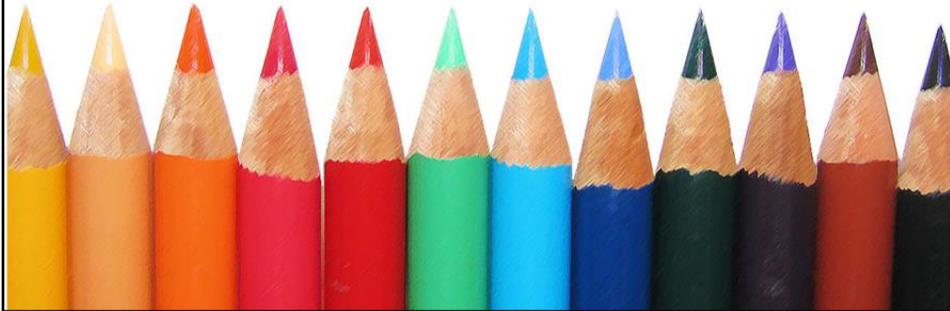


Colour Management in Photography

Simon Garrett

February 2014



Notes from a talk given to Framlingham Camera Club, February 2014.

When viewing as a PDF on a computer, it's easier to follow if you choose the option (or zoom) to fit one full page to the window.

Colour Management

- What is colour management, and why do we need it?
- How to do it
- Best practices and tips
- *Copies of slides and cheat-sheet on the web at <http://www.simongarrett.co.uk/>*



Colour management: getting the right colours on different devices (monitors, printers etc).

Articles on colour management often concentrate on how to do it, and become a series of cook-book instructions. This can often read like black magic unless you know why you're doing it.

This talk will concentrate more on “why” than “how”. Why it's a problem, and then how to deal with it. And what can happen if you don't!

Two Options

1. If you use any colour space other than sRGB, or if you have a wide-gamut monitor...
 - Then you need to use colour management
 - And it really helps to know something about it!
 2. Don't use colour management
 - Stick to sRGB. Don't worry about colour spaces, colour management...
 - ...set every option in your camera and software to sRGB, all the time.
- You will generally get more consistent results with colour management.



Easy option: if you don't want to use colour management, set everything to sRGB. That works, sort of, most of the time.

If you use any colour space other than sRGB, or you use a wide-gamut monitor (or any monitor that has colour space not close to sRGB), or you want the best, most consistent results – then you need colour management. And it really helps to understand what's going on.

I would recommend any serious photographer considers using colour management. The cost is £100-120 for a middle-of-the-road colorimeter.

Colour

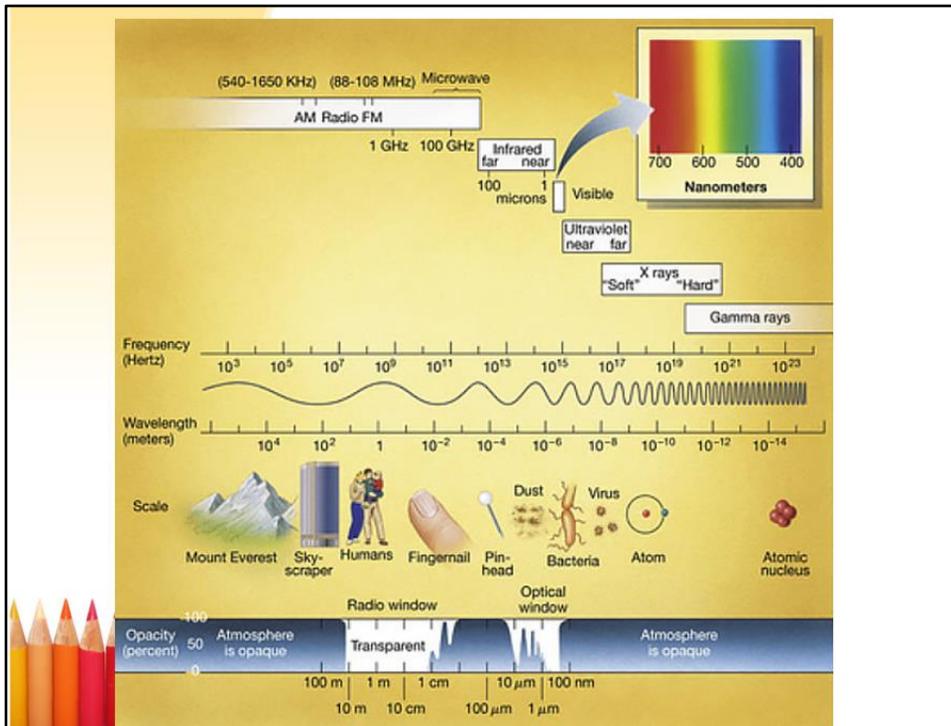
- What is colour?
 - Colour is an aspect of human perception of light
- What is light?
- How do we “see” light?



Back to basics.

Colour is to do with human perception of light. It's not about photons and wavelengths – it's about perception; how light is perceived in the brain.

What “colour” means in terms of perception is often poorly understood even by expert photographers. You read articles and books by photographers with obviously a powerful understanding of colour as a creative element, but when it comes to colour management they are often misguided – sometimes hopelessly wrong. A little bit of knowledge of how our eyes work can help sort that out.



Light is electromagnetic radiation, as is radio, microwave, x-rays, gamma rays... When that energy (usually from the sun) is reflected from objects, we can “see” those reflections, and use that to figure out what’s in front of us.

EM radiation covers a vast range of frequencies and wavelengths, but animals with vision normally use a small range between about 300 and 900 nm wavelength. That’s where the sun emits most strongly, and the atmosphere lets through these wavelengths (it absorbs most wavelengths). So it’s not surprising that evolution favours that band of EM radiation.

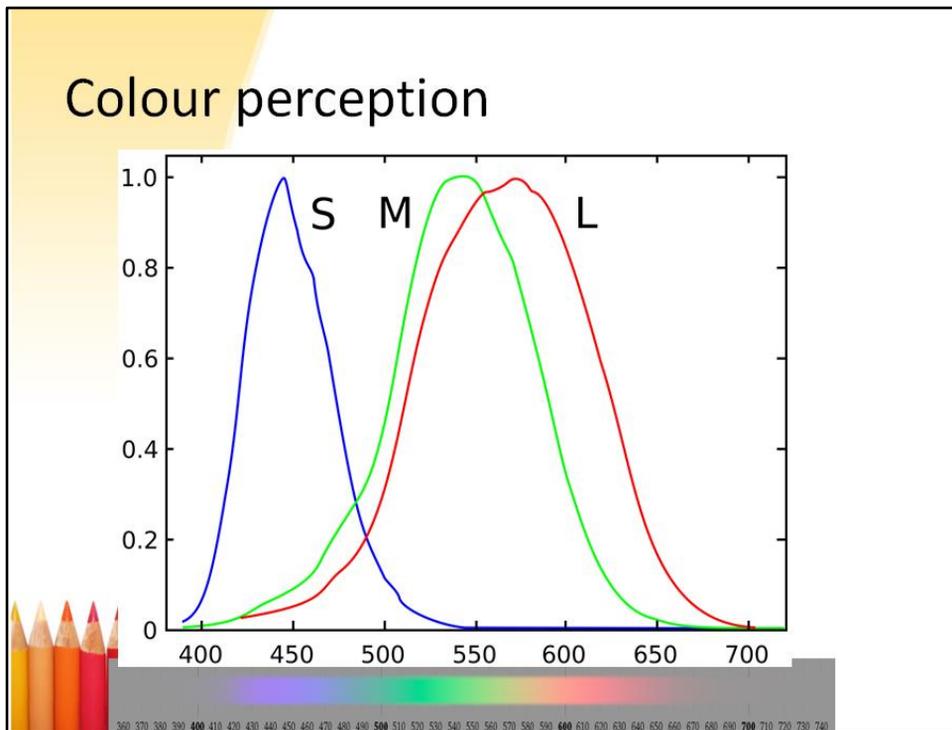
Humans can see light from about 400 to about 700 nm. Each wavelength in that band has a different colour to us – we talk about “colours of the spectrum”. But this isn’t the whole story. Wavelength is not the same as colour.

