TECHNICAL GUIDE

COLOUR MANAGEMENT AND REPRODUCTION

Second Edition

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Introduction to colour management and reproduction

Colour management is fundamental to process control and automation in media workflows. Whether your data is destined for viewing on a monitor or for print produced using different printing methods, colour management shapes margins and profits. With every advance in inks, substrates and printing processes, colour management becomes more vital for your productivity and your ability to serve customers.

Colour and its management are impossible to explain without resorting to a little bit of physics. If physics, even in small doses isn't quite your thing, check out the box for a more visceral explanation of the nature of colour.

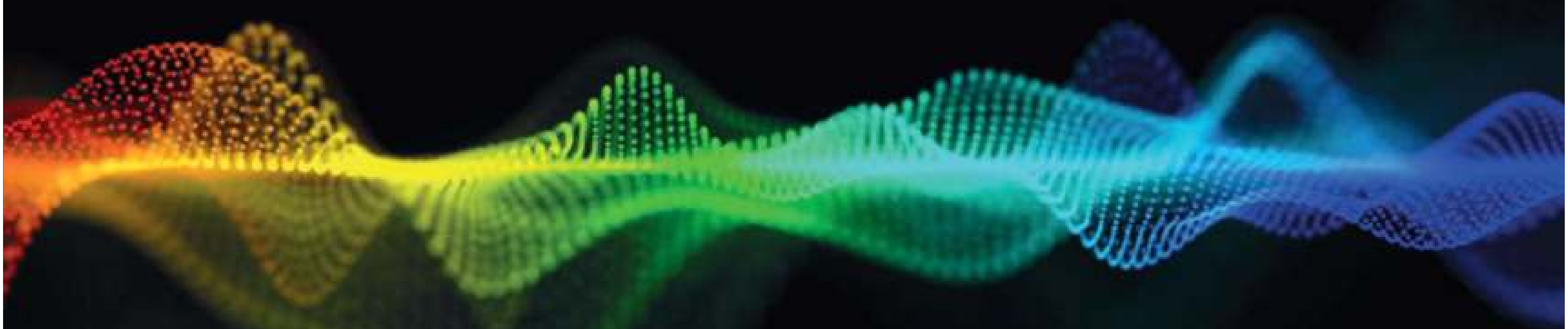
If you want to channel your inner Einstein, skip the box and read on.

AN ALTERNATIVE WAY TO UNDERSTAND THE NATURE OF COLOUR

It is dark. You are standing deep in an impenetrable forest and the sky overhead is densely overcast. You cannot see anything through the darkness, not the clouds or the branches or the tall trees, not even shadows. The dark is so absolute that when you raise your hand to your wide open eyes, it is as if your hand isn't there at all.

You can only imagine what the world around you looks like. Scary? Well this is the world without light, the world without colour, the world unreal and unknowable.

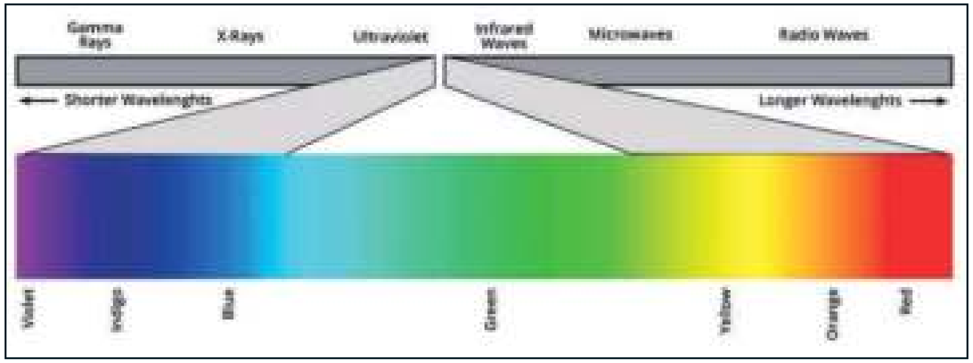
Add light to the scene and everything changes. With light you can see the trees, the shadows, the shapes of the clouds in the sky, because with light there is colour. This is why managing and controlling light is so very important for printers and for the success of their customers' jobs. In a darkened forest, the gradual addition of light reveals more and more colours as the light increases. This is the nature of colour and it is why its management has traditionally been highly subjective.



Colour is all about light, and how we perceive it depends on the interplay of light and texture. Colour is a function of how a surface absorbs and reflects lightwaves. Add ink or varnish to that surface and its characteristics change, and so will its colour appearance.

