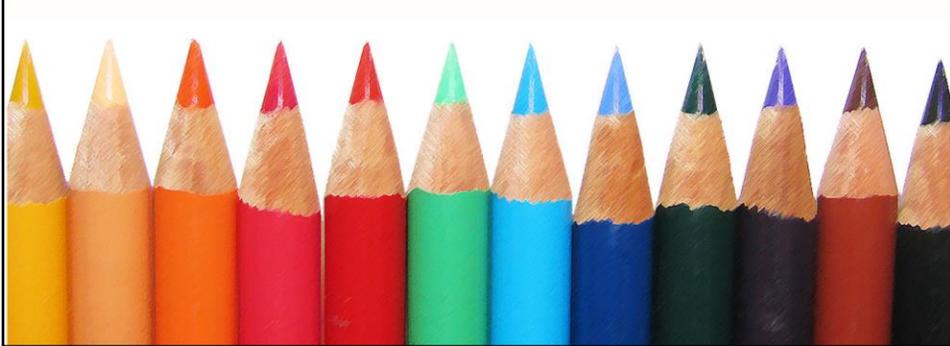Practical Colour Management

Simon Garrett
February 2016

Notes from a talk given to Framlingham Camera Club, February 2016.

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.

What I'll cover

- What are "colour profiles"
- How to create them
- How to use them (colour management)
- Why to use them
- How to avoid using them (and not use colour management)
- *These slides and other stuff at http://www.simongarrett.co.uk/colour.htm*

"All the colours of the rainbow"

Most colours we can see aren't in the rainbow!

Where's brown? Magenta? White?

These and most other colours we can see are not "spectral colours" – they're not single colours of the spectrum, but are combinations of two or more spectral colours – often many spectral colours – in combination.

However, our eyes don't respond directly to the spectral colour or wavelength of light.

Recreating colour – monitors
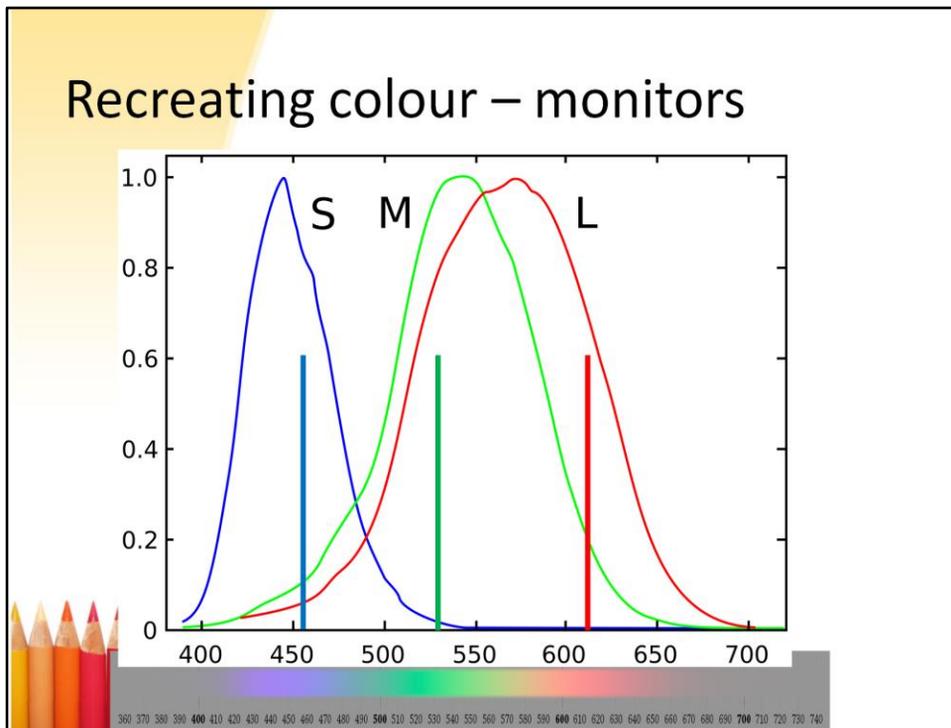
The cone sensors in our eyes are of three types, each responding to the amount of light in three broad, overlapping ranges of wavelength. This shows the spectrum along the bottom, and the response of the three types of cone cell: the blue-sensitive cells, green-sensitive and red-sensitive. The three types of cell respond the quite broad and overlapping parts of the spectrum.

In a typical scene, our eyes see a whole combination of wavelengths of light. It's the combination of the stimulation of the three sensors that gives us our sensation of colour.

In order to reproduce colour, we do not have to create the same combination of light as in the original scene. We can instead use a combination of red, green and blue to recreate the same sensation from our eyes. We don't even need specific colours for the red, green and blue. Any three colours roughly red, green and blue can be combined to create most colours we can see. This is what monitors and projectors do: create combinations of red, green and blue to make any other colour.