Colour

- Colour is not the same as wavelength
- Not all colours are in the rainbow (spectrum)
 - Where is brown?
 - Where is magenta?
 - Where is white?



Many colours we can see are not “spectral colours”. In other words, most colours aren’t in the spectrum.



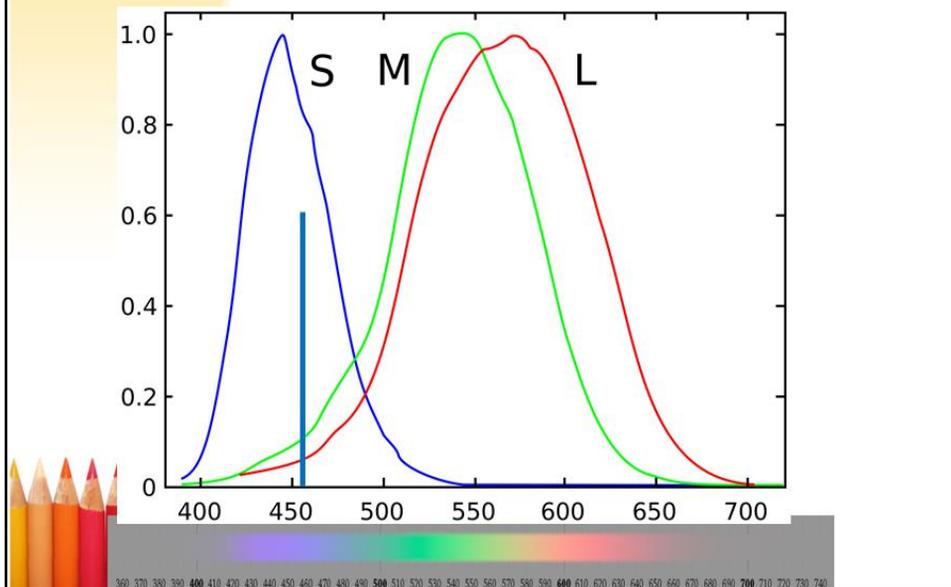
Our eyes do not discern wavelength directly. This is unlike our ears, which can discern individual frequencies of sound to a fine degree.

Our eyes have so-called “cone cells” of three types, with receptors that respond to three bands of wavelength within the visible spectrum, as shown. They’re called S, M and L for short (wavelength), medium and long. But as they are roughly in the blue, green and red parts of the spectrum, we can think of them as roughly “blue”, “green” and “red” receptors. This is an approximation, as each receptor covers a wide part of the spectrum.

What we perceive as “colour” is the combination of the stimulus signals from the three sets of receptors. The level of stimulation, and the relative stimulation of each of the three receptors.

The diagram shows relative sensitivity (vertical axis) and wavelength along the horizontal axis.

Colour perception

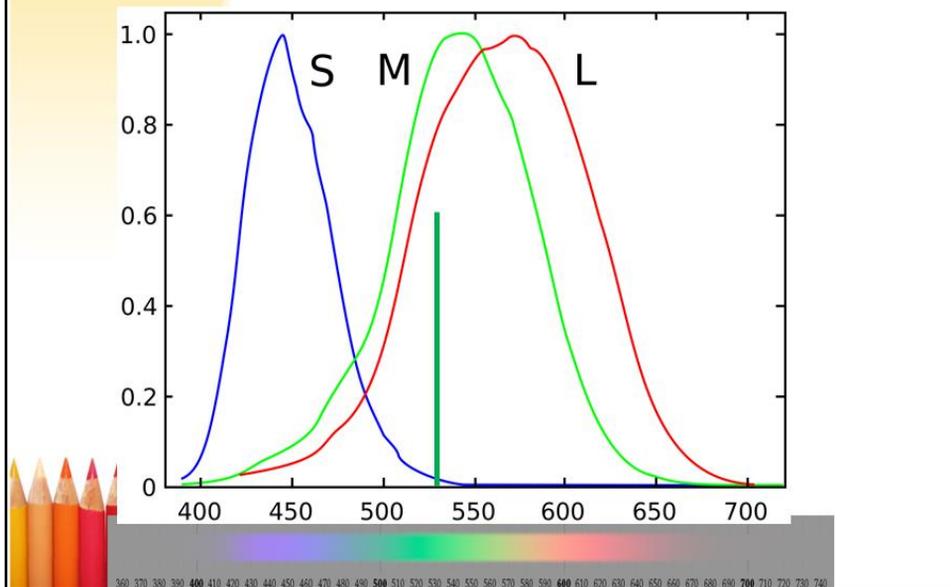


Let's see how that works for colour perception. We'll consider how these three cells respond to different single wavelengths of light.

First, what happens when we look at light of a single wavelength of around 460nm? We can see that's in the blue part of the spectrum, so we know it's going to look "blue" to our brain. That wavelength generates a stimulus in the "blue" receptors, and very slightly in the "green" and "red" receptors.

When those three stimuli get to the brain, it generates a "blue" sensation.

