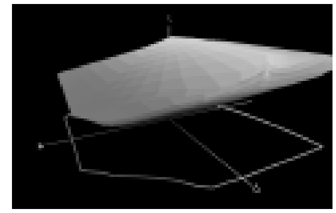
basICColor scan+ 2.2



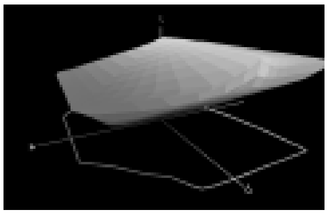
ColorBlind 5.1



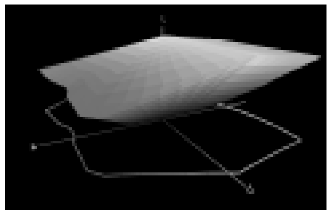
Fujifilm ColourKit Profiler 4.2



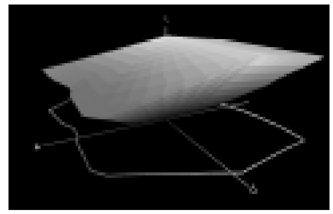
Gretag Eye-One Match 3



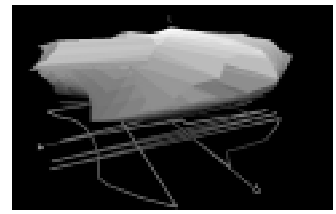
Gretag ProfileMaker 5



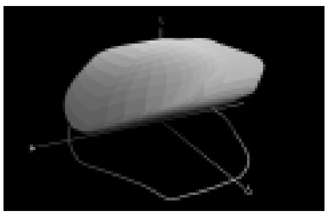
MonacoEZColor 2.6.3



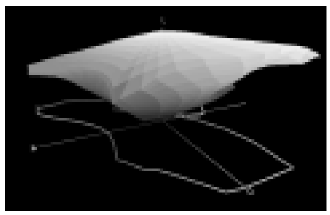
MonacoProfiler 4.7



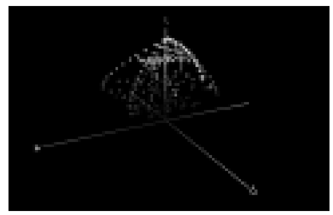
Profile Mechanic 1.0



TGLC PerfX 1.2.8



UMAX Generic Profile



Reference (target) data

sen illuminant, D_{50} and compared to an ideal D_{50} white point that has an LAB of 100,0,0. A $\Delta E_{a,b}$ calculation was done to establish how close each profile was able to create the requested color temperature. A $\Delta E_{a,b}$ figure was defined as:

$$\Delta E_{a,b} = (a^2 + b^2)^{0.5} = C$$

Thus, we see that the $\Delta E_{a,b}$ has a simple interpretation as the chroma, C, of the measured white point, referenced to the target white point. Finally, data for LAB (D_{50}) values for a 24-patch Macbeth ColorChecker were obtained and displayed in Photoshop. We used a PR-650 SpectraScan to measure the XYZ of the patches, which was converted to LAB (D_{50}), and the ΔE was calculated and averaged over 24 patches. One patch was out of the gamut of the display, and this produced an expected high error reading.

Results. The results show that Digital Light & Color Profile Mechanic produced the requested gamma for the display, while all other vendors missed this target value. However, in most cases the small difference from the expected gamma of 1.8 is not significant. Some vendors might be aiming for a gamma that is linear in L* and a log-log fit for the gamma value might not be the best way of estimating the display gamma characteristics. For the white point, a lower ΔE is better. For the colors of the Macbeth ColorChecker, a lower ΔE is better and a ΔE of about 3 or less is likely to produce good results. Keep in mind that from scrutinizing the data it is obvious that at least one of the chosen colors was out of the gamut of the display. In the table, pay attention to the instrument used. Some instruments are colorimeters (Sequel G4 CL, Eye-One Display 2, MonacoOPTIX and Spyder2PRO) and some are spectrophotometers (Spectrolino, Eye-One). Note that profiles were made with the different instruments listed in the table, but