We call these three colours the "primary colours" of the monitor or projector.
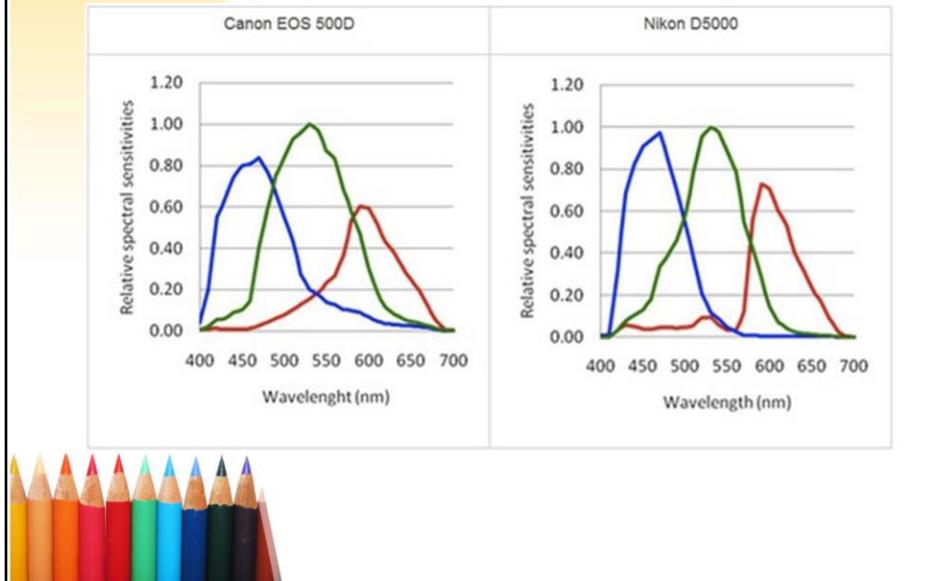
Camera sensors need to detect light in three bands like our eyes do, but again they do not need to accurately simulate the response of our eyes. This slide shows two different camera sensor responses. The are not the same as each other, and neither is the same as our eyes. This doesn't matter provided we know the response of the sensor.

Note: if the sensors don't accurately mimic the response of our eyes then they may not be able to capture all colours we can see. Similarly, if the red, green and blue used by monitors aren't well chosen, then they may not be able to create all colours. In practice, there's quite a lot of latitude where the sensor can capture most colour, and the monitor can create most colour.

Capturing and recreating colour

- Using three sensors we can capture most colours
- Using combinations of three light sources close to Red, Green and Blue we can create most colours
  - Manufacturers don't have to make the same choices.

These 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.

The rest of this presentation concentrates on output devices, rather than sensors.

Colours

- If two monitors use different primaries, the same RGB values produce different colours!
- "Colour Management" is the process of getting the right colours on different devices that have different primaries.
- Colour management means changing the RGB values where necessary so they produce the right colours on a 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.

CIE 1931 xy chromaticity diagram
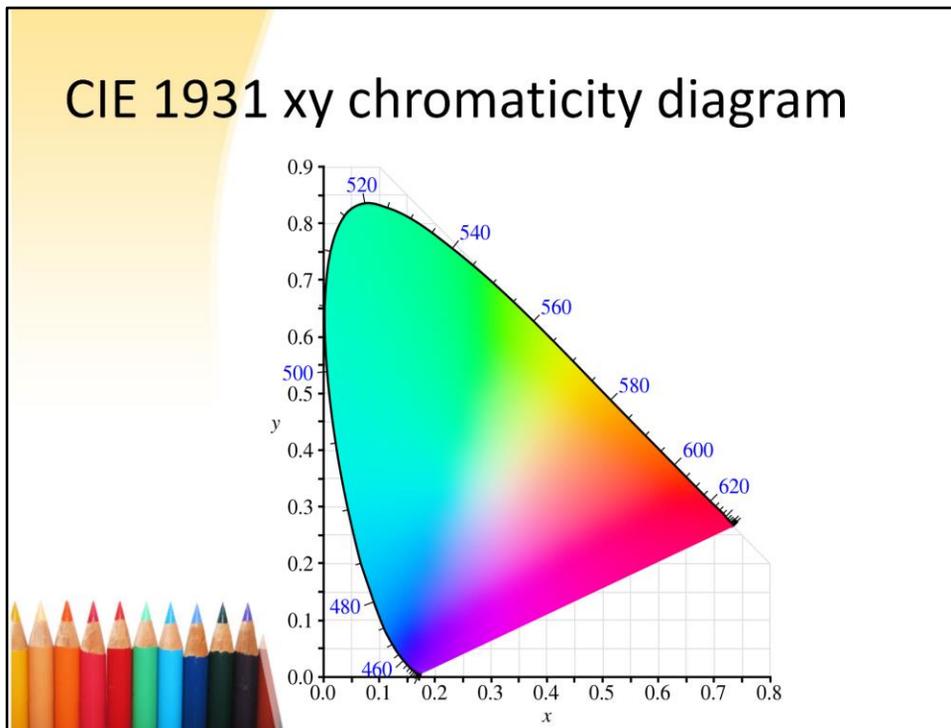
Colour specification is not new to digital photography. It's important for film, cinema, TV, printing, publishing, advertising…

This diagram shows all possible colours that can be perceived by a person with normal colour vision, 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.

This diagram is useful as it can show the capabilities of specific devices.