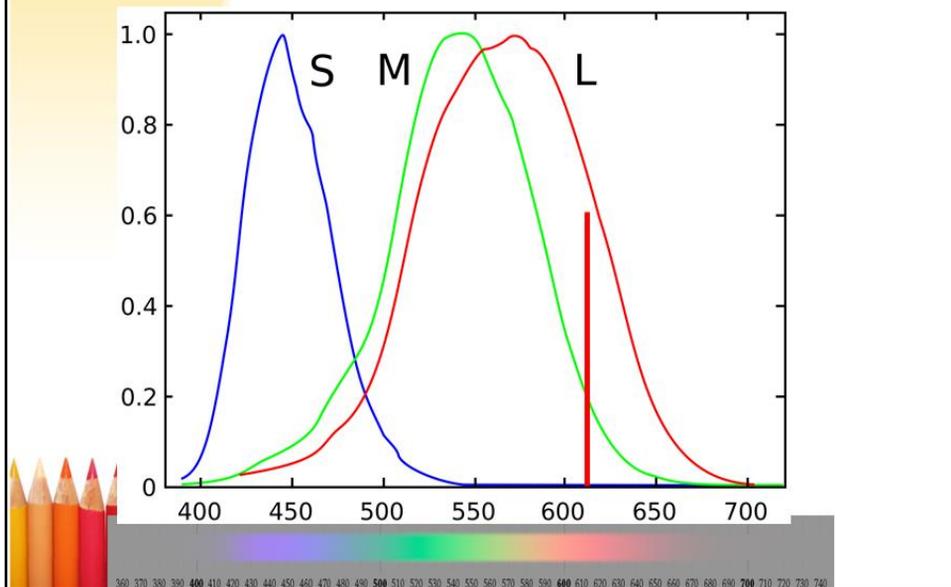
Colour perception



Similarly for light of a single wavelength of 530nm in the green part of the spectrum. Note that both “red” and “green” receptors are stimulated fairly strongly, but “green” more so.

It’s that combination creates a “green” sensation in our brains.

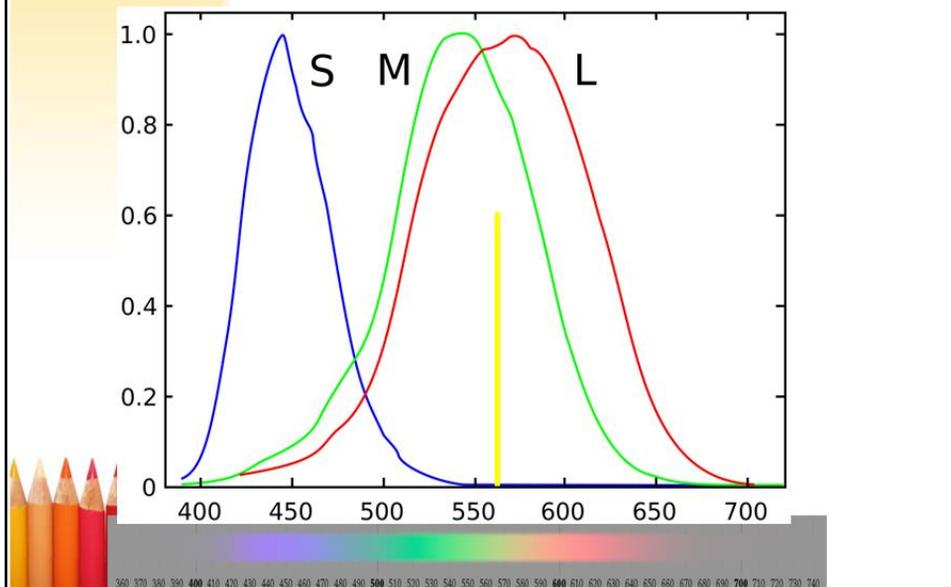
Colour perception



Similarly for red. Light of a single wavelength of around 620nm makes us see red, if you see what I mean.

Note that the “red” receptors actually have a peak sensitivity of around 550 nm wavelength, which is more yellow than red. That’s why I said it’s rather an approximation to call the three receptors “blue”, “green” and “red”, and it’s why they’re more correctly called S, M and L.

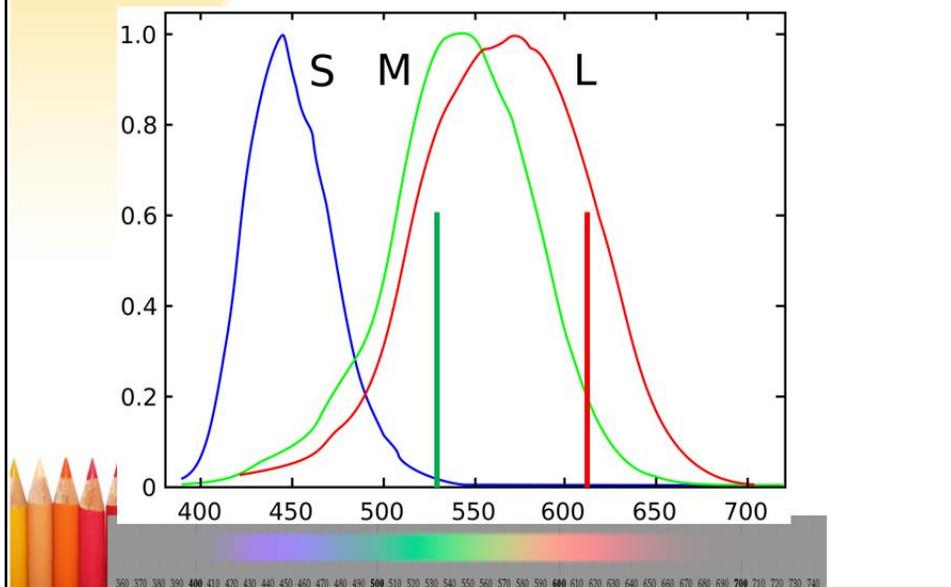
Colour perception



Light of a wavelength of 570 nm is yellow. That stimulates our “green” and “red” receptors about equally, and that creates a “yellow” sensation in our brains.

As with other colours, it’s the combination of stimulation of all three receptors that creates the colour. In this case, roughly equal red receptor stimulation and green receptor stimulation, and very little for the blue receptors.

Colour perception

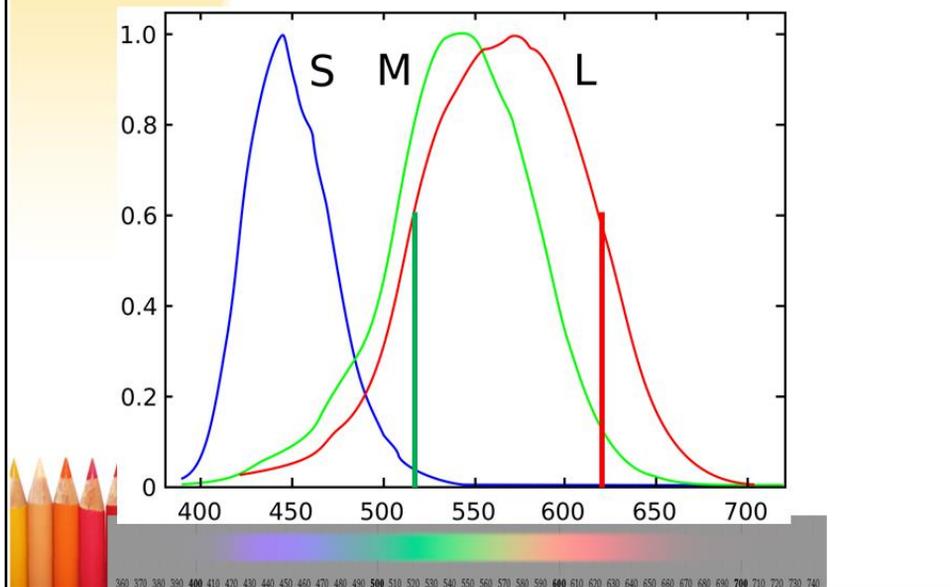


But we know that we can also create yellow light by mixing red light and green light. This shows how our eyes respond to a mixture of red light and green light.