Monitor Profile Quality

Apple 23-inch Cinema HD	Measuring instrument	Achieved gamma (Target was 1.8)	ΔE difference in white point from a target of D50	Average ΔE of 24 patch Macbeth ColorChecker
Digital Light & Color Profile Mechanic Monitor 1.0	Sequel G4 CL	1.80	5.83	2.92
GretagMacbeth ProfileMaker 5.0.1	Spectrolino	1.75	1.99	3.05
ColorSolutions basICColor display 3.03	Eye-One	1.72	3.37	3.20
Integrated Color Solutions Remote Director 2.6.3	Eye-One	1.97	4.26	3.35
Fujifilm ColourKit Profiler Suite 4.2	Eye-One	1.70	4.31	3.57
GretagMacbeth Eye-One Match 3	Eye-One Display 2	1.70	5.64	4.15
Monaco Profiler 4.7	MonacoOPTIXXR	1.71	6.14	4.22
Pantone ColorVision Spyder2PRO 1.0	Spyder2PRO	1.76	7.12	5.14
Apple Display Calibrator Assistant 4.2	None	1.65	6.86	5.55
MonacoOPTIX Pro 2.03	MonacoOPTIXXR	1.70	9.71	5.56
Monaco EZColor 2.6.3	MonacoOPTIXXR	1.71	9.61	5.81

measurement was done with a totally different but single instrument (PR-650 SpectraScan). Remote Director 2.6.3 is not (strictly speaking) a program intended for monitor profiling, but could be expected to achieve better results than ICC products as it is in total control of the display system: profile, CMM, video card, etc. RemoteDirector occupies a side-by-side ranking with ColorSolutions basICColor display with which it shares a common ancestry. We should point out that the Apple Display Calibrator is a simple utility that makes a valid monitor profile, but it is not generally used in graphic arts workflows because it is based on the user's visual assessment.

Printer Profile

There is a great deal of interest in evaluating printer profiles for direct printing of images. There is also interest in using inkjet printers in color management proofing workflows. In a printer profile there are three possible items to report:

- A2B1 (device to LAB, colorimetric tag)
- B2A1 (LAB to device, colorimetric tag)
- Round trip test

In this report, we measure the accuracy of the A2B1 and B2A1 tags of an output profile.

Equipment Used. Epson Stylus Pro 4000 inkjet printer with Epson Ultrachrome inks, ColorBurst 3.8 RIP, Felix Schoeller H74261 Semi proofing roll paper, GretagMacbeth SpectroScan/Spectrolino, ECI 2002 Random layout printer target, Photoshop CS (ACE CMM), GretagMacbeth MeasureTool 5, Mac OS 10.3.6.

Description of Test. We made an output profile for an Epson 4000 inkjet printer in CMYK mode using ColorBurst 3.8 RIP with Epson Ultrachrome inks and Felix Schoeller proofing roll paper. *In each case, the output profile was made from the measurements of the same ECI 2002 target measured on a SpectroScan/Spectrolino.* We used default values in each program for all settings of black generation and profile quality/lookup table size. When printing to the Epson 4000 via the ColorBurst RIP, we used no ink limiting or linearization. The ColorBurst RIP is used merely to print to the device. In ICC parlance, we might say that each vendor is asked simply to make a profile between the CMYK values sent to the printer and the LAB values that result from measurement of that target. In this test we separately measured the accuracy of the A2B1 and B2A1 parts of the output profile, and provide these results, as well as an average.

To evaluate the B2A1 part of an output profile, we converted the LAB values of the measured ECI 2002 chart into an image. (We used a program written in our lab, although Logo ColorLab can also be used for this purpose.) Using Photoshop, we converted the LAB image to CMYK using each profile in turn. We used the ACE CMM, and the intent selected in Image>Mode>Convert to Profile was Absolute Colorimetric. We printed the CMYK image and measured the LAB of each patch. We compared the measured LAB to the LAB that was in the image being sent to the printer. We averaged the mean ΔE over all the patches. Because of the way the test was conducted, all colors sent to the printer were in gamut. The test shows the difference between the particular LAB color you wanted to reproduce and the LAB you would get if you used that printer profile and that printer. The error between the LAB values you wanted and the LAB values you achieved is calculated and shown in terms of ΔE.

To evaluate the A2B1 part of the output profile, we converted the ECI 2002 CMYK image to LAB using each profile in turn. We know what LAB we had from the measurement file — when the ECI 2002 target was first printed and measured for profile generation — so if we use the A2B1 table of each output profile to predict the LAB, then the ΔE between the predicted LAB and the measurement file LAB tells us the error in the A2B1 part of the profile. To do this test, we opened the ECI 2002 CMYK chart image in Photoshop and used Image>Mode>Assign Profile for each profile in turn. We converted the image to LAB using Image>Mode>Convert to Profile (Lab Color). We used the ACE CMM, and the intent was Absolute Colorimetric. Dither was not selected. We averaged the LAB of each patch in the digital file using a special program we have written and, finally, we compared the values to the measurement file. We calculated the ΔE using GretagMacbeth MeasureTool.

