Whitepaper

Color Management for Demanding Visualization Applications

What is color management and why does it matter?

To answer this, we first need to make sure everyone has the same understanding of what "color" is.

Color is the interplay of light, objects, and vision.

Vision is the perceptual ability to interpret our surrounding environment using light interacting with objects in the environment. Missing any one of these variables means there is no vision, and vision cannot exist without the combination of all three.

Essentially, color is the result of light manipulation either by reflection, transition, or emittance of an object into the path of an observer which create the visual sensation of color.

The Importance of Accurate Color Reproduction

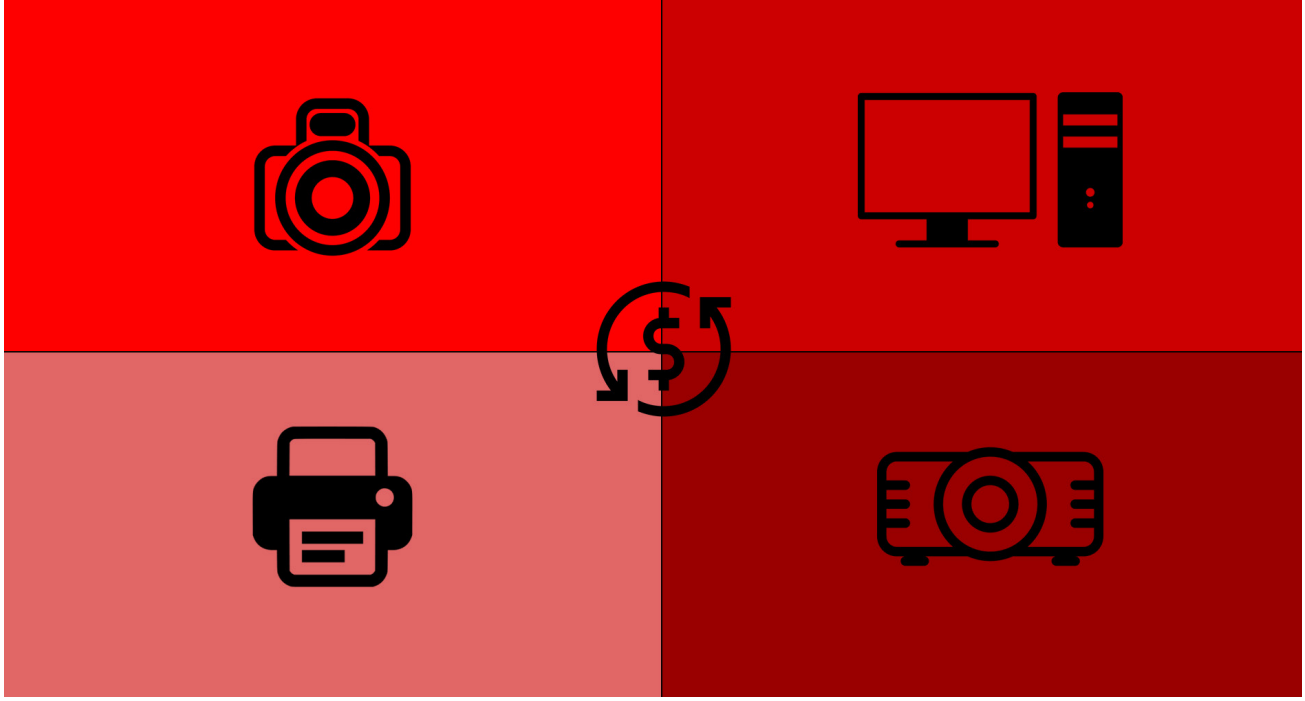
At home, most people are used to a 'set and forget' approach when installing devices like desktop monitors, televisions, and tablets. We trust the manufacturer has set and tested the device to the best quality before shipment.

At most, brightness and/or contrast gets adjusted. All other controls are intimidating. The value of making a discernible difference in image quality is not significant enough to risk making adjustments.