What our brains “see” is the summation of the stimuli of the three receptors. Provided we get the proportions of red and green right, then these two wavelengths together will stimulate our “red” and “green” receptors in exactly the same proportions as the single yellow wavelength.

Our eyes and brains can’t tell the difference, so this combination IS yellow, so far as our brains are concerned.

Colour perception



We could use different green and red wavelengths, and provided they create the same combination of stimuli in our “green” and “red” receptors, it’s the same colour.

Definition of colour

- For photography, colour is the combination of stimulation of the L, M and S (R, G and B) cone receptors in our eyes
 - So-called “tristimulus values”
- **Any** combination of wavelengths that creates the same stimulation (the same tristimulus values) creates the same sensation in the brain, and **is** the same colour.

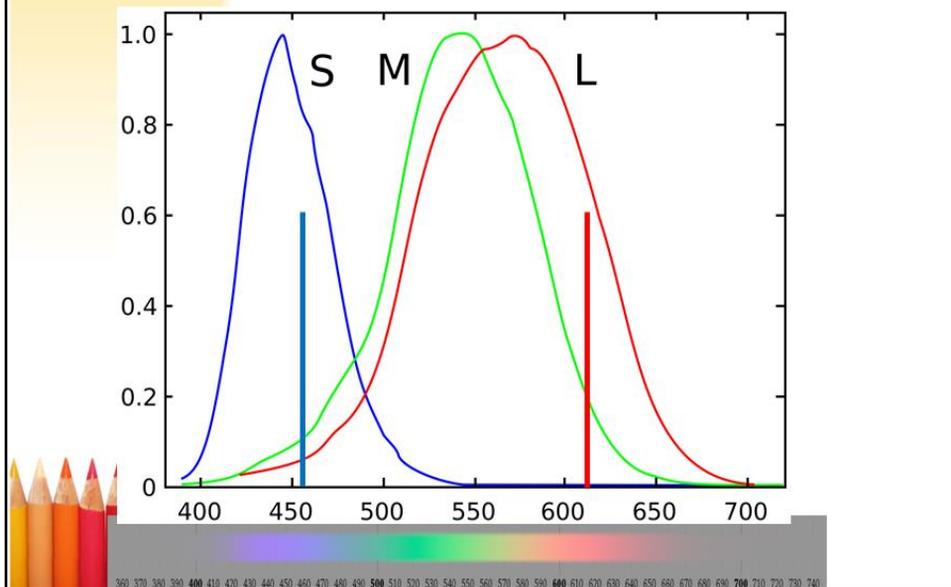


This is what colour is.

For photography, colour is the combination of stimulation of the L, M and S (R, G and B) cone receptors in our eyes. These three stimuli are often called “tristimulus values”.

Any combination of wavelengths that creates the same combination of stimuli in our three colour receptors (that is, the same tristimulus values) creates the same sensation in the brain, and so it's the same colour.

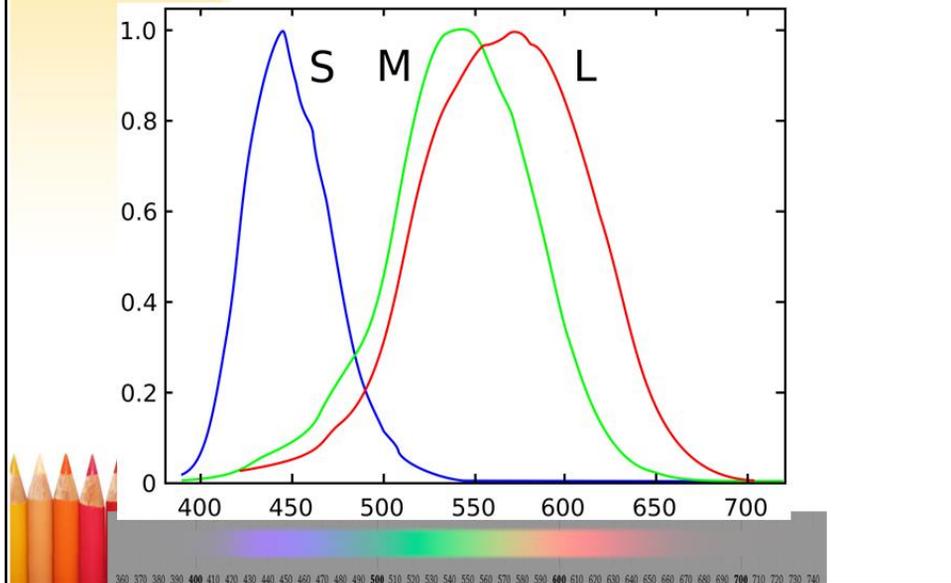
Colour perception



I mentioned earlier that many colours are not in the spectrum. Here's an example. Red plus blue light gives us the sensation of magenta. So magenta is definitely a colour, as we can see it! But it's not in the spectrum. Compare this to yellow: we can "make" yellow by a combination of red and green, but there is also a single wavelength that looks yellow. There's no single wavelength that looks magenta.

Most colours that we can "see" require a combination of at least two (and generally at least three) wavelengths of light in combination. But ANY combination that creates the same tristimulus values is the same colour.

Capturing colour - cameras

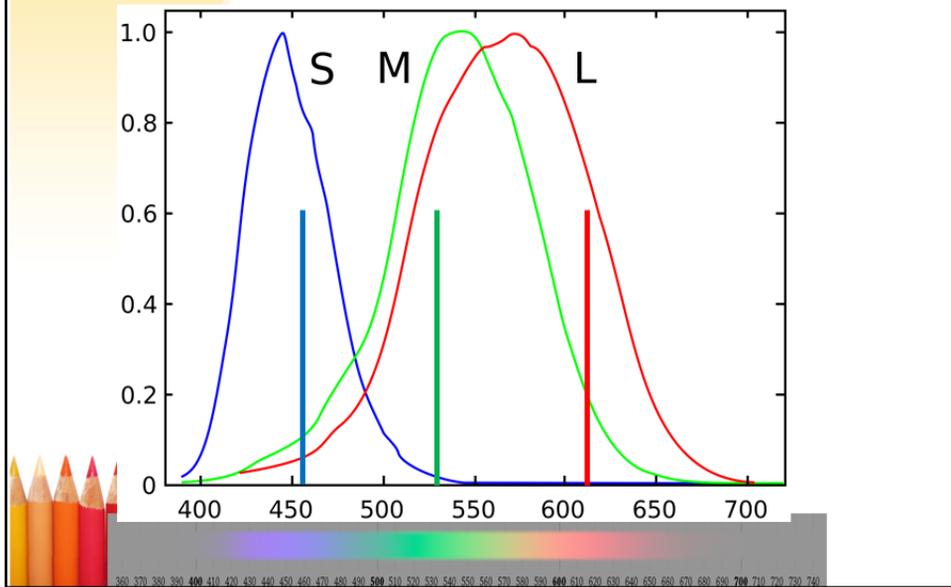


How does this work for photography? How do we capture, and then reproduce the colour in a scene?