Radiated light from a light source such as the sun or the moon or a light bulb, exists as electromagnetic radiation, and is expressed as light. The human eye can only perceive the wavelengths of light that occur in the visible spectrum, the wavelengths ranging from about 380nm to 720nm. Under normal daylight we see this spectrum as a range of colours starting with dark violet, then blue, green, yellow, orange and ending with dark red. But what appear to be the same colours could look different, depending on the lighting.

This means that unless the light is right, colour appearance in print production could vary and may not look as expected by the designer or print specifier. Not having a consistent lighting model is very risky for doing colour proofing and managing print approvals across multiple locations, print processes and viewing environments.



The visible spectrum is located in a narrow section of the total electromagnetic field of radiation.

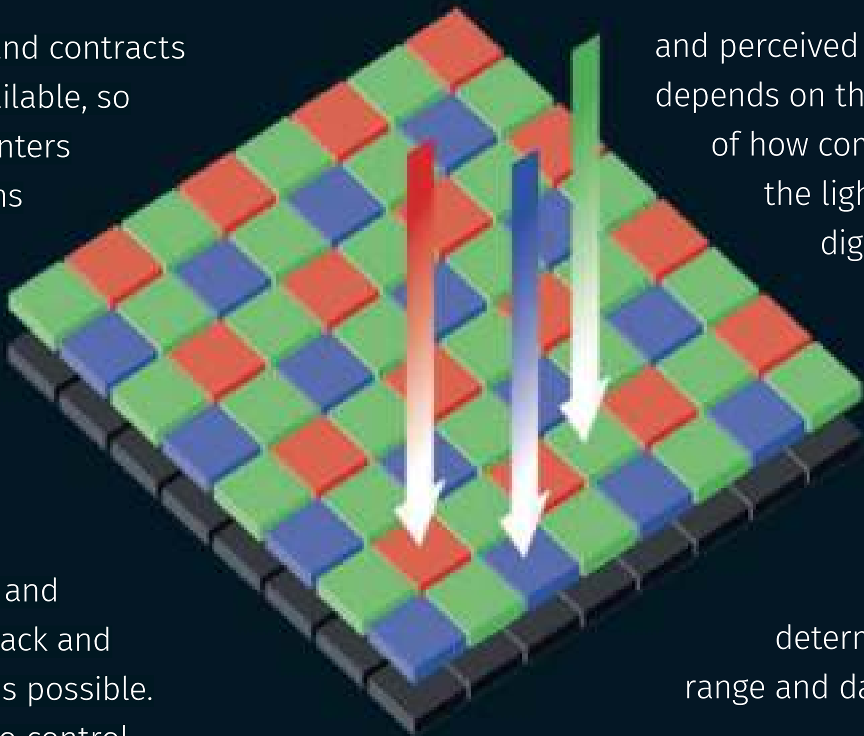
Light and the eye

When light enters the eye, dedicated photoreceptor cells at the back of the retina capture information about the light which the brain then analyses. The brain's interpretation of this data is the basis for how we differentiate colours. We use this information to make distinctions between surfaces in the physical world, assessing surface characteristics based on our colour interpretations. Colours help us to understand what we see, according to an evaluation of how much light the surfaces absorb and transmit. Colours only really exist in our brains: they are just light, transmission and interpretation. This is why colour is so tricky to reproduce accurately and consistently in print.

When all the available light is absorbed our eye perceives darkness, when all the red, green and blue light is reflected there is no differentiation of colours so we see white, the sum of all red, green and blue wavelengths. This is why RGB systems are called additive colour systems. They are the opposite of the system printers use to create colour on a substrate, the subtractive Cyan, Magenta, Yellow, Black (CMYK) model where light hits the surface but is also reflected back by that surface. By laying down these subtractive colours the RGB light is filtered out, and the brain is duped into seeing what it thinks is RGB colour. Thus printing transforms RGB data into a printed reality, mimicking the appearance of the natural world.

The eye as camera

The iris in the human eye expands and contracts according to the amount of light available, so that it can control how much light enters the eye. Contraction of the iris means less light enters the eye and expanding the iris increases the amount. The aperture on a camera follows the same principle. If there isn't much light around, a wide aperture allows you to use as much of it as possible to stimulate the red, green and blue sensors in the digital camera back and to capture the scene as accurately as possible. The iris does much the same thing to control the amount of light hitting the cone cells on the retina, which respond to red, green and blue wavelengths of light. The intensity and perceived character of this tristimulus response depends on the composition of the light, regardless of how complex it is. The human eye responds to the light as a continuum of information. But a digital camera or scanner samples points in the image as a discrete series of binary data. This is why the more elements a CCD or CMOS sensor has, the higher the pixel sampling rate. The sensor is the electronic equivalent of photographic film. In a digital camera it mimics the eye's functions, determining image size, depth of field, dynamic range and data capture when there isn't much light.

