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Unrivaled Displays. Breakthrough Colors?

Since Apple Computer made the switch to LCD technology to drive their Display Systems, some questions on the actual color capabilities remain unanswered. Today, most hardware manufacturers are switching to LCD technologies, and someday these technologies will show up on your desktop as well.

Especially in creative markets, ICC based ColorManagement systems are very important to guarantee predictable color from start to finish, anywhere, anytime.

This project was not intended to describe a scientific method on color measurement issues, nor is it intended to promote specific hardware or software.

It tries to give an independent view on the products and methods used for this project.

This report will therefore describe our color experiences with the tested displays, in combination with GretagMacbeth's EyeOne System for monitor calibration.

Although it is impossible to capture every little technical detail, we are confident that this report will answer the most important questions on the color capabilities of the hard and software.

With colorful greetings,

Erik Koldenhof
CEO, Koldenhof Grafimedia Expertise
Rijswijk, the Netherlands

This report describes the actual color capabilities for the 20" and 23HD Cinema Display Systems when using GretagMacbeth's EyeOne System for display calibration.

www.colormanagement.nl
The web-based version also contains extra material like some very interesting 3D color gamut animations. You can also find additional information on color behavior and ColorManagement basics on the site.

Before we go in to Color.
In the past weeks that we have been working intensively with both the 20" and 23HD Cinema Displays, we now know that we have been spoiled.

Normally we would do much of our work behind our PowerBooks and mid-range or high end CRT based Systems. Now that we've experienced working over a longer period with the Cinema Displays it's hard to switch back to CRT again.

Why?
One sure thing is the complete flicker-free image that you're looking at. Together with the overall incredible sharpness, it makes it very relaxed working behind these displays.

The other thing is about resolution.
A lot of LCD based systems are more and more based on some kind of wide-screen resolution, what we think is already great to work with.

The Cinema Displays deliver resolutions up to 1920x1200 for the 23HD version, which provide you with enough space to park your car in and still leave room for an additional motorcycle.

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Some faq's

Why should I use calibrated displays?
Well, to be honest, a simple calibrated display alone is not enough. Calibrating your display will make sure that the chosen Gamma (e.g. 2,2) and Whitepoint (e.g. 5000K) are simulated as close as possible (or corrected inside the display hardware). In order to get all colors reproduced on screen as predictable as possible, you need to have an ICC profile from that calibration so that your System exactly knows how to reproduce colors on that device.

Can I trust my default installed monitor profile?
It's our experience that you cannot. Every display has a different color behavior, not to mention their brightness and contrast settings. In this report, we've covered the quality of Apple's default monitor profiles. We always advise our customers to create their own monitor profiles. You know why when you read this section in the report.

I am a digital photographer. Why should I use ICC ColorManagement?
If you are working with digital photography, there are no analog reference materials like slides or negatives anymore, everything that you do is based on digital information. You should at least calibrate and profile your monitor. Programs like Adobe Photoshop are always using the ICC monitor profile to get colors from your RGB or CMYK working space correctly on to your screen.

I am using software which is not ICC or ColorSync compatible. Why should I calibrate and profile my display?
If color is important to you, then it's even more important to create an ICC profile for your monitor. Remember that most things that you do are based on what you see on your screen. With a correct ICC monitor profile that you can send along with your images for output (or use the standard installed AppleScript to embed the profile into it), your printer also has the exact information on what you actually saw on your display.

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About Koldenhof Grafimedia Expertise.

Koldenhof Grafimedia Expertise, a respected independent knowledge and solution provider for the Graphic Arts industry, is located in Rijswijk, the Netherlands.

In the past nine years, we've consulted for and implemented numerous national and international ICC based ColorManagement solutions from Digital Photography up to the complete standardization of sheet-fed and web-offset based printers.

We do not sell any hardware or software. Knowledge is our core business.

In our own research and training facility 'The Studio - the learning zone', we do our research, and train end users, support engineers, commercial trainers and educators on every aspect of color- and workflowmanagement. Koldenhof also provides third-level technical support for various hard- and software developers.

More information about us is available at:
www.koldenhof.nl (sorry, Dutch only)
www.colormanagement.nl

The purpose of www.colormanagement.nl is to inform you on the daily problems on (digital) color reproduction, and the possible solutions, based on ICC ColorManagement technologies. Because many are still kept in the dark on predictable color reproduction, it is not our intent (for the time being) to publish the information on the highest technical level possible. We would first like to make ICC based digital color reproduction available for everyone, and not for those who already are experts on this area.