In business, the reproduction of color becomes more important when, for example, trying to evaluate a new design or represent a recognizable brand/logo properly.

Although not every business needs color management, there are organizations, like automotive, fashion, and some retail, where color is critical to branding and product aesthetic. Colors are known to evoke emotion and affect a buyer's impression. Color can alter thinking, change intended actions, and cause reactions. Ensuring color is accurately presented and reproduced to all viewers, from design to sale, becomes very important to perception and understanding. Incorrect color reproduction may negatively influence decision making or brand image.

Even when color is important, only a few people are brave enough or trained enough to adjust the settings on more professional devices like meeting room projectors and monitors.



Quite often, the factory settings are not touched and display devices are used "out of the box."

Thought also has to be given to source and presentation media, like cameras, monitors, printers and projectors and how they capture and share color electronically. This is especially an issue because color is never captured and recreated identically across devices. Even between individual viewers, color is perceived differently. Follow any type of product through its life cycle from an idea to a manufactured product. There are many touch points where color is captured, viewed, shared, and can be adversely altered by an unmanaged system.

The Opportunity to Manage Color Reproduction

Digital color creation and representation can be managed. The color performance of capture devices and the output of screens, projectors, printers, and more can be maximized, standardized, and maintained for consistency. Establishing a good baseline on all devices in-use and proactive maintenance practices can keep colors consistent even through updates and device changes.

Establishing a color management system requires knowledge of the intended color as measured by industry standard levels of red/green/blue (RGB) used in electronic devices and cyan/magenta/yellow/black (CYMK) used in print output.

Color management boils down to two objectives:

1. Define what perceived colors the RGB and CMYK numbers actually represent visually.
2. Keep those colors consistent to obtain the best possible color match and/or conversion between viewing devices over time. By measuring and standardizing the imaging performance of equipment used to create and view content, and configuring our systems consistently to use well-defined workflows, we are able to control how color is reproduced accurately.

Color imaging devices include, but are not limited to:

- Desktop monitors
- Projectors for large scale visualization systems like display-size walls
- Printers
- Meeting room screens and projectors
- PC tablets (iPads, Surface Pros etc.)
- Cameras
- Scanners

When products are being designed and assessments and decisions are required, a wide variety of devices may be involved in the development workflow. The scope and complexity of managing color between devices can start to become apparent.

We should note at this point that color management cannot compensate for:

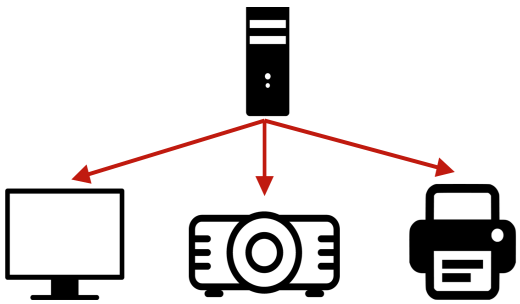
- Bad images or bad content. Color management can't guess what the designer intended. Without knowing the original color intent or access to an embedded profile, any color management system won't know what to compensate for.
- Inconsistent lighting, backgrounds, or drastic differences in viewing conditions. Working environments where color is being assessed should be known and maintained.
- Devices that cannot be repeatedly recalibrated to a predetermined state.
- The set color gamut limitations of a given device. More or new colors can't be created on that device.

Color management, in its current form, will not be able to achieve identical color reproduction. This is primarily due to the fact that color vision is not a fully understood science and therefore all of the workflows and imaging technologies currently used are based on approximations and mathematical algorithms.

Color Management in Digital Workflow

Managing Color in a Closed Loop Workflow

A closed loop workflow is one where there are very few variables. It's often a single source of content and single destination or device. Traditionally this type of workflow was used when content creation and publishing was done on a very small number of devices.