Printer Profile Quality

Epson Stylus Pro 4000 With ColorBurst RIP 3.8	Mean (Max) ΔE B2A1 – used for Printing	Mean (Max) ΔE A2B1 – used in Proofing	Average ΔE
Heidelberg PrintOpen 5.1 (Windows)	2.32 (10.82)	1.11 (8.42)	1.72
Fujifilm ColourKit Profiler Suite 4.2	2.56 (14.83)	1.07 (9.78)	1.82
GretagMacbeth ProfileMaker 5.0.1	3.26 (12.40)	1.12 (6.27)	2.19
ColorSolutions basICColor Print4c 2.1	3.02 (14.30)	1.49 (11.39)	2.26
TGLC PerfX Color Management 1.2.8	3.64 (14.00)	1.69 (8.39)	2.67
X-Rite Monaco Profiler 4.7	4.17 (19.72)	1.54 (9.85)	2.86
CHROMIX ColorValet Print 2.3	3.75 (12.84)	3.22 (20.34)	3.49
ColorBurst RIP 3.8 Generic Profile Epson Premium Semi Matt Paper[1]	4.05 (10.73)	Not applicable	Not applicable
GMG ColorProof 04	4.57 (19.51)	Not applicable	Not applicable

1) Generic profile supplied by ColorBurst/Epson but intended for Epson paper. We used Felix Schoeller paper, which is similar but not the same.

To eliminate inkjet print instability, we allowed all prints to stabilize for at least 24 hours before measurement.

Note that it is possible to do a software-only "round-trip" test, and earlier versions of this review have done that. Round-tripping involves taking some (optionally in-gamut) LAB values and converting them to CMYK and then back again to LAB. The ΔE between the start and finish LAB gives us an indication only of the accuracy of the *reversibility* of a profile lookup table. This does not, however, tell us much about the likely result when processing images, as a very poor profile can have excellent reversibility.

Results. Keep in mind that the B2A1 table is used to process and print images and is the more important column in this table. The A2B1 column is expected to be better than the B2A1 column, as the A2B1 calculation involves only a software process, while the B2A1 entails printing and measuring that leads to greater inaccuracies. Heidelberg PrintOpen created the most accurate profile in our tests. We should note that PrintOpen now provides a mechanism to iteratively lower the ΔE figure even farther (this option was not used here). The results produced by vendors with an average ΔE of about 2 are very good and are likely to produce excellent results in all printer-based workflows. However, keep in mind that a large maximum ΔE has the potential to cause problems in particular image colors. In looking at the B2A1 table size, we see that MonacoProfiler is disadvantaged in this comparison, as its profile had a lower number of cube nodes (the default setting) in the lookup table than all other entries in the list. We made the Chromix ColorValet profile using a special target supplied by the vendor. We downloaded the target from the vendor's Web site, printed on the Epson 4000 printer and sent it by Fed Ex to Chromix. After six days, the profile was received as an e-mail attachment. The charge for this commercial service was $99. We created the ColorValet profile with a vendor-specified target, but it was subjected to testing based on the ECI 2002 target used in the main series of our tests.

In the lower part of the results table, an entry is shown for the ColorBurst RIP 3.8 Generic Profile Epson Premium Semi Matt Paper. To generate this entry, we set the printer environment (ink limits and linearization) in accordance with how the generic profile was made, but the paper used was different. The profile assumed Epson Premium Semi Matt paper, while we used Felix Schoeller Semi Matt paper. This entry is shown for the situation where a user might have a printer and paper, but no profile. The user needs a generic profile to complete the workflow. Instead of custom profiling, another option is to use the closest available generic profile. The entry shown in the table is the accuracy the user can expect in this situation. We obtained the result for GMG ColorProof external to this testing. The GMG system is a PC-based system and directly controls the Epson 4000 and the SpectroScan. The measurements of the ECI 2002 target used in the main series of tests formed the "aim" or "target" values for the GMG system. GMG ColorProof took control of the Epson printer and iteratively created an ECI 2002 target, which we measured and compared to the target values. The data shown here for GMG is not typical of this system and is much worse than normally expected.