CIE 1931 xy chromaticity diagram
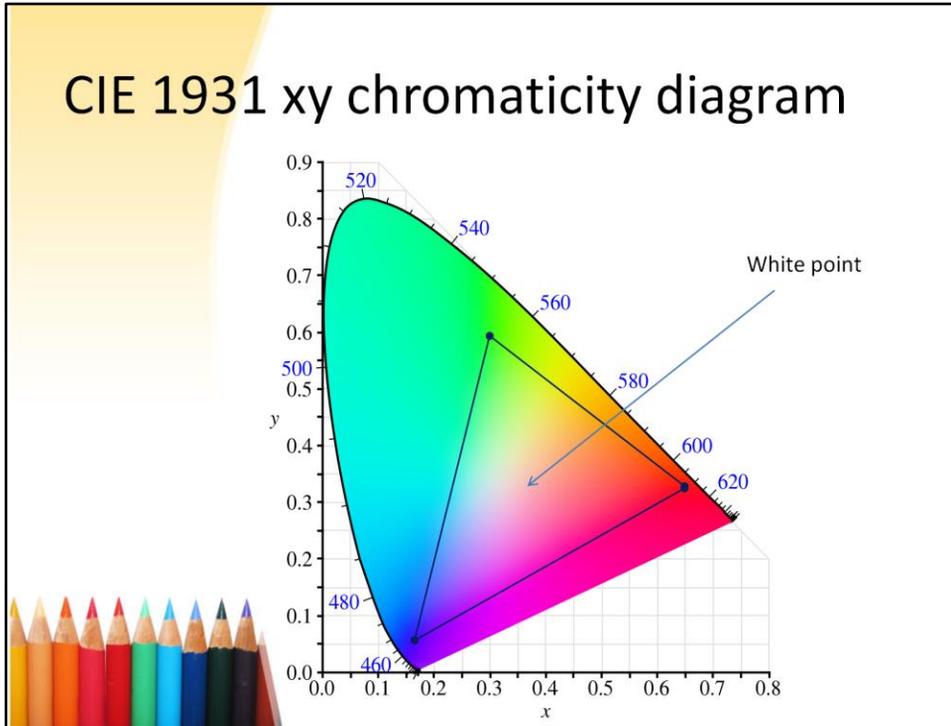
Let's take a typical monitor, and show where the monitor primary colours appear on the CIE diagram. The three points correspond to the three primaries. The area within the triangle formed by these three points represents the possible colours we can create with these three primary colours. With those primaries we can't create colours outside the triangle.

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).
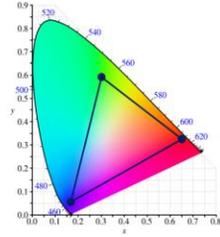
CIE 1931 xy chromaticity diagram
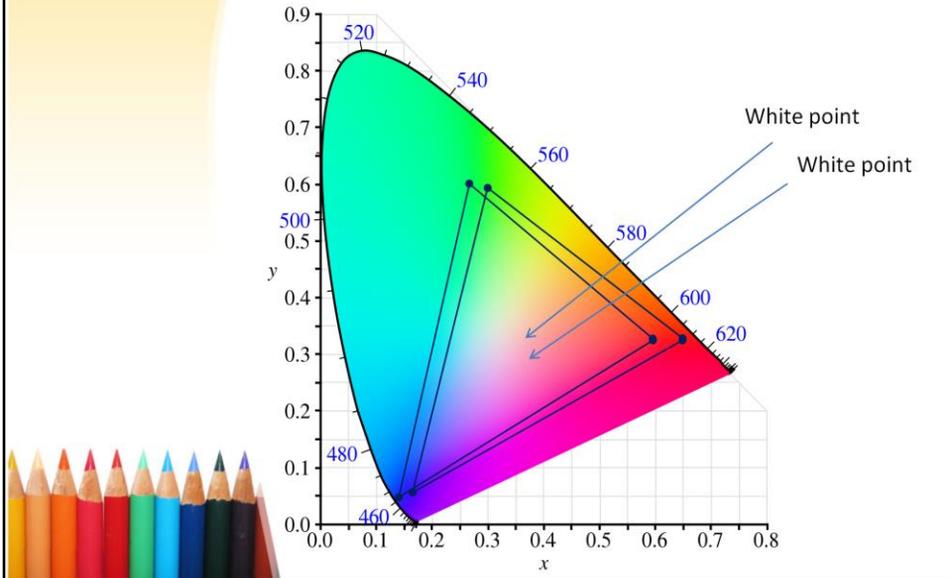
This shows two possible monitors. It's quite typical of the difference between two different models of monitor. Any set of RGB values will result in noticeably different colour on the two monitors.

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.