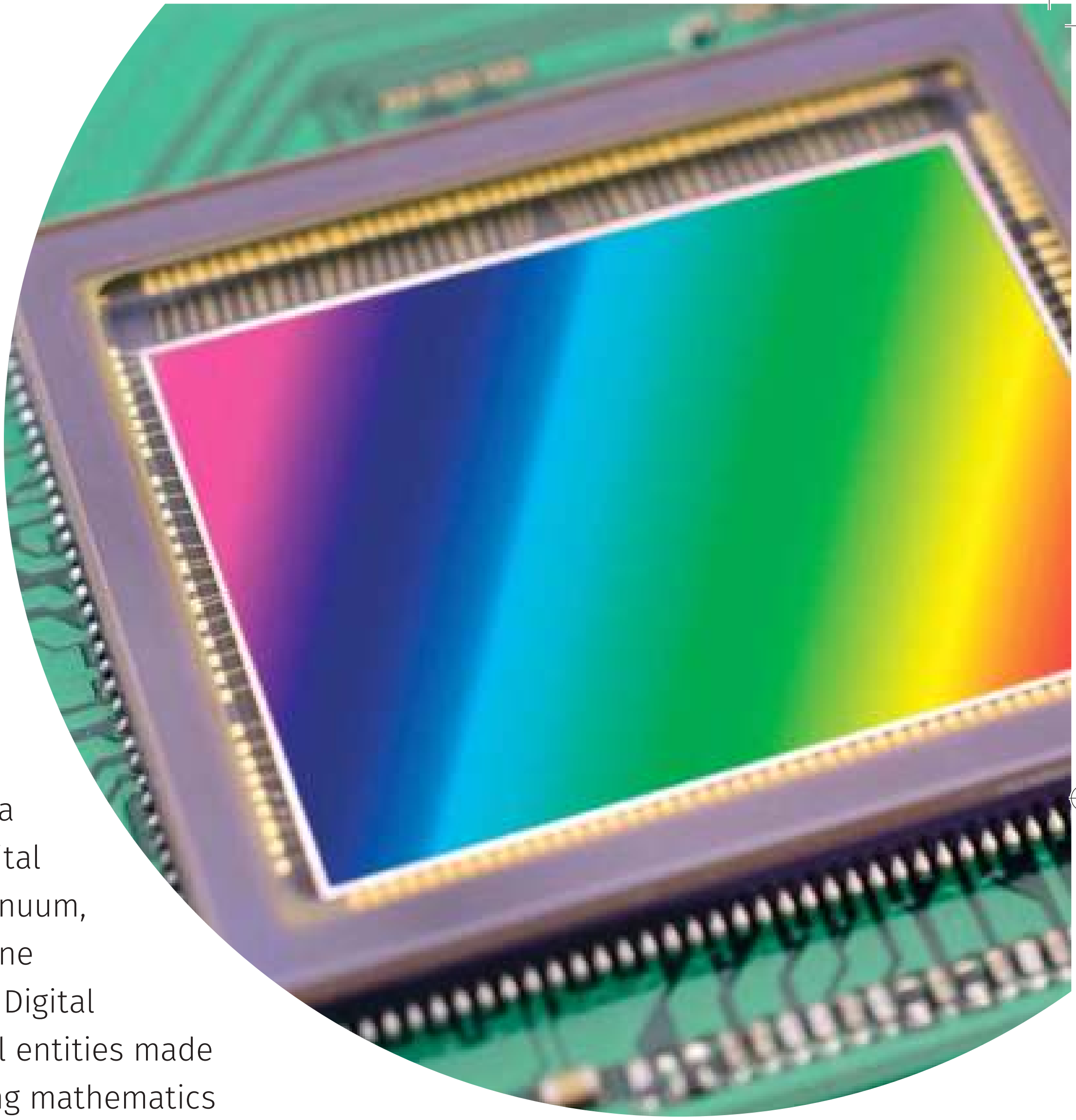


To digitise an image, a sensor such as a CCD or CMOS chip filters the RGB signals. Here a filter pattern called a Bayer filter.

A digital image sensor converts the image that you see into an electronic signal. Digital cameras and scanners rely on sensors to convert light into a digital image.