Overall conclusions

Before we go in to all details, one thing should be clear to all.

While most of the devices color capabilities are compared to High End CRT, we do want to state here that some features found in High End CRT technology is not available for LCD.

One of those features is the ability to calibrate a High End CRT at all regions in order to deal with purity issues (mostly called 'full display calibration').

But then again, based on current pricing, you can buy three Cinema displays for the price of one High End CRT.

Even if you're not interested in all those color issues, current Cinema Displays provide superb overall sharpness and of course a complete flicker free image.

The incredible resolution (up to 1920x1200 for the 23HD) gives you the possibility to have a full A4 spread at 100%, while maintaining enough space for all those additional pallets.

Color gamuts.
Although the color gamut for the 23HD is just a little smaller then the 20" Cinema Display, both have color gamuts that are fully comparable to High End CRT.

Contrast ratio and luminance.
Contrast ratio is excellent, we measured a contrast ratio of 379:1 for the 20", and 236:1 for the 23HD. Luminance for the 23HD measured 165Cd/m2, and 235Cd/m2 for the 20".

For the color critical users: You might want to dim the display to approx. 100Cd/m2 to guarantee an excellent Photoshop softproof (see our quote on calibrating displays).

Warm-up time and color stability.
Both Cinema Displays provide consistent color after a warm up period of about 90 minutes. After this period the displays stay within roughly 1.00 Delta-E (CIE94), which is excellent.

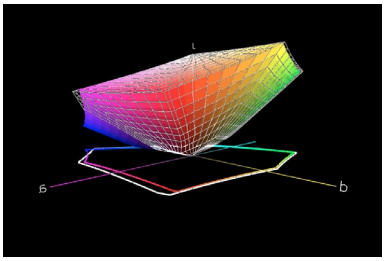
Purity.
This describes the displays ability to display the same color at every region of the screen, from top left to bottom right.

While displays that have no issues with this have to be invented yet, High End CRT technology have the capability to actually adjust colors at all regions. This is not possible for LCD at this time.

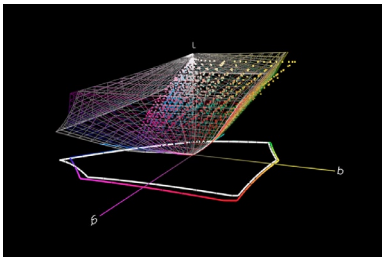
Therefore, LCD technology will produce bigger color differences between all regions, when compared to the center of the screen.

Purity for the 20" Cinema Display was calculated to an average of 4.4 Delta-E (compared to the center of the screen) and 4.0 Delta-E for the 23HD. As you can see from the graph, purity issues mainly consists of differences in brightness between regions (Delta-L).

Ghosting effect.
When closing a window after it has been opened for some time, it's possible that you can still see some ghosting effect on your Desktop pattern or image. This effect differs from display to display and will most of the time disappear within 1 minute. It seems that both 20" and 23HD displays suffer this problem.



Color gamuts are fully comparable to High End CRT.



To view the complete 3D animations in Quicktime, visit www.colormanagement.nl

Overall conclusions

As you probably now, all devices have their own way of dealing with colors. Therefore, when using equal percentages (eg. 50% Cyan) printed on two (or more) devices, you'll face different color perceptions (You can find more info on www.colormanagement.nl).

ColorManagement Systems (like Apple's System Level ColorSync) deal with these different color behaviors by using device specific color profiles to transform color perception from one device to another.

In the beginning, profiling solutions were expensive and sometimes difficult to use, but in the past years manufactures developed less expensive and more intuitive solutions for ICC profile creation.

Calibration.
For predictable color reproduction, you have to calibrate your display. If you choose not to calibrate your display, color differences between actual printed artwork and a Photoshop softproof can run up to more then 26 Delta-E (CIE94) !!!

When calibrated, overall color differences can be reduced to 1.10 up to 2.5 Delta-E (CIE94), which is very good.

Calibrating with the EyeOne Display.
During this project, we worked with the GretagMacbeth EyeOne Display System, and the new version of EyeOne Match 2.0.

The EyeOne System provides excellent entry level ColorManagement tools, which are very easy to use as well.