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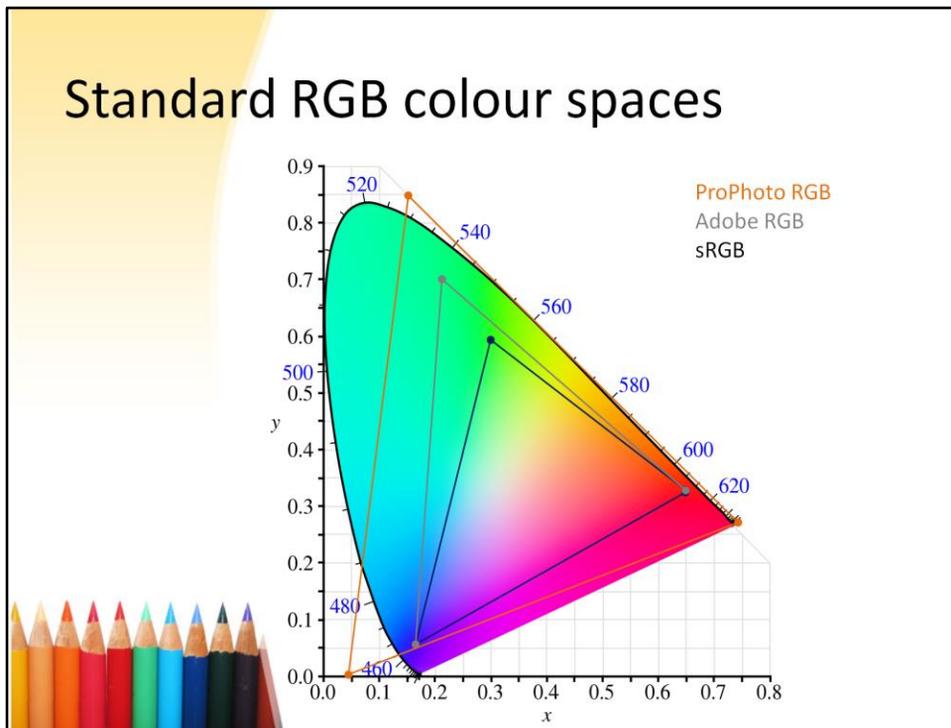
Note that "RGB" is a colour model, not a colour space. sRGB, Adobe RGB and ProPhoto RGB are all RGB colour spaces. That is, they are colour spaces using the RGB model.

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.

Adobe RGB has a wider gamut than sRGB (i.e. a bigger range or colour), and ProPhoto RGB has an even wider gamut.

ProPhoto RGB has primaries outside the coloured area, which means that the don't correspond to real colours. However, the advantage for ProPhoto RGB for processing colour in software is that the colour space is so big that colours don't disappear off the edge, as they can with smaller colour spaces.

That's not to say there's no benefit in using Adobe RGB, many pictures won't need it. 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 printer has its own set of primary colours and its own colour space
- Every camera generates unique sensor data
  - Images are normally converted to a standard colour space such as sRGB, Adobe RGB or ProPhoto RGB
- Images need to be converted from the image colour space to the monitor (or printer) colour space before output.
  - That's colour management
- Do you always need to do this?
  - Not necessarily if everything is in one colour space and all devices have the same colour space (so no conversion needed)
  - More later

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 is not *necessarily* needed if everything is in one colour space, and all devices have the same colour space – so no conversion is needed. This places some restrictions on use of colour – more later.

Colour Profiles

- A **colour profile** is a measurement 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
- Digital images often have a profile embedded (to indicate the colour space of the image)
- For monitors and printers, a profile is in a small .icm or .icc file (typically 1-4Kb).

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, which also contain calibration – adjustment - information.)

Recap

- **_Colour space:_** set of colours a device can reproduce, defined in CIE or other co-ordinates
  - Every device has it's own unique colour space
  - There are standard colour spaces: **_sRGB_**, **_Adobe RGB_**…
- **_Colour profile:_** definition or measurement of a colour space: primaries, white point and tone curve
  - Stored in a .icm file or embedded in an image file
  - Enables software to convert image data from one colour space to another

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*.

How to use Colour Management

1. Create monitor and printer profiles
   - Create a monitor profile by calibrating and profiling your monitor
     - With a hardware colorimeter such as ColorMunki, Spyder... costing from about £70. It can't be done by eye.
     - Some monitors have factory calibrations/profiles. Monitor colour space drifts over time, and it's often more accurate to calibrate yourself.
   - If you print, then create a profile for your printer, or use supplied profiles
     - supplied profiles normally OK
2. Use colour-managed software
   - Once you have calibrated/profiled the monitor then if you use colour-managed software, colour management is automatic: it just happens.
     - For printers, you have to specify the profile

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.
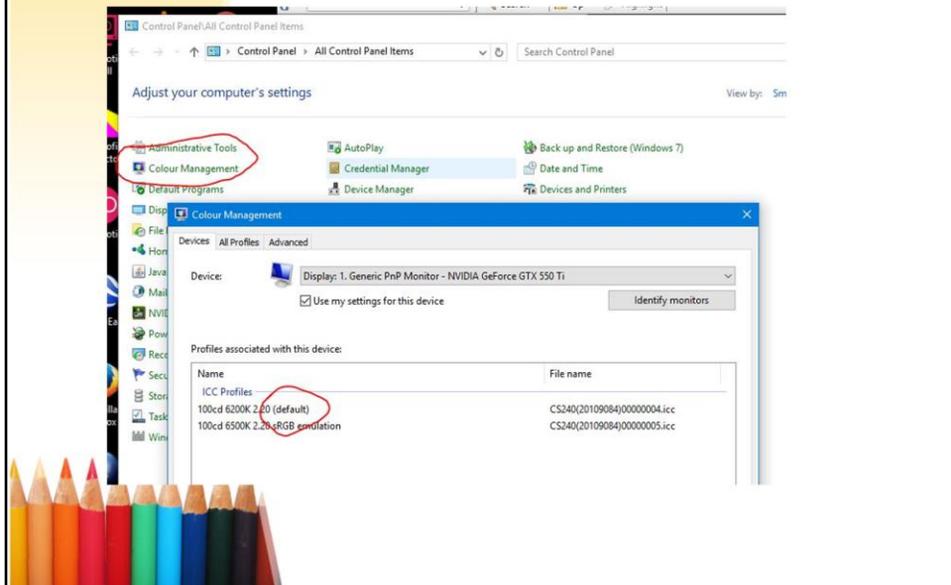
Factory calibrations and profiles aren't usually very accurate for monitors. Monitors vary a bit from model to model (even for two monitors of the same type), and the colour varies with time. Better to calibrate/profile yourself.