Managing colour information

Appreciating how light and perception determine colour appearance in our heads shapes our understanding of how to manage colour data in a print production workflow. Workflow automation depends on data management, manipulation and control. Understanding colour behaviour and how surface structure and light interact is key to understanding why colour appearance can differ and how it can be controlled. This is particularly important when print data files are output across a range of substrates and using a range of production methods, such as screen and digital printing. The colour we perceive is analogue, a continuum, a gradual phasing of shades and tones that combine to make up a scene's overall colour appearance. Digital production systems describe colours as logical entities made up of binary data, that is bits and bytes. Using mathematics to define colours makes it possible to have absolute commonality between the colours. The colours we think we see and the colours a computer thinks we will see on screen and when they appear in print, can be numerically defined.



The sensor in a digital camera captures the whole visible spectrum at a resolution limited by the size and quality of the CCD or CMOS.

Printed colour

Printers use cyan, magenta and yellow, complemented with black ink as their basic inkset. Using these primary colours as printing inks is quite literally a trick of the light. It relies on the principles of subtractive rather than the red, green and blue of an additive system. Combining cyan and magenta primaries produces blue, a secondary colour in the subtractive colour model. The combination of magenta and yellow primaries produces red, and yellow and cyan produces green. Mixing all three in theory produces black.

Printing inks can appear to produce the same colours as the eye perceives in the red, green and blue world. They exploit the behaviour of light as it is reflected and absorbed by a surface printed with cyan, magenta and yellow (CMY) inks. The inks work like filters to create an illusion of colours that appear to mimic in print the red, green and blue world we see all around us. In the same way that the sum of red, green and blue light presents as white, in the subtractive CMY system the sum of all three should appear black.

However CMY inks are rarely pure enough to absorb all available light, so printers add black in order to enhance contrast and ensure really deep, rich blacks and sharp black text. This is why black is called the key (K) colour in the CMYK process ink set. Nonprimary colours such as light magenta and light cyan, greys, or orange, green and violet can sometimes be added. This enhanced gamut printing adds to process complexity, so a more usual approach to expanding the gamut of CMYK is to use specially blended inks with a specific colour, generally referred to as spot colour inks. The Pantone system for specifying and matching colours is the industry's standard reference for spot colours but there are other manufacturers as well.

Rainbows

In theory there should be no limit to the range of colours that can be printed, however the range depends very much on the precision of the print process and the interaction of inks, coatings and substrates. A designer's colour and substrate choices, how data is managed in the workflow, prepress decisions over screening, trapping and platemaking, and the press itself will all influence colour appearance. The human eye can distinguish over ten million colours, but the range of colours that can be printed with CMYK inks is around 400,000 for most offset printing processes. Screen printing by the nature of its process allows considerable flexibility in colour gamut depending on the substrate, and wide format digital printing can sometimes manage over 600,000 colours, depending on the combination of technology, inks and substrate.

Colour spaces

Whether it is the human visual system, a digital camera or a computer monitor, all RGB systems have a finite range of colours that can be expressed. And the same applies for CMYK systems, regardless of the method used to print the colour. The colours in all cases can be mathematically defined in a three dimensional reference colour space. Colour management for print output is the management of colour data from colour space to colour space, ideally ensuring that wherever colours appear – in reality, on your computer monitor or in print – they look as much the same as possible. Colour spaces share many colours in common, however at their boundaries they will differ. If you produce work for big brands it is imperative that their brand colours retain colour integrity, wherever they appear, be that on shelf hangers and leaflets, through to billboards and textiles. If the required brand colour is near the periphery of a colour space, be especially careful in how you handle the data.

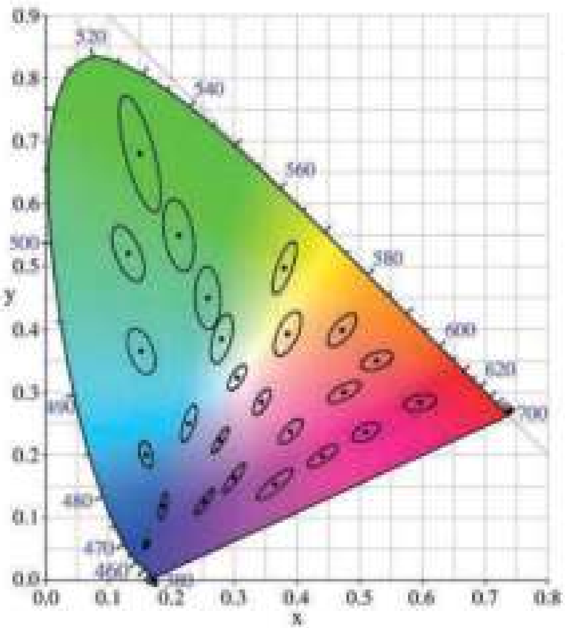
Colour spaces are abstract, mathematically defined models of colours. The RGB space, for instance, is an additive colour space that represents

the colours that could result from all possible combinations of the red, green and blue additive primaries. All RGB spaces must include a gamma correction curve for coding and decoding tristimulus values, and the coordinates within the space that define white. The most common RGB space is probably sRGB which is the default standard for web publishing. For high end photography Adobe RGB is larger and generally preferred. CMYK colour spaces are subtractive spaces that represent all colours possible by combining cyan, magenta, yellow and black. There is no standard CMYK colour space, so be careful to ensure that the CMYK colour space you work with is correctly defined. If you print the same job on several different presses, you are likely to be making colour conversions between multiple CMYK colour spaces.