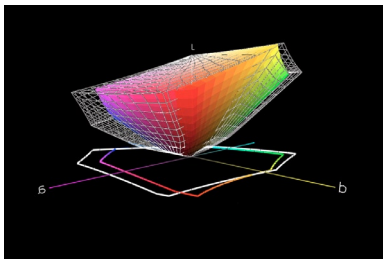
After calibration, we used Adobe Photoshop's softproof function (setup with the actual ISO 12647-2 profile from eci/fogra) to display various CMYK colorpatches.

We measured the on screen colors with our GretagMacbeth Spectrolino. We then compared those measurements with the actual printed colors to get an idea of the quality of the profile (in combination with the Cinema Displays).

The profile's whitepoint has been verified to 2.42 Delta-E (CIE94).
All color patches that we've used for softproofing, resulted in a color difference between 1.10 and 2.5 Delta-E, which will give you a very close simulation of how colors will actually be printed.

Results in detail

The new line of Cinema Displays have color gamuts that are larger then the gamuts found for their predecessors (17" and 22").



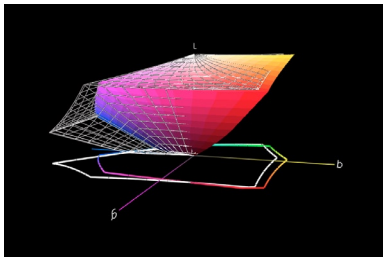
To view a complete 3D animation in Quicktime, please visit www.colormanagement.nl

Bigger Color Gamuts for the 20" and 23HD
To compare the color gamuts of the displays, we first calibrated both Displays for a target Gamma of 2.2 and a simulated Whitepoint of 5000K (D50). From this calibration ICC profiles were created.

For calibration and profiling we used the GretagMacbeth EyeOne Display System.

The 3D CIE-Lab simulation clearly shows the difference between the former 17" Studio Display (LCD), drawn as flat shaded gamut, and the new 20" Cinema Display which is represented by the white outline.

For Creative Markets, the need for big color gamuts is obvious. Previous LCD display Systems had smaller gamuts then most CRT displays.



To view a complete 3D animation in Quicktime, please visit www.colormanagement.nl

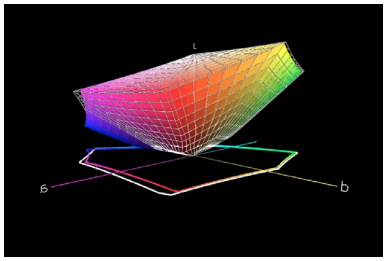
Former (22") Display compared to High End CRT
The CIE-Lab simulation shows the difference between a High End CRT (white outline) and the former 22" Cinema display from Apple (flat shaded gamut).

You can easily see the differences between both color gamuts. High End CRT systems are capable of showing more colors, specially in the blue hues.

Although this can be a major advantage for digital photographers who are actually working in RGB most of the time, many do not know that for CMYK workflows the smaller color gamut of the Apple 22" Cinema Display is already capable of showing most colors (CMYK softproofing).

So, now we know the previous Apple LCD Displays had smaller gamuts compared to High End CRT Systems, and we also saw that the new Cinema Displays had an overall larger color gamut compared to their predecessors.

The new Cinema Displays have overall color gamuts that are comparable to High End CRT.



To view a complete 3D animation in Quicktime, please visit www.colormanagement.nl

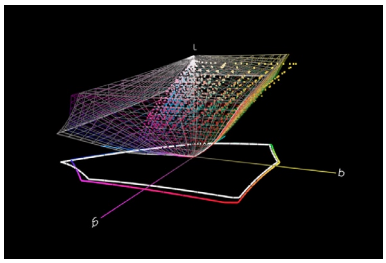
New 20" Cinema Display compared to High End CRT
For this comparison we've used the ICC profiles for both High End CRT and the new 20" Cinema display. By plotting them in CIE-Lab we can now exactly tell the difference in color gamut between the two systems.

What you'll see in this simulation, is that the new 20" Cinema Display has an overall color gamut that is comparable to High End CRT.

In this example the Apple 20" Cinema Display is rendered as Flat Shaded Gamut, while the High End CRT stands as Full Color Outline.

Results in detail

Great results on Offset Euroscale (ISO12647-2:2002+) softproofing



To view a complete 3D animation in Quicktime, please visit www.colormanagement.nl

For everybody who normally works with CMYK data, here's the comparison between the new 20" Cinema display and the latest standard for Euroscale Offset printing (ISO 12647-2:2002+). We also included the High End CRT gamut again.