By contrast, printers don't vary so much from one to another (of the same type), and they don't vary so much with time. Profiles provided by the printer manufacturer (or paper manufacturer) may often be good enough.

Calibrating/profiling a monitor

This shows the profile that has been set. This is done by the profiling program – normally the user doesn't need to adjust this.

Colour-managed programs (Windows)

- Photoshop, Elements, GIMP, PSP, Lightroom
- Windows Photo Viewer
- Firefox, Chrome, Safari
- NOT:
  - IE, Edge, Win 10 Photos app, FastStone, IrfanView
  - Windows Desktop
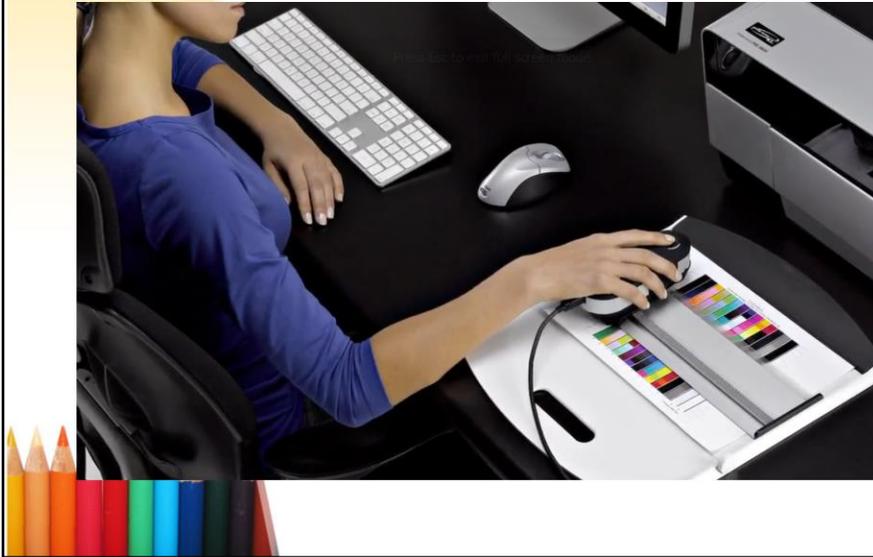- Colour management is done by programs, not Windows (or Mac OS)

Note colour management done by programs, not the operating system (Windows or Mac OS).

Colour managed programs work automatically. Normally no need to "turn on" colour management.
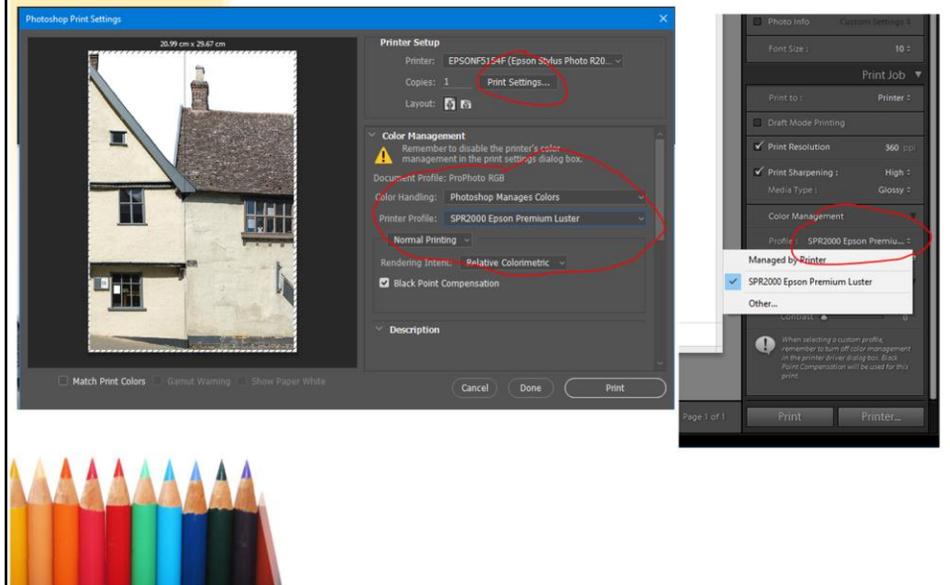
Calibrating a printer
(or use supplied profiles)

The spectrophotometers needed to profile printers are much more expensive than the ones used for monitors. However, some services will do it for you. Print out the test pattern on your printer, send it to the service provider and they will make a profile and send it back to you.