Understanding that colour spaces define different collections of colours is vital for colour management, and especially for designers and content creators. RGB and CMYK spaces are not the same shapes and they describe different colour sets. It is also vital to understand that they are only models and on their own they are more or less arbitrary. In order to be useful for print production a reference colour space is required, a colour space to which colour values can be compared.

Delta blues

To measure colour difference quantitatively we use Delta E (ΔE), a formula for calculating colour values. The E stands for “Emfindung”, German for sensation and a ΔE value is a single figure that expresses the distance between two colours in a colour space. It is determined by calculating the Euclydian distance, that is the shortest straightline difference, between two points.



CIE XYZ 1931 McAdam diagram showing tolerance ranges for different colours.

As we can see the CIE XYZ colour space is not uniform, which means that the same actual value for ΔE visually represents a larger area in the green section than for example in the blue or violet areas. That’s why CIE Lab formula was developed.

A ΔE of one or less is considered to be undetectable to the human eye, whereas, ΔE values of two to four are just noticeable. Colour differences of ΔE five and above are extremely easy for people with normal colour discrimination to detect. Around ΔE10 and above and you get the impression that it's actually no longer the same colour, because it doesn't match at all.

There are several versions of the ΔE formula still used in the market, so it is important to make sure your production workflow uses your preferred ΔE reference consistently, and that your customers know which one to work with.

RGB colour distance

$$\text{distance}^2 = (R_2 - R_1)^2 + (G_2 - G_1)^2 + (B_2 - B_1)^2$$

Distance calculation for RGB colours. This is a very simple equation showing how it is possible to calculate the distance between different colours. However it lacks precision and accuracy and is rarely used in the market. Far more common and far more complex is the Delta E calculation.

Delta E formula

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

The classic 1976 formula calculates the colour difference between two samples in a fairly straightforward way. The colour encoding is in the CIE Lab colour space. Other formulas such as ΔE00 are more complex.

For many years the most widely used version was ΔE_{76} (Delta E 1976) however with the 2016 revision ISO 12647-7 ΔE_{00} (Delta E 2000) is more widely preferred. ΔE_{00} varies the luminance values depending on the actual colour itself and gives a more mathematically accurate value. It also aligns better with how humans perceive colour differences. ΔE_{76} and ΔE_{00} are both calculated from the same base set of values, but express the perceived colour difference using different scales. Depending on the measured colour, a colour difference expressed in ΔE_{76} is roughly twice that of ΔE_{00}. A tolerance expressed as ΔE_{76} needs to be half the value expressed in ΔE_{00} to be comparable.

Whether you work with ΔE_{76} or ΔE_{00} most important of all is to use a properly calibrated spectrophotometer and to be able to correctly interpret the results. This is especially key if you are moving colour data across different colour spaces. The most common reference colour space in the graphic arts industry and the one from which colours are calculated is CIELab, a three dimensional space defined by the International Commission for Illumination (CIE).