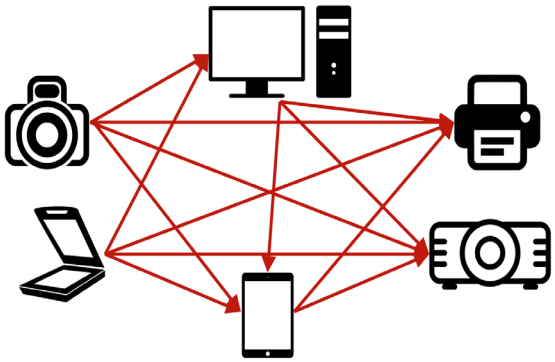


The beauty was that because there were so few variables, you could manage color through trial and error a few times to develop a process to stick to.

Today there are far too many devices and variables that make their way into the content creation workflow, that it becomes impossible to use trial and error to create a process for every single possibility.

Color Management in Open, Modern Workflow

In modern workflows we have many source devices and locations where we can create and retrieve digital imagery. Think about how many types of cameras (DSLR, iPhone, iPad) and scanners we use to capture content and then think about the variety of sources where we can download electronic files (internet, digital render, etc.).



We are also required to work with this content, sharing between multiple users using different screens and computers across different geographic locations.

There are many more destinations where content is viewed and evaluated on than ever before. This is why color management can benefit from the mathematical models that describe color perceptually and translate color accurately between these devices.

Defining an Original Color for Evaluation

First and foremost, when talking about color management, we need to understand how and what we are evaluating our results against. Ideally we need to reproduce the original content creator's intent. However, the original intent needs to be well-defined because it can lead to some very subjective arguments.

Because of gamut size differences between devices, we need to know that getting an identical color match is going to be extremely difficult. Fundamentally, color management is there to reproduce the original to the absolute best of the outputs capabilities.

If we know the original intent, the source gamut of the content or device and the destination gamut of the output medium, we can predict the outcome and there won't be any surprises.

So, what is the "original intent?"

The gamuts are quite trivial to figure out, but without the original intent it will be a struggle. Think about it as a treasure map. The directions may be crystal clear but if you don't know where the starting point is you will end up lost.

So the question becomes, "what is being matched?" Consider, for example, the original picture of a sunset. Is the original the actual picture the camera produced or is the original the sensation of color that you experienced on the day?

Who decides the original? For the most part it's going to be the customer/stakeholder, but expectations need to be set and the output aligned to those expectations. Another example is the logo of a corporate brand. The color of the logo is the original to be matched whether it's a Pantone color or a physical sample supplied. The expectation will be to match the original faithfully.

The "original" can quite easily change through digital and print workflows. This is more of a statement of fact than a negative or positive observation.

Let's say that the photo of the sunset will be published in the morning newspaper. The original was the photograph but the printing press will not recreate all of the colors in the original. The colors need to be manipulated to achieve the look and feel of the original to be produced given the limits of the press. So, for the press operator, the original is the new manipulated file not the photograph.

The fundamental question becomes "what is the starting point?" Is it the original photo, the product sample, or the PDF? What is the intent? Exact match? Relative match? Close enough? Is exact even possible? All of these questions help to form a solution, and it's observable that the closer the customer wants something matched, the higher the cost will be. Setting expectations sooner rather than later is beneficial to control the process and costs.

The 5 C's of Color Management

To improve consistency between different electronic display types as well as printed material, the proper equipment, assessment, and maintenance practices are required.

Consistency can be delivered through Color Management Services based on the 5 C's.

1. ***Color measurement***, including standardization of the tools used for color measures. Tools such as light and color meters used to measure and record the current state of image quality metrics on new or operational devices that present color in some form to users.

The 5 C's of Color Management

1. Color Measurement
2. Calibration and Linearization
3. Characterization
4. Conversion
5. Conformance

An initial calibration of tools and the work enviroment must be achieved. Once a baseline is set, adjustments can be made to achieve desired color values. The tools and environment must be maintained for future color management.