Using printer profiles – program settings

For colour managing a printer, as well as using a colour-managed program, you need to tell the program doing the printing which profile to use. This is because printers have multiple profiles – one for each paper type. Monitors have only a single profile, and you don't have to tell the program which one to use.
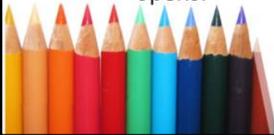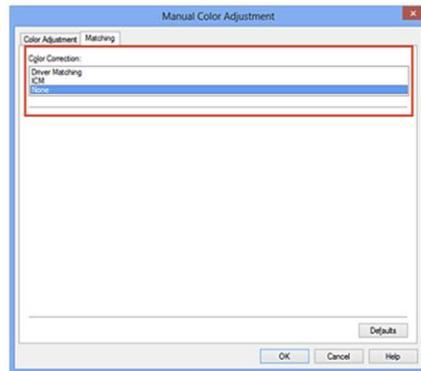
Using printer profiles – Epson printer settings
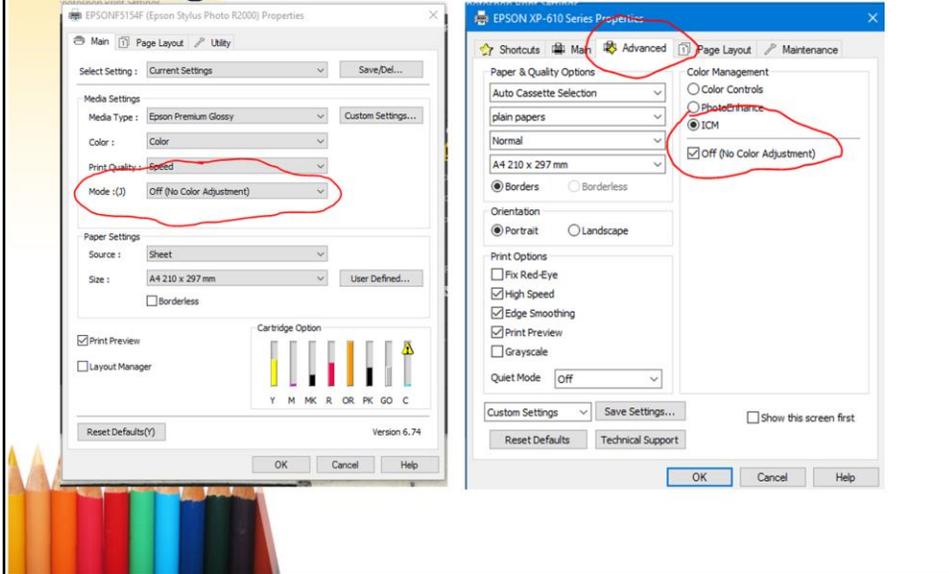
As well as telling the program which printer profile to use, you must tell the printer driver not to do any colour adjustment. This shows typical settings for Epson printer drivers…

…and this shows typical settings on Canon drivers.

In both cases, there may be a setting to say that you are using colour management, and to turn "off" all adjustment in the printer driver.

Summary – how to colour-manage

- To use colour management with a monitor:
  - Calibrate/profile the monitor
  - Use colour-managed programs
- To use colour management with a printer:
  - Use supplied profiles or create your own
  - Use a colour-managed program, tell the program which profile to use, and turn off all colour adjustment in the printer driver

Once the monitor is calibrated/profiled, colour management just works. Nothing else to do except use colour-managed programs. And recalibrate the monitor every month or two.

For printers, the extra steps are to tell the program which printer profile to use, and tell the driver to turn off all colour adjustment.

What if you don't use colour management

- Stick to one colour space: sRGB
  - Create sRGB images in camera (or in the raw convertor)
  - Use a "standard gamut" monitor (which will be close to sRGB)
  - Use printers that emulate sRGB (most do by default)
  - Set every option everywhere to "sRGB"
  - You need sRGB for the web
- No need for colour management if everything is the same colour space.
- In practice, monitors aren't precisely sRGB, and printers aren't precisely sRGB, so this is not quite so accurate as using colour management.
- Does it matter that it's not accurate?
  - Most people prefer pretty, vibrant colours to accurate colours

You need colour management whenever you need to convert from one colour space to another, or the colours will be wrong. So – stick to one colour space, an then there are no conversions needed.

In practice, that one colour space has to be sRGB.

I think not using colour management is more complicated!