We capture colour information in a camera, and then reproduce it on a monitor, for example.

In cameras, we need three sets of sensors that mimic, as far as possible, the receptors in our eyes. We want the camera sensors to produce something that maps to the tristimulus signals created in the eye.

Recreating colour - monitors



Reproducing those colours is a bit simpler. We've seen that we don't need specific wavelengths to create colour. That means that we don't need to recreate any complex curves – we can use any convenient wavelengths that, in combination, can create the required tristimulus values. To create all possible colours we need at least three wavelengths, and it's most convenient (but not essential) to choose three that are roughly from the red, green and blue parts of the spectrum.

Creating colour

- Using three “primary” light sources close to Red, Green and Blue in combination can create most colours
 - Manufacturers don’t have to use exactly the same primaries.
- But...



These (usually) three wavelengths that we’re going to use to create all our colours are often referred to as our “primary” colours, or just “primaries”

We don’t need exact colours for our primaries, and manufacturers have a bit of flexibility. A poor choice simply means you can’t create all colours with that combination.

Colours

- ...if my monitor and your monitor use even slightly different primaries, the same RGB values produce different colours!
- “Colour Management” is the process of getting the right colours on different devices.
- Colour management means changing the RGB values from my device so they produce the same colours on your device.



That's all colour management is: mapping the RGB values that work on (for example) my monitor so that they produce the same colours on your monitor.

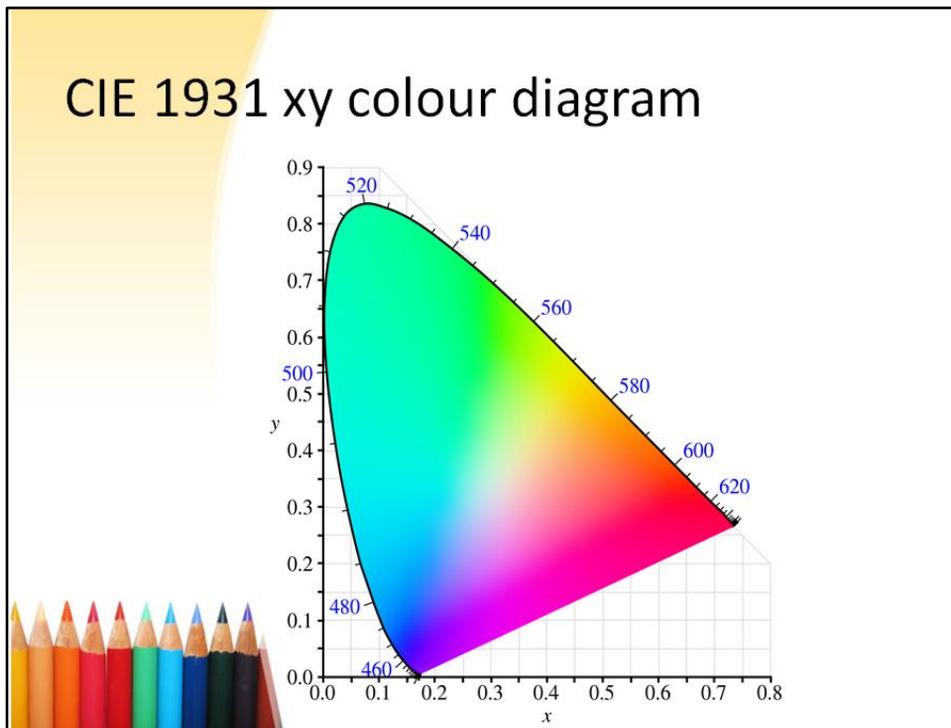
Colour management

- We need a standard way of measuring RGB primaries, so we can convert RGB values
 - From the primaries of my device
 - To the primaries on your device
 - So they produce the same colours on your device
- Standards for defining colours from the CIE



In order to do colour management, we need some standard for specifying the primaries in monitors (and a few other parameters) so we can do the conversion of RGB values.

The CIE is the principle standards organisation that has done this.



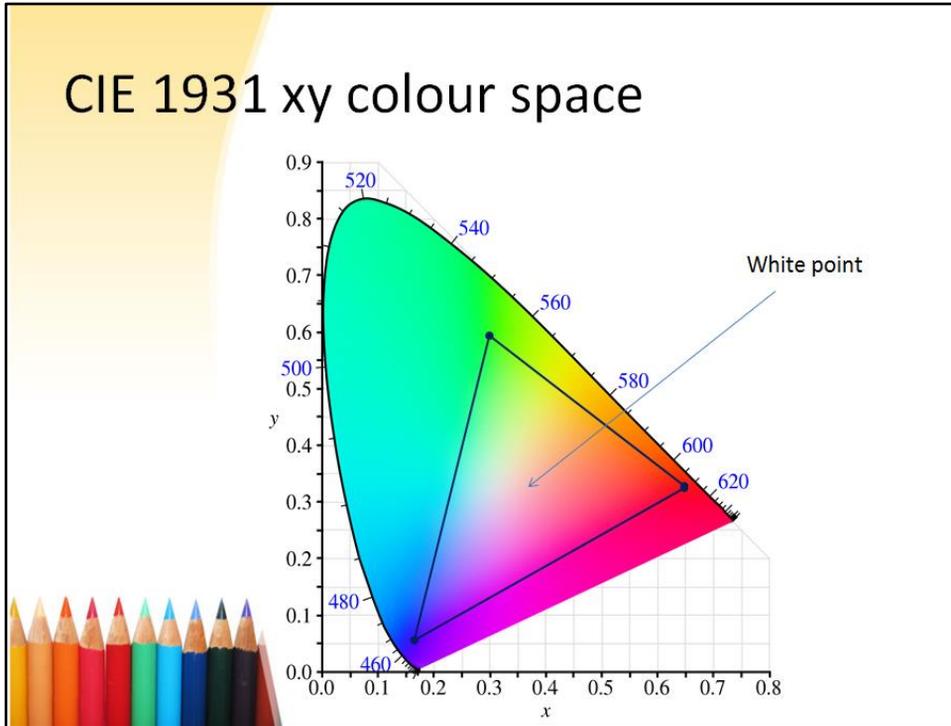
Colour specification is not new to digital photography. It's important for film, cinema, TV, printing, publishing, advertising...

This diagram shows all possible colours at one brightness level. Round the edge of the curve are the spectral colours, with wavelengths shown. All the colours except on the curved edge are non-spectral: they need at least two (generally at least three) wavelengths of light in combination to create those colours. The straight line along the bottom right is sometimes called the "magenta line" for obvious reasons.

White is somewhere in the middle. It's not in a precise place – it depends whether you want warm white, cool white...