2. ***Calibration and linearization*** of devices, such as displays and printers, used to view and judge color. Calibration is the act of bringing an imaging device to a consistent and reproducible state. This essentially makes mechanical changes to the device using available physical controls. Linearization involves making changes using the devices' software. The software in question is almost always specific for the device and usually provided by the manufacturer. Once a device is physically calibrated to a known state, software will then produce known values that can be adjusted. Every device used to present and assess color will need this full attention.

3. ***Characterizing*** the "gamut" (color input and output capability) of every device using values from the calibration process. Gamut values are compared to international color standards to create a defined profile for each specific device in the workflow. These profiles allow building the connectivity between very different devices, like a monitor and a printer, for the conversion process.

4. ***Conversion*** between color devices. Though devices have different color profiles, they can be programmed and/or recalibrated so the color they reproduce will be consistent with other devices. This requires experienced technicians to make the adjustments to each device necessary for color consistency.

5. ***Conformance***. Over time, equipment will age and/or be updated, which can affect their color profile. In order to maintain devices and profiles over time, a disciplined process is required to track their performance relative to set targets and tolerances. Any changes in the working environment, such as lighting, are also taken into account. Through regular checks and maintenance, color reproduction across devices will continue to conform to desired requirements.

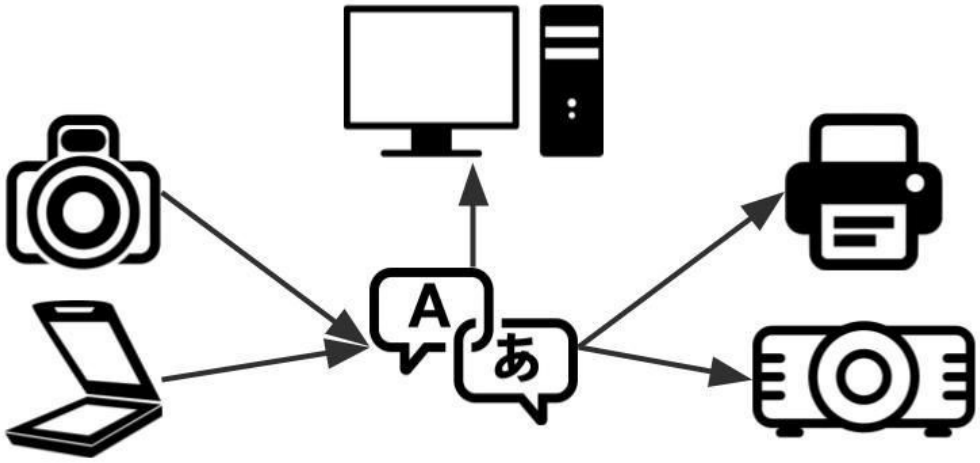
Ways to Alter Color

Gamut compression

Gamut compression is inevitable. The devices we use to capture and create content are far more "color capable" than the devices we use to reproduce content and color.

Therefore, we need ways to move colors around in an attempt to maintain their original intent. Altering color can be done through changes in color characteristics.

Hue is a name we use to characterize color, or the human friendly name we give colors like red, orange, yellow, green, blue, indigo, and violet for example. When moving between gamuts, from a DSLR camera to a Projector for example, the most important characteristic of color we must preserve is the hue. Hue must never be compromised because our eyes are less tolerant to changes in hue.



For example, seeing a rust-colored cola can would look odd because it is not what we expect, or seeing a person with yellow skin tones would make you think they were ill.

Lightness and substrate are keys to defining the details in the shadows and highlights. When moving between gamuts or compressing colors down to the reproduction capabilities of a different device, we don't want to damage the relative difference between highlights and shadows.

Saturation can be described as the colorfulness of a color. Mathematically, fully saturated is the furthest point away from the grey scale (the scale between white and black) a device can produce. If something is described as unsaturated it basically means that it looks more neutral or closer to grey. The eye is more tolerant to saturation loss than it is to hue or lightness because our eyes adjust to light and viewing condition very quickly, and our color memories are not very good. When people view a less saturated image in isolation from a more saturated version of the same image, most would say they were the same until shown side by side.