These are unadjusted pictures from online brochures for televisions. The colours are certainly not accurate! Most people prefer vivid colour to accurate colour.
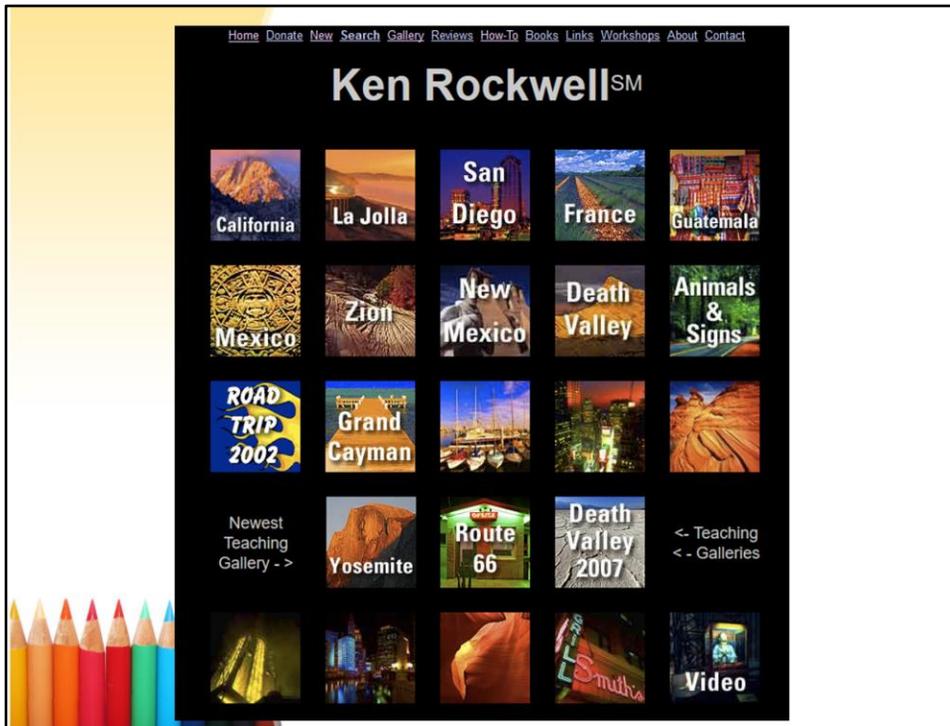
Ken Rockwell's two-step colour adjustment process:
1. Turn the saturation up to 100%
2. Enjoy!

Ken Rockwell says colour management is not necessary. It's certainly not necessary for him: he just sets colour as high as it will go. That's not wrong: it's just his style of photography, with bright colours that don't have to be accurate.

Ken is a bit extreme in his liking for bright colour, but most photographers will, in many photographs, use higher saturation than the original scene.

Colour management isn't about reproducing the original scene colours, but accurately and consistently representing the colour on the screen.

Advantages of colour management

- More consistent colour, takes the uncertainty away, gives a controlled environment
  - No more *"why the heck did it come out **that** colour ??????"*
  - If the colour looks wrong, it's the image. It's not the monitor, not the printer...
- More accurate colour
  - No device has *exactly* sRGB colour space
- Without colour management, you can't be sure image colour is what you want
  - Have you compensated for an error in monitor colour by tweaking colour in the editor?
  - There's no way of telling, as you don't know if your monitor is accurate
- Enables you to get to full range of colours your camera can capture (by using wider colour spaces). You can work in any colour space.
- If you use any colour space except sRGB, or a wide-gamut monitor, then without colour management colours are likely to be very incorrect.
- And colour management is easy! It saves time.
  - With colour management, no more tweaking of monitor or printer colour

Colour Management

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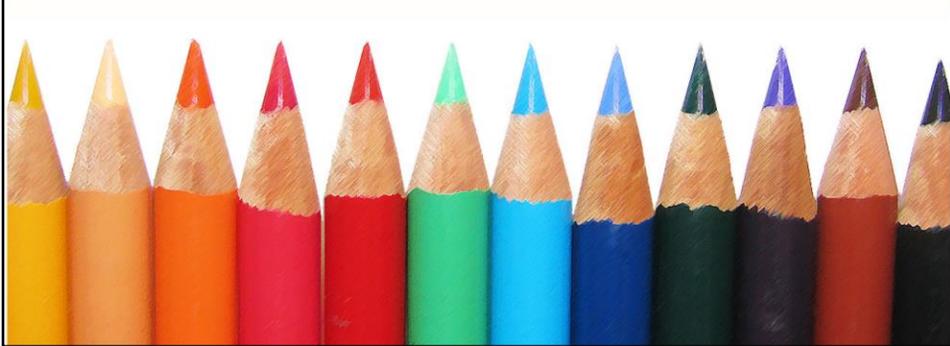- And a copy of these slides (with notes).

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

Notes from a talk given to Framlingham Camera Club, February 2016.

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Additional slides

- The following slides are not used in the presentation.

In which colour space should I keep my images?

- If you don't use colour management, use sRGB. Always.
- If you use colour management, can use any:
  - Converting to a narrow working space such as sRGB risks losing colours
  - Does it matter? Yes, for bright colours.
  - For jpegs, consider Adobe RGB
  - For 16-bit TIF, consider ProPhoto RGB
  - But if the image is already sRGB, keep it there
- For the web, convert to sRGB before uploading.

Quick workflow recommendations

- If you don't profile your monitor or you don't use colour-managed software, then set everything to sRGB.
- If you shoot jpeg, probably stick to sRGB.
- If you're uploading to the web (or FCC DPI), convert to sRGB first if not already sRGB, and embed a profile.
- If you have a wide-gamut monitor, to get correct colour 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. 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.