In this simulation the Full Color Outline represents the new 20" Cinema Display, the White Outline shows the gamut of the High End CRT. The colored dots (Color List) stand for the 1485 color patches that we actually used to create the official Euroscale Offset ICC profile.

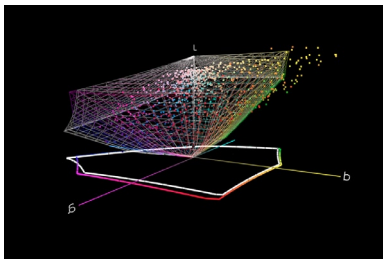
Now we can make a good comparison between all systems. As both displays are calibrated to 5000K (D50), it's clear that LCD and High End CRT have equal color capabilities when working in CMYK.

To double check on that statement, we've used the actual CIE-Lab based measurement file from the Offset profile, and calculated the theoretical number of colorpatches that could be displayed on every display, within a certain Delta-E (color difference) tolerance. As with all Delta-E statements, we've used the CIE94 method to describe color difference.

Euroscale Offset (ISO 12647-2:2002+)		Theoretical Delta-E (CIE94)				
		<=1.00	<=2.00	<=3.00	<=4.00	>4
20" Cinema Display	percentage of total (1485 patches)	31%	93%	95%	97%	3%
	number of patches in range	467	1378	1410	1440	45
23HD Cinema Display	percentage of total (1485 patches)	29%	88%	93%	94%	6%
	number of patches in range	438	1312	1366	1402	83
High End CRT	percentage of total (1485 patches)	32%	92%	95%	96%	4%
	number of patches in range	472	1360	1405	1429	56

Delta-E (CIE94): <=2.00: Good Visual Match, <=3.00: Slight Color Difference, <=4.00: Visible Color Difference, >4: Large Color Difference

Good results on Pantone Solid Coated



To view a complete 3D animation in Quicktime, please visit www.colormanagement.nl

Knowing the display quality for CMYK, the next question will of course be about Pantone simulations. For this test we've used a CIE-Lab based Pantone library to be displayed as color list. Again, we've used the CIE94 method for our Delta-E calculations.

The 3D simulation shows the 1018 Pantone colors from the library in combination with the 20" Cinema display (Full Color Outline).

As we all know, the Pantone Solid Coated library is not based on standard RGB or CMYK systems. The simulation clearly shows, Pantone Solid Coated contains a lot of high saturated colors, which can be pretty far outside the monitors gamut.

The diagram below shows the theoretical results for Pantone simulations.

Pantone Solid Coated		Theoretical Delta-E (CIE94)				
		<=1.00	<=2.00	<=3.00	<=4.00	>4
20" Cinema Display	percentage of total (1485 patches)	37%	81%	86%	89%	11%
	number of patches in range	379	820	871	910	108
23HD Cinema Display	percentage of total (1485 patches)	35%	75%	80%	84%	16%
	number of patches in range	358	763	813	860	158
High End CRT	percentage of total (1485 patches)	38%	77%	82%	86%	14%
	number of patches in range	391	786	834	876	142

Delta-E (CIE94): <=2.00: Good Visual Match, <=3.00: Slight Color Difference, <=4.00: Visible Color Difference, >4: Large Color Difference

Results in detail

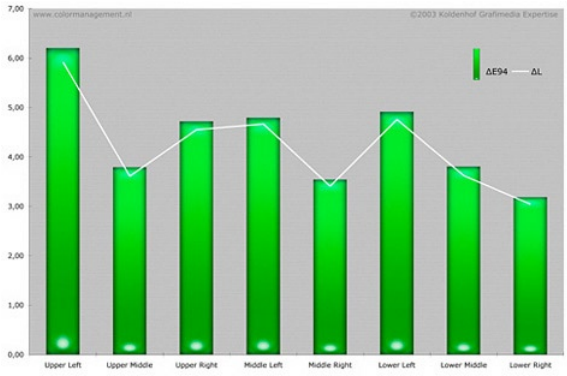
The purity describes the ability to produce consistent color across every region of the display.

Some purity issues.
When you take a closer look to your own display, you notice that there will be slight (or large) differences in color between the center and the outer edges of the screen.