CIELab

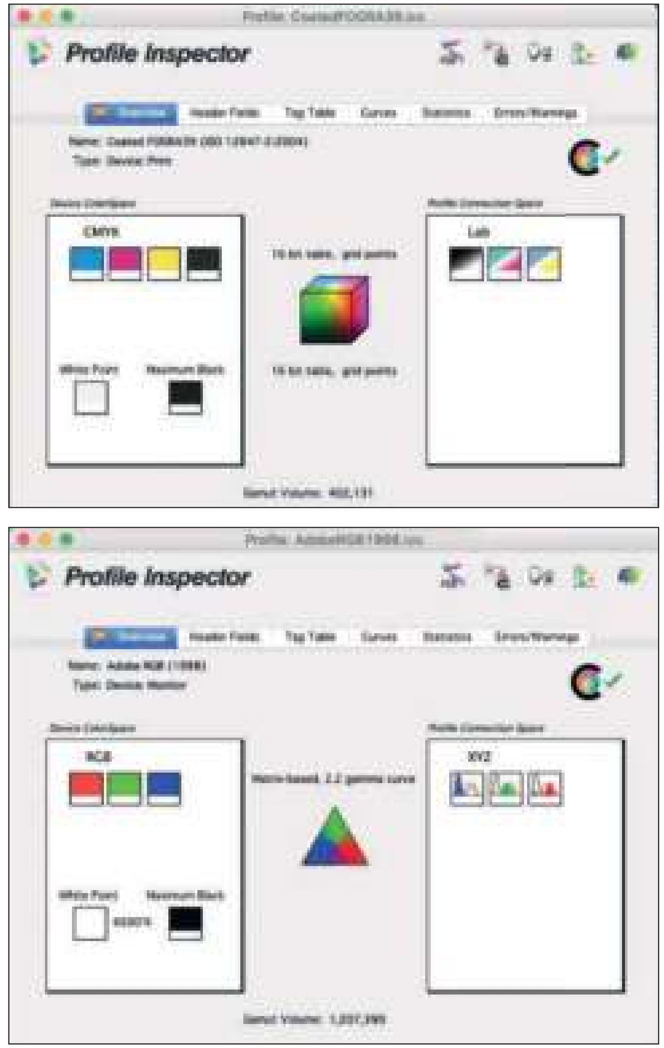
The CIELab colour space represents the entire spectrum of colours, even those beyond what most humans can perceive, using a standard illuminant such as D50 or D65 (daylight). In CIELab, colours are mathematically defined using three values. These are how light the colours are, from absolute black at 0 to complete illumination which is 100, and their a and b values. The a value indicates red to greenness and b yellow to blueness. The International Color Consortium (ICC) colour management model, which is the industry standard in the graphic arts, uses mainly the CIELab colour space as its reference colour space, calling it the ICC Profile Connection Space (PCS).

The International Color Consortium and profiles

In 1993 a group of eight leading manufacturers in the graphic arts industry, Adobe, Agfa Apple, Kodak, Microsoft, Silicon Graphics, Sun Microsystems and Taligen, established the International Color Consortium. They wanted to encourage open colour management, through the development of common colour descriptor technologies that all hardware and software manufacturers could use. Together they created a system based on human colour perception and CIELab, introducing the concept of a PCS that works in conjunction with ICC profiles. Today the ICC has over fifty members in addition to its founders and ICC profiles are the standard for sharing characterisation data for colour input devices, output devices or colour spaces. The reference standard is ISO 15076 (Image technology colour management -- Architecture, profile format and data structure) and it is widely cited in other ISO standards.

Using ICC device profiles simplifies the translation and sharing of colour information for images and files created on different devices and using different softwares. Operating systems suppliers and colour management professionals fully support the specification, helping with colour management and making colour accuracy more predictable and reliable. Taking the mystery and complexity out of colour management has encouraged much wider use of colour in print and a healthy growth in colour applications and technologies.

Using ICC profiles (characterisation data) embedded in images and PDFs across systems is now commonplace, and ICC characterisation data is regularly assigned to images and PDFs to ensure that they have the correct CIELab values. ICC profiles are also used to define the characteristics of hardware and how colours can be expected to appear. Device calibration and characterisation makes sure that colour managed workflows can be automated for optimal performance, cutting colour errors and ensuring high quality prints, even across printing methods.



Overview of Adobe RGB and Fogra39 profile, with gamut volume showing number of printable colours in ColorThink Pro.

Version 4.0 of the ICC specification was published as ISO 15076 in 2005 and most profiling software developers have adopted the standard. It is the foundation of all professional colour management systems, however the ICC introduced ICC version 5 also known as iccMAX in 2016. ISO 20677 (Image technology colour management -- Extensions to architecture, profile format and data structure) was published in 2019, however market uptake of this standard has been relatively limited. The jury is still out on its usefulness primarily because of the difficulties of implementing it in mixed workflows.

iccMAX extends the existing ICC architecture to also define the structural and operational requirements for writing and reading ICC profiles. It introduces the concept of an Interoperability Conformance Specification (ICS) to specify additional workflow requirements and limitations. iccMAX also goes beyond D50 colorimetry which is easy to define mathematically and assumes a light source with a spectral power distribution equivalent to daylight. However D50 does not provide as much flexibility as a spectral colour model, so iccMAX provides more illuminant flexibility, which is increasingly of interest in packaging and other applications with different light conditions. iccMAX supports colour references made using raw spectral data, rather than data converted to CIELab to improve support for communicating spectral values through an optional spectral PCS. Spectral values allow for colour calculations using difference light sources, different ink sets and for different observers, and are based on physical models. This makes it possible to predict how materials interact, so spot colours can be more accurately simulated. iccMAX also supports the Colour eXchange Format (CxF), a relatively new format specifically designed for colour data exchange. The format originated with X-Rite however it is now an ISO standard.