Gamut compression is automatic with rendering intent which we will get into more detail later.

Evaluating Differences in Color

Visual Evaluation (same image, different outputs side-by-side)

Evaluating differences in color can be done when looking at the same image on two different viewing devices (electronic and/or physical, such as a printed picture). First, focus on the balance of greys in the images.

If there is grey in the file under proper lighting conditions, look at the color of the substrate, moving from highlighted areas to shadowed areas.

Then, look for tonality. Loss of tonality will show as missing or defocused areas in the highlights and shadows. Examine details in the image to determine if any are lost. Note that when reviewing print output, the quality of paper plays a large part in preserving tonality.

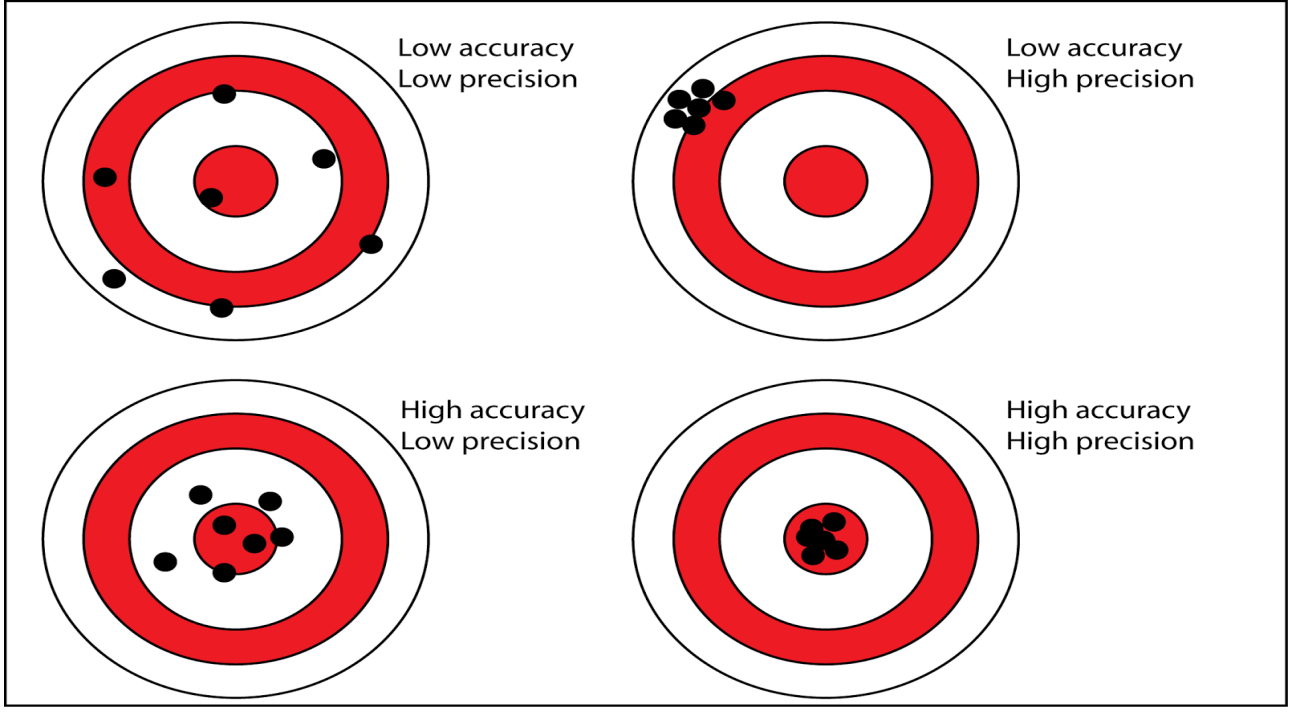
Quantifiable Evaluation

Using measurement tools, the differences between color in the same image on different devices can be measured as "Delta E."