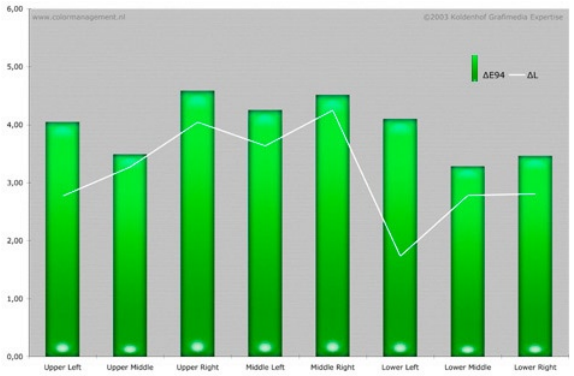
Because of the huge size of the 20 and 23HD Cinema Displays, we've divided the screen into 9 regions: TopLeft, TopMiddle, TopRight, MiddleLeft, Center, MiddelRight, BotttomLeft, BottomCenter, BottomRight.

Next, using the EyeOne and GretagMacbeth MeasureTool 4.1.1, we measured a color target which consists of 99 equally divided color patches, for every region. We then calculated the difference in color (average for the complete target) between the center and the surrounding regions. The result of this test gives us exact information on the purity of the display.
Again, all information is described in Delta-E (CIE94).

In the diagram, we combined two graphs, the Delta-L difference (Luminosity) and the Delta-E (CIE94) color difference. As you can see from this the color differences between regions mostly consist of differences in brightness and not in color.



Purity graph for the 20"



Purity graph for the 23HD

Besides the info from the diagram above, we also prepared some visual simulations for the purity effects.

The images on the left show a theoretical 'optimal' purity, with equal color behavior for all regions.

The images on the right are simulating (as closely as possible) the actual purity effects that we've found on our 20" cinema display.

Results in detail

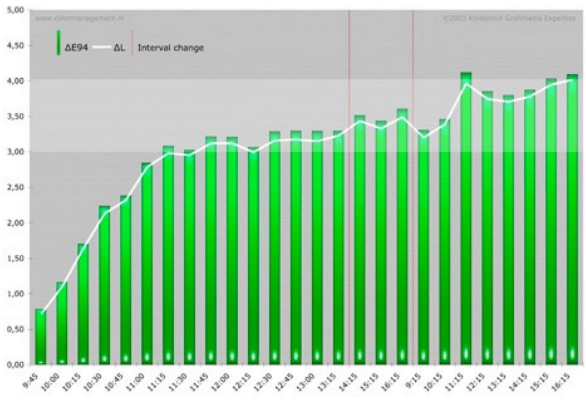
Excellent color consistency after a warm-up period of 90 minutes

Warm-up time.
For this test we measured a color target with 99 color patches, over a period of 36hrs with an interval of 15 minutes to 1 hr.

The color appearance for both displays became more or less stable after a warm-up period of 90 minutes. After that period an average difference between timed measurements was calculated to about 1.00 Delta-E (CIE94) for the 23HD, and 0.50 Delta-E (CIE94) for the 20", which is very good.

We found that the 20" Cinema Display was some more sensitive to temperature changes, but it should be mentioned that the effects cannot be seen with the human eye. During our overnight stability test, temperature in our studio drops from about 21 degrees Celsius to about 18 degrees Celsius. This is what you can see in the graphs as well.

Warm-up graph for the 20"
The 'light gray bar' in the graph represents a color difference of 0.50 Delta-E (CIE94).



Warm-up graph for the 23HD
The 'light gray bar' in the graph represents a color difference of 1.00 Delta-E (CIE94).

Calibrating the Displays

In order to get all colors reproduced on screen as predictable as possible, you need to have an ICC profile for your calibrated display so that your system exactly knows how to reproduce colors.

Why you should calibrate and profile your Display.
When working in RGB or CMYK, you're actually not talking about color perception. The only statement that is made with these color systems, is a percentage of a maximum.

As you probably now, all devices have their own way of dealing with colors. Therefore, when using equal percentages (eg. 50% Cyan) printed on two (or more) devices, you'll face different color perceptions (You can find more info on www.colormanagement.nl).

ColorManagement Systems (like Apple's System Level ColorSync) deal with these different color behaviors by using device specific color profiles to transform color perception from one device to another.

While many manufactures install default factory profiles inside your ColorSync profiles Folder (/Library/ColorSync/Profiles), it's our experience that you will achieve better results when you build your own custom profiles (check out the section on profile quality for this).

In the beginning, profiling solutions were expensive and sometimes difficult to use, but in the past years manufactures developed less expensive and more intuitive solutions for ICC profile creation.