Colour eXchange Format (CxF)

ISO 17972 (Graphic technology – Colour data exchange format) is an exchange format for process control data and colour, including metadata associated with the file to aid its interpretation. CxF is an XML application used to support data exchange within and beyond graphic arts workflows. ISO 17972 has numerous parts customised for different workflows, to facilitate process automation in colour management. The data can also be shared beyond graphic arts workflows, making CxF is a useful format for communicating colour data for different applications such as backlit displays or textile printing. CxF characterisation data provides a means of converting colours for different print conditions to simulate the intent, however a CxF file is not a device profile.

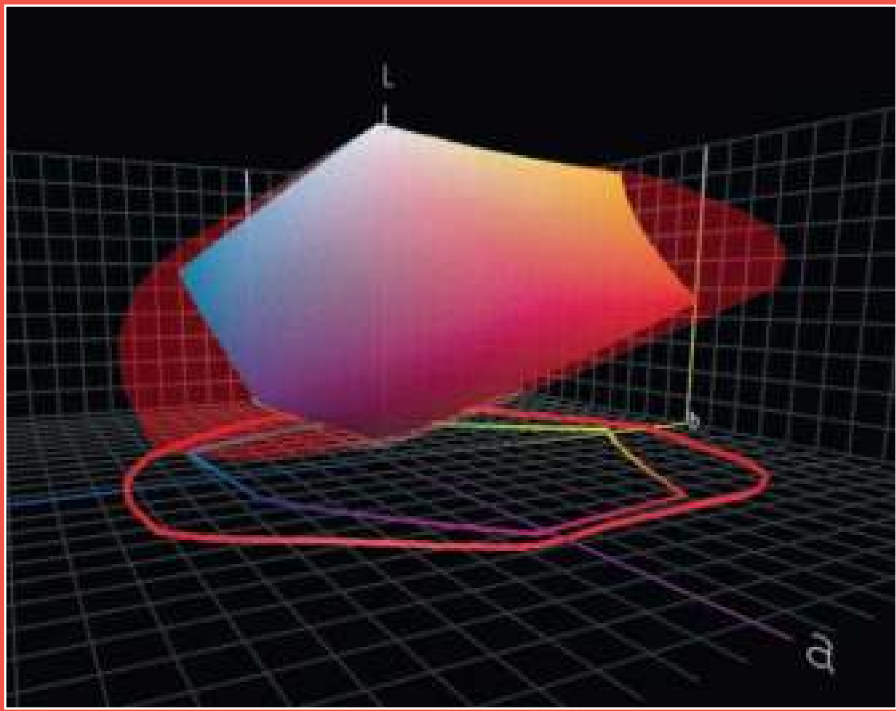
Working with device profiles

Colour managed workflows use ICC profiles and the PCS for colour transforms and communicating colour data accurately in the workflow. The ICC device profile is a bridge between colour characterisation data

The ICC's Profile Connection Space (PCS)

and the PCS. Calculations in the PCS ensure that outbound colour transforms and subsequent input data are accurate as the data file moves through the workflow, from monitor to monitor across a local area network or via remote locations. Profiles must be accurately computed, particularly in distributed production environments, because they provide instructions for colour description calculations. The accuracy of these transforms determines colour appearance on screen, proofs or final output.

Profiles contain tables and the mathematics for colour value conversions. An input data transformation renders colours to the PCS, and an output transformation applies gamut mapping, re-rendering and separation for the colours. Devices are characterised by measuring how they behave relative to a set of reference colours, using reference measurement charts such as the IT8 and ECI charts. These have multiple colour patches specifying cyan, magenta, yellow and black in different percentages and are measured with a spectrophotometer. The values are stored in the device profiles which also provide the native values for the device that will reproduce the desired CIELab colour. Obviously the more patches are measured, the better the device profiles. A Colour Management Module (CMM), either in a computer's operating system or as part of a dedicated colour management system, performs colour calculations using information the device profile provides. It sounds simple but in most colour production involves numerous people and devices which inevitably complicates matters.



Example of Fogra 39 CMYK gamut volume within Adobe RGB (1998) gamut

Managing all processes from design through to proofing and final output and installation, requires control of diverse workflows and of the system as a whole.

Controlling the workflow

Colour management is all about control and process automation. Colour print professionals manage every aspect of their workflows, to deliver high quality colour to customers consistently and without a second thought. High error rates on colour work, disappointed customers or suboptimal colour output on a newly installed wide format digital press are not things you should live with or try to work around. Manage colour data processing in the workflow and these expensive problems, plus others will disappear.