This CIE diagram is not the only possible representation – some people use 3D diagrams that show all brightness levels (this shows all colours at one brightness level) but the 2D representation makes it much easier to follow, in my view.

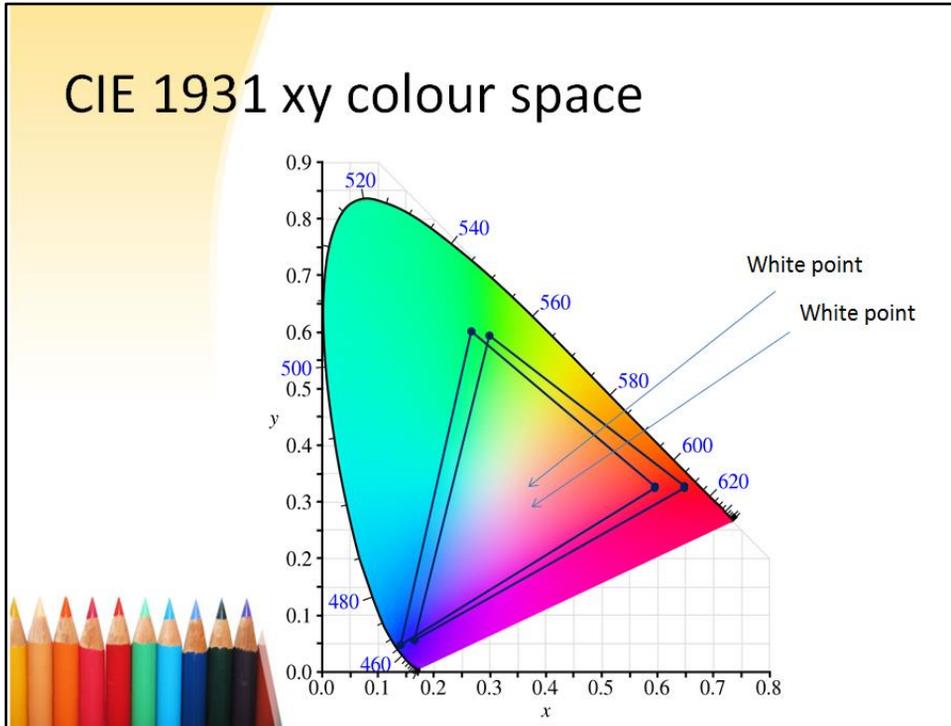
CIE 1931 xy colour space



Let's take a typical monitor, and show where the monitor primary colours appear on the CIE diagram. The three points correspond to the three primaries. The area within the triangle formed by these three points represents the possible colours we can create with these three primary colours.

Note that this diagram is not perceptually uniform. Our eyes are much more sensitive to changes in pastel colours than to changes in saturated colours round the edge. In practice, the triangle contains a much greater proportion of colour than appears from the diagram. Besides: highly saturated colours are not common in nature (and thus in our photographs).

CIE 1931 xy colour space



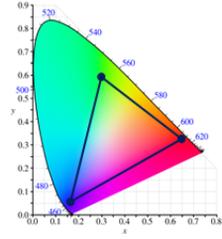
This shows two possible monitors. It's quite typical of the difference between two different models of monitor. Any set of RGB values will result in noticeably different colour on the two monitors.

If the white points are different between the two monitors (they usually are) then there will also be a colour caste between the two monitors.

But if we can measure the primaries of the two monitors, it's possible to convert RGB values so that the same colours are created in the two monitors.

CIE 1931 xyY colour space

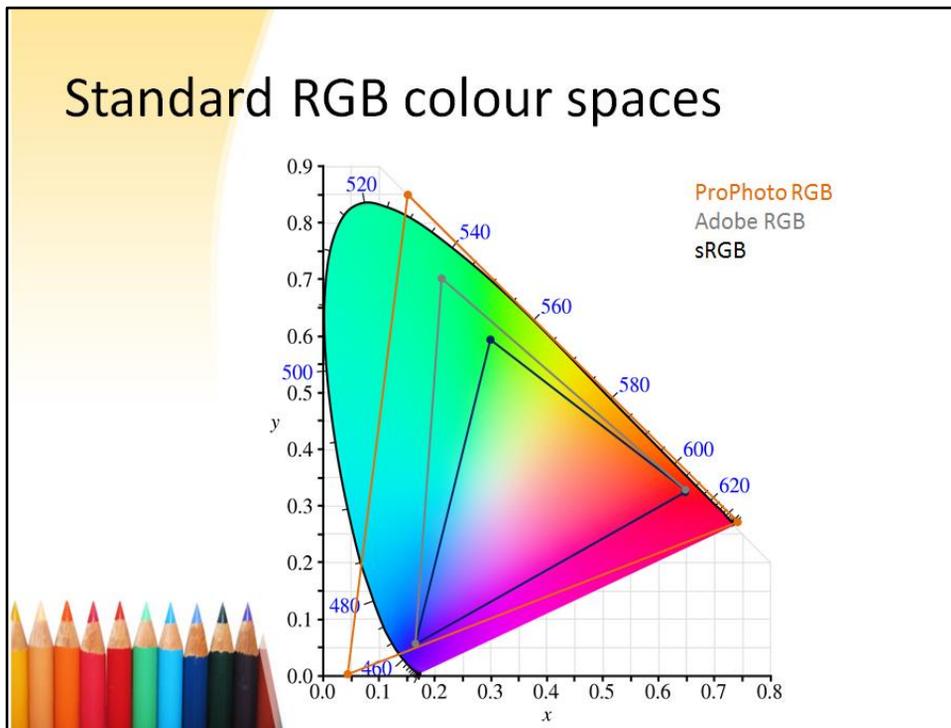
- **Colour space:**
 - A set of colours and the co-ordinates to describe them
- Every device has its own colour space
 - With its own white point
 - With its own tone or “gamma” curve (contrast)
- There are also **standard colour spaces**
 - CIE 1931 xyY is a standard colour space
 - Others include sRGB, Adobe RGB, ProPhoto RGB
- **Colour gamut:**
 - The colours within a colour space
- **Colour model:**
 - A mathematical way of modelling colours in three (sometimes four) values
 - RGB, CIE xyY and CMYK are colour models



Some definitions.

Note that “RGB” is a colour model, not a colour space. sRGB, Adobe RGB and ProPhoto RGB are all RGB colour spaces. That is, they are colour spaces using the RGB model.

You sometimes read “you can use sRGB or RGB”. That’s like saying “how hot is it in Celsius or in temperature?”



This shows the common standard colour spaces.

As I said before, sRGB includes virtually all colours in virtually all pictures. In fact: many pictures have NO pixels with colour that can't be represented in sRGB.

That's not to say there's no benefit in using Adobe RGB, but in my view the benefits are sometimes overstated. Camera sensors typically can record all the colours in Adobe RGB, sometimes a bit beyond. Similarly photo printers often have a gamut comparable with Adobe RGB. But most monitors have a colour gamut that approximates to sRGB.