About the EyeOne System.
During this project we used the GretagMacbeth EyeOne System, a complete profiling solution which consists of a photospectral measuring device (the EyeOne) and software tools for calibrating and profiling a variety of devices like scanners, printers, beamers and of course, monitors.

The EyeOne System is a really easy to use, entry level ColorManagement solution, which provides endusers with a set of tools to create ICC profiles for most of their Equipment.

GretagMacbeth has build various functional software solutions around the EyeOne System, suited for almost every purpose.

Together with the EyeOne, GretagMacbeth released a great freeware application, called EyeOne Share. With EyeOne Share you can measure, evaluate, transform, store color information, and maybe most important, share consistent color information with others, using the CXF file format.

Especially for those who want to start working with ICC ColorManagement, the EyeOne System is a good choice.

More information on these specific solutions can be found on www.i1color.com.

Calibrating the Displays

The smart design of the EyeOne Display makes it possible to calibrate both CRT ands LCD displays without the use of special adapters.

The EyeOne Display System.
For our monitor calibration and profiling, we used the new EyeOne Display System. Based on colorimeter technology, the device is capable of calibrating and profiling both LCD and CRT displays.

While you need different adapters in order to use the EyeOne for CRT or LCD displays, the smart design of the EyeOne Display makes it possible to attach the device to both CRT and LCD displays without the use of special adapters.

Another improvement is the new suction cup, which actually consists of many small suction cups, so that the device won't fall of your display as easily as some other devices might do when using one large suction cup.

The smart design of the EyeOne Display device also ensures no damage to the LCD Display (via the suction cups) when you position the device on your monitor.

Display calibration is made even more easy with EyeOne Match 2.0.

EyeOne Match 2.0.
We found that the new software, EyeOne Match 2.0, incorporates many improvements when compared to the previous versions.
The new interface now reacts faster on user interaction, and there are more user definable settings in advanced mode (target Gamma and Whitepoint simulations).

Profiling with both the EyeOne and EyeOne Display system is very easy, as the the EyeOne Match software guides you through the whole process.

There was only one issue with the software. The software chooses the optimal brightness for you. When calibrating displays, we particularly like to have the ability to control display brightness, based on Luminance. This will make it easier to calibrate multiple displays within the same dynamic range and create a setting that makes a closer match to your viewing booth (if you have one of course).

Calibrating the Displays

All color patches that we've used for softproofing, resulted in a color difference between 1.10 and 2.5 Delta-E, which will give you a very close simulation of how colors will actually be printed.

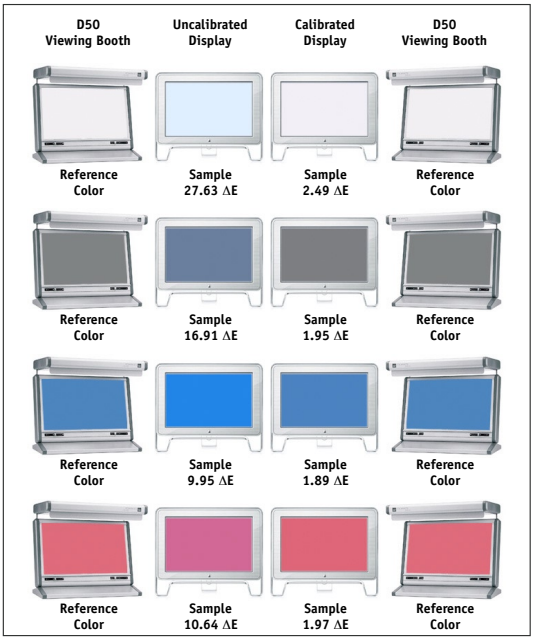
Profile quality.
Because every profile is as good as it's accuracy, we evaluated the quality of the monitor profiles by measuring actual displayed colors from Adobe Photoshop (with softproof function) with our Spectrolino photospectral device.

During calibration, the target setting for Whitepoint simulation was set to 5000K (D50). Using Photoshop, a large white patch was put on screen and measured with the GretagMacbeth Spectrolino.

The whitepoint for the display profiles, which were created with the new EyeOne Display System and EyeOne Match 2.0, verified within 2.42 Delta-E (CIE94) which should give you good results.

Because the Whitepoint check does not tell you everything on profile quality, we setup various CMYK color patches in Adobe Photoshop, and displayed them with softproofing function. We then measured the displayed patches with the Spectrolino again.