Working space

- Editing programs use a colour space called the *"working space"*.
- The program uses the working space internally for the maths.
- Often there's no choice. Lightroom always uses ProPhoto RGB.
- For Photoshop and some other programs, you can choose the colour space that the program uses internally.
  - *Choose only a standard space such as ProPhoto RGB, Adobe RGB (or sRGB if you don't use colour management)*
  - *Never "Monitor RGB" or a device profile*
    - *Use "Soft Proofing" if you want to see device colours*
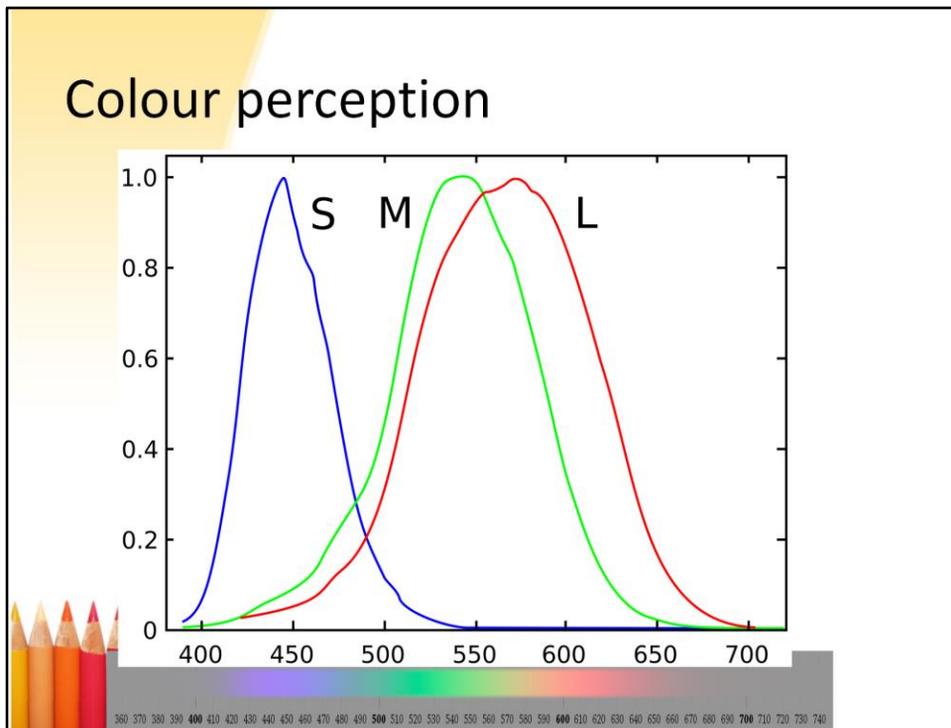
Our eyes do not discern wavelength directly. This is unlike our ears, which can discern individual frequencies of sound to a fine degree.

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.

Definition of colour

- Colour is not the same thing as wavelength.
- 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.
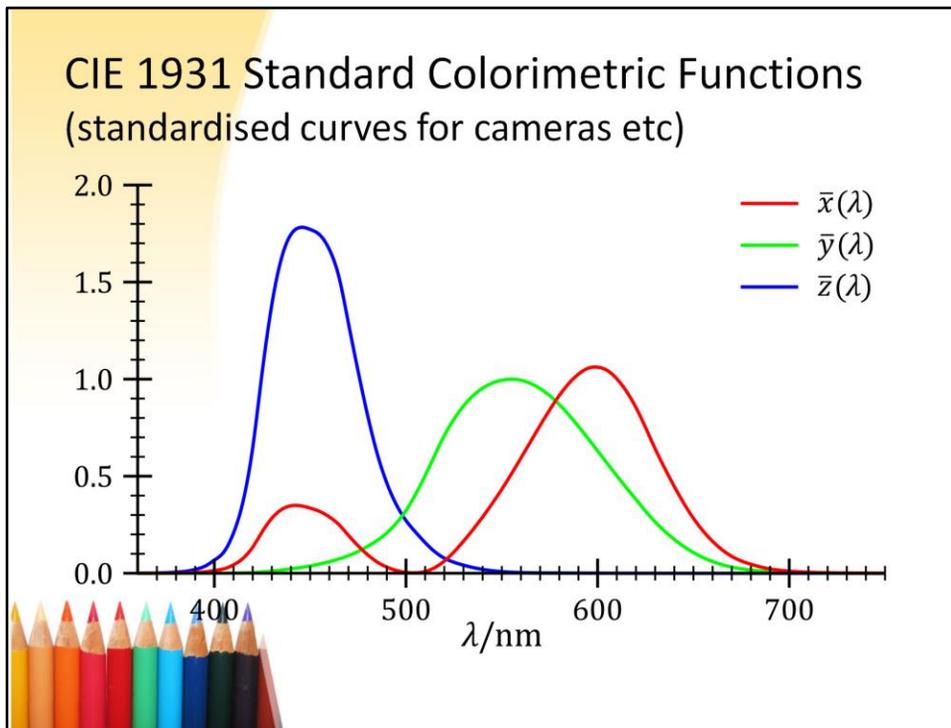
In practice, camera sensors are designed to map these three standard curves, which are idealised approximations to the responses of S, M and L receptors in our eyes.