ProPhoto RGB includes nearly all colours. The ProPhoto RGB primaries are outside the visible limits – which means they are not colours! That doesn't mean they're infrared, or ultraviolet or some such – they don't represent any combination of wavelengths, they're just a mathematical anomaly of the CIE model. You can't have a ProPhoto RGB monitor, as those primaries don't exist. However, ProPhoto RGB is still very useful for representing colour internally in photo manipulation software (e.g. editing programs). For example Lightroom always uses ProPhoto RGB internally.

Colour Management

- Every monitor and output device has its own set of primary colours and its own colour space
- Every camera generates sensor data unique to its sensor
- Images are normally converted to a standard colour space for storage
 - often sRGB, Adobe RGB or ProPhoto RGB
- Images must be converted to the monitor (or printer) colour space before output.
- Fortunately...



Camera sensors all have their own colour characteristics, but strictly they don't have a colour space.

Images are normally stored in a standard colour space such as sRGB, so they have to be converted from camera sensor data to sRGB (or whatever). But cameras normally do that bit of colour management automatically: they convert images from the sensor data to a standard colour space (usually sRGB or Adobe RGB) and save as a jpeg. (If you shoot raw, the camera stores the sensor data as is, any conversion is done by the raw convertor.)

The colour space then needs to be converted again (more colour management) from the stored colour space (sRGB, for example) to the monitor's colour space.

Colour Management

- Fortunately:
 - Most monitors have a colour space *approximately* the same as sRGB
- So if you store images in sRGB, even without colour management, colours are *approximately* right.
 - (tone curve and white point may be inaccurate)
- If you use any other colour space (or a wide-gamut monitor), you must use colour management, or you get the wrong colours.
- In any case, colour management is likely to result in more accurate and more consistent colour.
- So why isn't colour management automatic? For most (non photographic) purposes, accurate colours don't matter!



Colour management for a display means mapping RGB values from the colour space the image is in, to the colour space of the device on which you want to display the image. If your software doesn't colour-manage, then the RGB values are sent straight to the display without any conversion. That's what Windows does with the desktop; desktop colours aren't colour managed. Many non-photo programs (e.g. office suites) aren't colour managed.

However, if the image to be displayed is sRGB and the monitor has a colour space of sRGB, then that's OK – you don't need any conversion! That's why sRGB was created by Microsoft and Hewlett Packard – to be typical of computer monitors, so colours are about right without colour management.

That's why most computer users don't need to use colour management (and don't even know what it is, or know what colour spaces are) because they're looking at images in sRGB colour space on monitors that have roughly sRGB colour space, so colours are roughly right. And most people are not bothered if colours aren't exactly right so long as they're bright and pretty.

Remember, though, that few monitors have a colour space of exactly sRGB, and nearly all have a white point and tone curve (contrast) markedly different to that specified in sRGB. Without colour management, there will generally be a false colour cast, and incorrect contrast.

Colour Management

- To use colour management with a device, we need a **colour profile** for that device.
- A colour profile includes a definition of a colour space.
- It contains among other things:
 - A measurement of R, G and B primaries
 - A measurement of white point
 - A measurement of tone (contrast) curve



A colour profile contains a description (or a measurement) of the colour space of a device.

Profiles *measure* the characteristics of a device, not *alter* them.

(An except is monitor profiles – that's covered later.)

Colour Management

- For output devices, a profile is normally stored in a .icm or .icc file (small ~ 1-3kb)
 - Created using a calibration tool (ColorMunki, Spyder...) which calibrates/profiles the device
- For images, often there is a profile embedded in the file (to say the colour space of the image)



Note that on the web, many images and graphics DON'T contain embedded profiles. A web page may well have dozens – even hundreds – of graphic elements, often tiny ones only a few bytes in size. It doesn't make sense to embed a 1kbyte profile in each one. But photos are normally 100kbyte or more in size, and it's of little consequence whether they contain an extra 1K for a profile.

However, perversely many hosting sites strip out profiles.

And except for Firefox, browsers don't colour-manage coloured elements unless they have an embedded profile. This is also perverse: if you are colour-managing colours that *do* contain a profile, then why not make a guess at the colour space of elements that *don't* contain a profile? After all, 99.999999999999% of colour elements on the web are sRGB, so taking a wild guess at sRGB might just be a good move.

Even Firefox doesn't colour-manage elements without an embedded profile by default. You have to set "gfx.color management.mode" to 1 (Google for how to do that).

Unfortunately most people designing computers and web systems aren't photographers, and don't give a fig for colour accuracy. When you look at how non-photographic software treats colour, and consider some of the design decisions the software authors have made, you seriously question their sanity. To put it another way: it shows that "colour" is generally very poorly understood.

Recap

- **Colour space:** set of colours a device can reproduce, defined in CIE or other co-ordinates
 - There are also standard colour spaces: **sRGB**, **Adobe RGB**...
- **Colour gamut:** colours within a colour space.
- **Colour profile:** definitions of a colour space: primaries, white point and tone curve
 - Stored in a .icm file or embedded in an image file



These terms are important. It's useful to have a working idea of what they mean.

Jpeg images produced by cameras often don't contain a profile, but use various naming conventions to indicate the colour space.

A name "DSC_0001.jpg" conventionally signifies sRGB colour space, a name

"_DSC0001.jpg" conventionally signifies Adobe RGB.

Sometimes files contain a metadata tag to describe colour space, but use of this is haphazard (and the tag is not always accurate).

Recap

- **Colour management:** using two profiles to convert RGB values from one colour space to another.
- **Calibration/profiling:** creating a profile for a device (monitor, printer...)



Colour management needs *two* profiles: one for the colour space you're converting *from*, and one for the colour space you're converting *to*.

Calibrating/Profiling a monitor

- **Profiling:** measuring the colour space, white point, tone curve... of a device.
- **Calibration:** adjusting a device to bring it to a defined state.
- Printers are not calibrated, just profiled.



“Calibration” and “profiling” are not the same thing. When you use a colorimeter tool (ColorMunki, Spyder or whatever) then the software with it does both, but it’s useful to understand that they are different things.

Calibration means adjusting something – in this case the monitor – to a defined state. You can calibrate the brightness, white point and tone curve of a monitor. This done by creating “Look Up Tables” that are used by the video driver (sometimes by the monitor hardware) to correct these parameters. You can’t normally calibrate the colour space, as this is fixed by hardware (that is, by the physical colours of the primaries in the monitor).

Some modern monitors simulate calibration of colour space. Effectively, they’re doing colour management in firmware inside the monitor, so the monitor can simulate a perfect sRGB colour space. Be aware that these factory calibrations are generally not as accurate as doing it with a colorimeter (because monitors drift with time). Calibration and profiling yourself will nearly always get better results. And it does NOT obviate the need for colour management, which is still needed.

Calibrating/Profiling a monitor

- Using a colorimeter: ColorMunki, Spyder...
- The software calibrates and profiles:
 - First: calibrate. Calculate corrections for white point and tone curve, which go in a LUT (Look-Up Table) and is used by the video driver
 - Next: profile. Measure colour space (primaries), white point and tone curve
 - Create profile (which also contains the LUT).