All measured color checked within a 1.10 – 2.50 Delta-E (CIE94) color difference.



This really proofs the necessity for good monitor profiles: When using the default system profile, color difference can run up to 27.63 Delta-E (CIE94) between displayed and printed colors!

So, in a conclusion for this, we can state that the use of custom display profiles is really necessary.
The EyeOne Display System will provide good results.

**What's better then to have one calibrated display?
Have two!**

Using multiple calibrated displays and Adobe Photoshop.
Using the Apple DVI to ADC Adapter, two Cinema Displays were connected to one videocard. Because both connected displays have their own ICC profile (which can be selected from the System Preferences: Displays: Color), Adobe Photoshop is capable of showing colormanaged images on all screen at the same time.

The image shows two PPC G4's, both with an 23HD and a 20" Cinema Display connected simultaneously. We calibrated all Displays to 5000K and Gamma 2.2. Luminance was targeted to approx. 100Cd/m2.

All displays measured within 2.5 Delta-E (CIE94) from their target settings
(based on actual measured Whitepoint).

Additional information

HARDWARE USED

Apple PowerMac G4

www.apple.com

Dual 1.25Ghz/2Gb Ram, ATI Radeon9000Pro, 64Mb. MacOS 10.2.4, ColorSync 4.1

Apple 20" and 23HD Cinema Display

www.apple.com

Resolutions: 1680 x 1050 (20"), 1920 x 1200 (23HD)

Apple DVI to ADC adapter

www.apple.com

Used to connect multiple Displays on one VideoCard.

GretagMacbeth Spectrolino

www.gretagmacbeth.com

The Spectrolino was used to double check our measurements with the EyeOne (Display) System.

GretagMacbeth EyeOne and EyeOne Display System

www.i1color.com

The EyeOne was used to perform the Warm-up, Stability and Purity tests. The Displays were calibrated with the new EyeOne Display system.

SOFTWARE USED

GretagMacbeth Measuretool 4.1.1

www.gretagmacbeth.com

Used for Warm-up time, Stability and Purity tests (LCD Reference 2.0 target) in combination with the EyeOne.
Spot color measurement was used to check profile consistency (Spectrolino).

GretagMacbeth Delta-E.xls

www.gretagmacbeth.com

Great Excel sheet which we used to calculate the various color differences.

GretagMacbeth EyeOne Match 2.0

www.i1color.com

Calibration of the Displays.
During the project, the new EyeOne Display System was used with this new version of EyeOne Match.

Logo ColorLab 2.8

www.gretagmacbeth.com

ColorLab's ColorCalculator was used to do CIE-XYZ to CIE-Lab conversions.

Chromix ColorThink 2.01

www.chromix.com

All 3D gamut visuals were made with this appropriate utility.

Praxisoft VectorPro 3.01

www.praxisoft.com

We used VectorPro to calculate the theoretical number of colors (both CMYK process and Pantone Solids) that can accurately be displayed on the Cinema Displays.

INTERNATIONAL STANDARDS

Offset standard

www.eci.org and www.fogra.org

During this project, comparisons were made towards Offset standards (gamut comparisons and calibration results).

We have chosen to work in accordance with the latest proposal for Offset Euroscale (ISO 12647-2:2002+) by ECI (European Color Initiative) and the FOGRA Institute.

Pantone Solid Coated

www.pantone.com

Calculations on the theoretical number of colors that can accurately be reproduced on screen, are based upon the build-in (CIE-Lab based) Pantone Solid Coated library from Praxisoft's VectorPro 3.01.

Delta-E color difference

All color differences are calculated via the CIE94 method.

CIE-XYZ to CIE-Lab calculations

All XYZ to Lab conversions were normalized to Y=100.

Target values for Monitor calibrations

All displays were calibrated with the following target settings:
- Whitepoint: D50 (5000K)
- Gamma: 2.2
- Luminance: 100Cd/m2

Environmental aspects.

All measurements were done at our local research and training facility 'the Studio - the Learning Zone', located at Rijswijk, the Netherlands. We used 'normal' office conditions, which means that the average temperature during daytime was 21 degrees Celsius (during nighttime, temperature drops to about 18 degrees Celsius).

Lighting conditions in the Studio are set to ±4000K, no direct Sunlight was allowed to enter the facility during the tests.

We've chosen this setting for a special reason: We want to make sure that anybody can achieve more or less the same results with the hardware that we did.

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