Summary

Pictorial images might be processed using the perceptual intent or, as is becoming more common, the relative colorimetric intent. The colorimetric intent is also used during the facsimile reproduction of images; during soft proofing, when images are evaluated on a monitor; and during proofing, when press images are "returned" to the Profile Connection Space and printed on a proofing device. The colorimetric intent might also be used when legacy CMYK images are opened. A number of significant ICC workflows use the colorimetric intent, and as such it is an easily calculated profile accuracy measurement. Nonetheless, the appearance of images is an important criterion that should also be considered in conjunction with these test results.

GretagMacbeth continues to provide a suite of well-rounded products. Its software is powerful, but easy to understand and use, and provides reliable results. GretagMacbeth continues to provide users with unique and powerful tools. For example, two of its systems, Eye-One and Eye-One Display 2, allow measurement of ambient light conditions. GretagMacbeth has an excellent technical support system and a free phone number (877-628-6868), which is quickly answered by experienced people in the U.S. who are familiar with the products. Its support mechanism is to be commended. Our main criticism of GretagMacbeth is that its software does not provide any feedback following profile generation. In other words, its products signal no warning of any problems that might have occurred during the making of a profile.

The X-Rite Monaco marriage continues to produce new offerings, and we await the opportunity to evaluate its new Pulse product line. MonacoProfiler was a good a product and has become even better, especially in the area of scanner profiles, which are extremely accurate and smooth. Monaco products continue to provide excellent feedback to the user about profile quality. Monaco makes available data files that are created during monitor, scanner and printer profiling. This is very useful and highly commendable. X-Rite Monaco has problematic software registration systems and unimpressive technical support. We had separate, unnecessary problems and issues with installation and support of its products last November 1 and 18, and provided details of these incidents to the company, but received no response.

Fujifilm's ColourKit Profiler Suite offers scanner, monitor and printer profiling. The software is available in identical Mac and PC versions and comes in nice, neat components. We had one problem with this product involving communication with the SpectroScan.

We see a growth in the number of new companies. This infuses new blood into the market and promotes healthy competition in our industry. Some new products provide novel technologies, such as PerfX by TGLC, which uses artificial intelligence, while others target niche markets, such as Profile Mechanic, which is aimed at the digital photographer. We found the monitor profile created by Profile Mechanic using the Sequel sensor to be the most accurate (and most affordable) in this work.

We have included two products that are not intended for stand-alone profile generation. In the monitor category, we evaluated ICS RemoteDirector. On colorimetric accuracy alone this product was not superior to other general ICC products. In the printer category we used GMG ColorProof. Again, this proprietary system had significant advantages, primarily the ability to iterate and reprint the test target. However, in the unique (unusual) situation of our testing, it was unable to produce good results.

This report shows that new-generation inkjet printers, such as the Epson 4000 with Ultrachrome inks and commonly available microporous semi-matt paper, can produce accurate printer profiles and can be used as a stable proofing system.

This work revealed some serious issues that limit the effectiveness of ICC color management implementation that must be urgently addressed for ICC color management to continue to grow. The main problems were:

- Adobe Photoshop's lack of control for correctly directing the use of rendering intents — in particular, the scanner and monitor profile rendering intent.
- The inability of the Windows platform to provide color management support — e.g., video luts and lack of CMM support for version 4 ICC profiles.
- Profile-making packages and users continue to have mixed, uncertain feelings about version 4 ICC profiles.

Why Is My Favorite Program Not Listed?

Some vendors expressed interest in participating in this study and cooperated with us, but for various technical reasons, we were unable to include their data in this version of the review. These vendors are Quato Technology iColor Proof 1.0.5 for monitor profiling and Colour Confidence PrintProfiler and QPI ColorBlind for printer profiling. We hope to include these products in the future.

We attempted to contact all vendors and invite them to participate. No product has been refused entry into this review. If your favorite software is not listed, please contact the vendor and ask it to talk to us. The following vendors were repeatedly invited to participate but declined: Kodak (Colorflow), Agfa (ColorTune), EFI (ColorProfiler), Creo (Profile Wizard).

Further Details

Further details about this work are available at www.wmich.edu/pci/staff/downloads/index.html. **TSR**

About the Author

Abhay Sharma has a bachelor's degree in Imaging Sciences from the University of Westminster, U.K., and a Ph.D. in Physics from King's College, London. He worked as a senior research scientist for FujiFilm Electronic Imaging before joining Western Michigan University as an associate professor in color imaging. He has recently published a book on color management titled *Understanding Color Management* (Delmar Thomson, 2004). Sharma is a member of the ICC and chair of the working group that is looking at the issue of profile quality assessment.

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