The format of a colour profile is defined by International Color Consortium and includes, well, profile information. Adobe designed a bit of a bodge to allow calibration information (in the form of LUTs) to be added to a profile file.

Calibrating/Profiling a monitor

- When the computer boots, Windows/MacOS extracts LUT from profile, and loads into the video driver
 - All programs get the calibrated white point and tone curve automatically (done by video driver)
- Only colour managed programs use profile to map colour space of images to monitor's colour space



I found this rather confusing. When you calibrate/profile a monitor, images look different afterwards. Even the Windows desktop looks different, and Windows doesn't colour-manage the desktop. The reason is that *calibration* affects (nearly) all programs – because the video driver uses the calibration information to correct white point and tone curve.

But only colour managed programs use the profile to map colour spaces, and thus get the correct colours on the monitor.

Some games and video viewers bypass the video monitor, and go straight to the video hardware. These programs bypass the LUT, and won't get the corrected white point and tone curve.

What does it mean to use Colour Management?

- Calibrate and profile your monitor
 - With a hardware colorimeter such as ColorMunki, Spyder... costing from about £100
 - You can't do it by eye
- (Optionally, profile your printer – but supplied profiles OK)
- Use colour-managed software:
 - Elements, Photoshop, Lightroom, PaintShop Pro and most photo programs
 - Most browsers: Firefox, Safari, Chrome but not Internet Explorer
 - (Wide-gamut monitors need Firefox)
- In most programs software colour management is automatic (you may need to specify printer profiles)
- Once you have a profile for the monitor then if you use colour-managed software, colour management is automatic: it just happens.



Windows control panel colour management (and I believe the same function in the Mac) contains a tool to calibrate by eye. This is better than nothing. But only just. You can adjust the tone curve (contrast) by eye approximately, but you can't accurately adjust white point by eye, and you can't measure colour space by eye.

Quick workflow recommendations

- If you don't both profile your monitor and use colour-managed software, stick to sRGB
- If you shoot jpeg, stick to sRGB
- If you're uploading to the web (or FCC DPI), convert to sRGB first (if not already sRGB)
- If you have a wide-gamut monitor, you *must* use colour management (profiled monitor, colour-managed software)
- If you shoot raw, consider using colour management and working in 16-bit with a wide colour space (ProPhoto RGB or Adobe RGB)
- Colour management (profiled/calibrated monitor and colour-managed applications) will generally result in more accurate and more *consistent* colour, white point and tone curve



These quick recommendations are expanded in the “Cheat Sheet” on the web site. (See next slide.) On the Cheat Sheet I explain the reason for the recommendations.

These suggestions are my opinions, and some people might disagree. However, I'd say they are appropriate in most circumstances.

Using any colour space other than sRGB (or using a wide-gamut monitor) without colour management can lead to mysterious problems. If the colour doesn't look right on your monitor, is that because the colour in the image is wrong, or because the monitor is displaying the wrong colour? You have no way of knowing.

Without colour management, when you adjust the colour until it looks right on your computer, you may be introducing an error to compensate for an error in your monitor's colour. You have no way of knowing if this is happening. The **ONLY** safe(ish) rule is to stick exclusively to sRGB unless you use colour management. And using colour management is almost always more accurate, consistent and reliable.

Colour Management

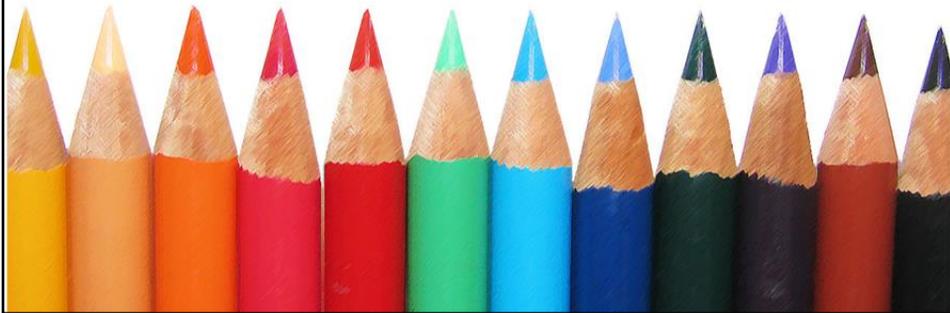
- For more information, see:
 - <http://www.simongarrett.co.uk/>
- For a “Colour Management Cheat Sheet” with more explanation and lots of links and references.
 - *The Cheat Sheet gives more practical advice.*
- And a copy of these slides (with notes).

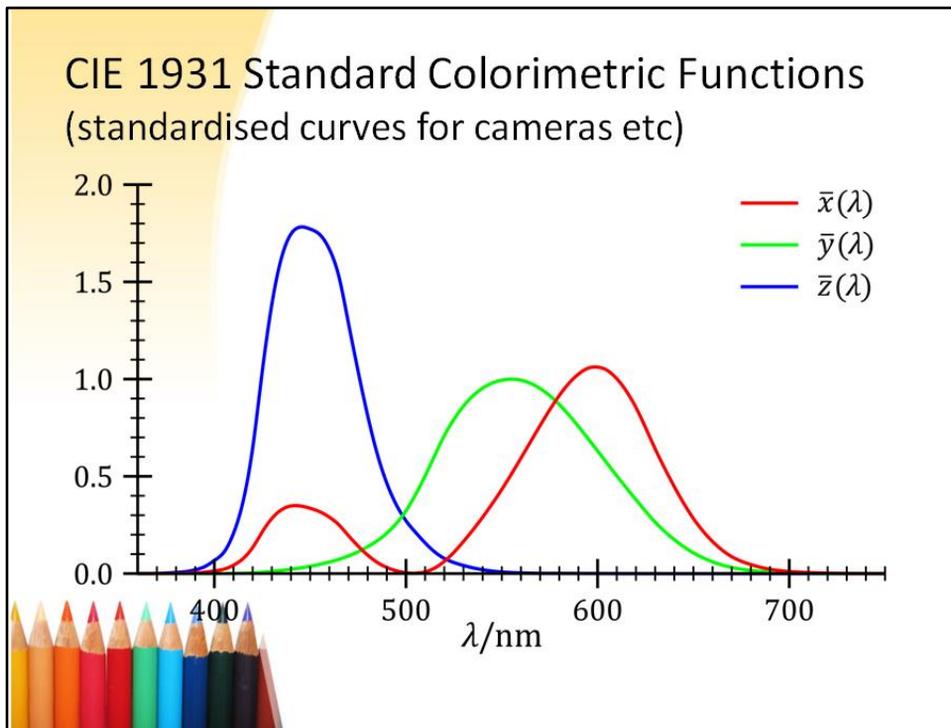


The Cheat Sheet gives more practical suggestions, and contains many further references and links to information I've found helpful.

Colour Management in Photography

Simon Garrett





In practice, camera sensors are designed to map these three standard curves, which are idealised approximations to the responses of S, M and L receptors in our eyes.