Image colors can be measured and plotted in the CIE LAB colorspace. The difference between the plotted numbers can then be calculated. The closer the numbers (smaller delta), the smaller the number and smaller the perceptual difference. The further away (the bigger the number), the bigger perceptual difference. How small the Delta E needs to be will depend upon the use cases for the images.

- 1: Extremely Close (Textiles, Automotive paints etc)
- 2-3: Very Close
- 3-6: Reasonable
    - Fair Color match

Quantifying the color difference between two samples allows us to describe the real difference between colors and avoid the subjective adjectives that are typically used, "Too Red", "not bright enough" etc.



Reasons for Quantifying Color Differences

Given the many ways the human eye can be fooled, we need to distinguish between what looks good and what looks accurate. The following are the influences on the eyes perception of color:

- Accurate lighting conditions: Consistent lighting is critical for ongoing evaluation of color in the same work setting.
- Consistent observer: If evaluation of color is critical, the same person/people should review. Constantly changing who reviews will affect results.
- Retinal Fatigue: Viewers can experience 'after images' when viewing for long periods. Rest to let eyes recover.
- The Background Effect: Always be aware of what is in your field of view. In a perfect world have a neutral background. This is not usually the case when working with color.
- Color Memory: Our color memory is quite poor from session to session.
- Color Deficiency:1 in 12 males suffer from a red green "color blindness" whereas only 1 in 250 females experience this. As we age, our color perception changes.
- Experience: The more people look at color critically, the better they become at judging it.

Creating a Universal Color Translator

We need color management, and use profile connection spaces, defined by The International Color Consortium (ICC) so that devices can talk to each other. Formed in 1956, the ICC established a standardized, cross platform file format enabling matching colors between applications and operating systems.

Essentially, devices can be made to 'talk' with one another through a universal translator. But this can occur only after skilled measurement and profile building practices mentioned previously. Further, a disciplined management process must be developed to monitor and proactively maintain devices to ensure color integrity.

Low A and Low P

Low A and High P

High A and Low P

High A and High P (this is our goal for the color management system)

Precision/Repeatability-using the correct color measuring devices, proper calibration of devices and instruments for repeatability purposes.

Accuracy means to match to a defined condition which will depend on proper characterization and proper ICC profiles to do correct conversions between devices.

Maintaining Color Through Conformance

Conformance will verify if everything is working, verify that elements of Precision are working and that elements of Color Accuracy are working within our specifications.

If any of the first 4 Cs aren't working properly, color conformance will fail. We need to make sure lighting is correct for viewing color. Instruments must continue to perform correctly, though this can only be achieved after understanding the full capabilities of the imaging devices, and monitoring any variances over time. Once baselines and desire conditions are established for all elements of the workflow, then a process can be developed to regularly monitor baselines and desired conditions.. How often devices are re-calibrated depends on tolerance and on the device's capability to remain stable over time. A good process will document the conditions over time to allow identification of unplanned variances in any condition or device, including the addition of new/upgraded devices and any upgrades to device firmware.

Color Management Conclusions

While not all business users require accurate and repeatable reproduction of colors across devices, there are a number of applications for which color is an important factor in development and/or presentation. For those critical applications, colors can be defined, matched throughout digital workflow, and maintained.

A disciplined process performed by knowledgeable technicians is required, but finding the required skillset could be difficult.

The time required to manage color has to be evaluated as a full-time or part-time task. Full-time may warrant recruitment of a skilled technician. Where head count can't be increased or where management is considered a part-time task, outsourcing of color management is a possibility. The capabilities of the outsourced partners should be evaluated against knowledge and criteria that go into even more detail than presented in this article.

About Mechdyne

Mechdyne is one of the world's leading providers of innovative visual information technologies. Mechdyne bends technology to our will in ways that transform complex data into insights and ideas. To ensure our customers succeed, Mechdyne provides comprehensive, customized solutions that include consulting, software, technical services, and hardware integration.