To do this, audit the production department and take stock of all production equipment, software and processes. Describe step by step what happens to files when they arrive in your factory and how long each step takes.

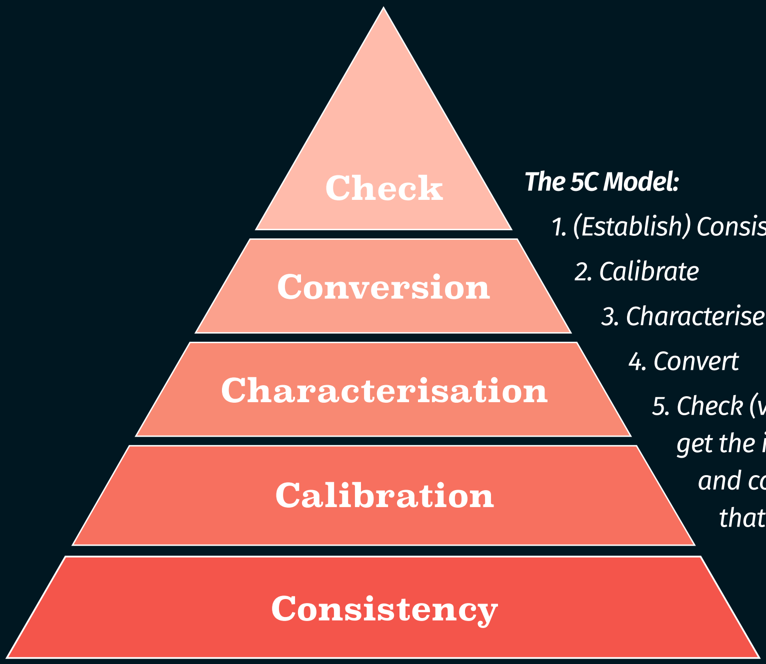
What costs does each step incur? Consider if any equipment or software is out of date and list anything in need of upgrading or that is underutilised such as Raster Image Processors (RIPs). Look at how customers prepare their PDFs and any additional processes they apply, such as screening and find out why. Plan to invest in software upgrades and training and in kit that works in your environment. Don't forget the viewing booth, because without the correct light environment, colour appearance will be inconsistent.

The five Cs

Once you are confident about what happens to colour data in your workflow, apply the five Cs of colour management. The first step is to check the **Consistency** of the device, followed by **Calibration**, **Characterisation**, **Conversion** and **Checking**. The five Cs apply throughout the workflow, starting with monitors used to view colour files, and including customers and agencies. ISO 12646 (Displays for colour proofing) covers how to set up and manage monitors, but output devices are a little more complex to colour manage.

Consistency is about establishing processes and sticking to them. The production environment should be suitable for the device, and all parameters required for stable and predictable device behaviour should be identified.

Output device characterisation first requires device linearisation and calibration. If you specify a 40% cyan tint for instance, the output device should print that. You then characterise the device by measuring output for different paper types, optimising the screen settings, ink amount and black generation for each one. This is the next step where ICC profiles are created. This is required for all output device and substrate combinations in the workflow, and for digital cameras and scanners if used. Use standard test forms and ICC profile creation software and remember the substrate is the single most powerful influence on colour appearance.



The 5C Model:

1. (Establish) Consistency
2. Calibrate
3. Characterise (build ICC-profiles)
4. Convert
5. Check (validate) that you get the image quality and colour accuracy that you expected

Calibration is just one of the five major steps to ensure that a device can be colour managed in an accurate and reliable way.

The fourth step is conversion, using the device profiles in different scenarios. This part of the colour management process is where most colour howlers happen, particularly if you are moving data defined in an RGB space, for instance a softproofing system, into a CMYK space. Errors can also get introduced moving from one CMYK space to another, say between different wide format digital presses.

The fifth and final step is to check to make sure that you have completed the previous steps correctly. Only then can you be confident that your colour management processes are robust and colour production consistent and of the highest possible quality.

Digital technology in the graphic arts allows us to quantify information that is otherwise very difficult to define. Colour is an analogue phenomenon, subjective and changeable, a function of light. Binary systems make it possible to define colours numerically so that they can be accurately processed for printing. As a result the cost of colour print has fallen dramatically, expanding the market, the design community and applications, especially for short run printing.

New ways of using colour in print come up almost daily, because we know how to digitise colour and how to manage it. It isn't always easy, but it's entirely possible and it can be very profitable.

A tonal value increase test strip can be used to confirm that a device is fully calibrated.

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