

# Introduction to color management

Author: Arnaud Frich

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Through these pages, I will teach you the specific vocabulary linked to color management. As this is a quite new vocabulary, this is often not part of the well known vocabulary linked to argentic technics. Here, monitor calibration devices and ICC profiles replace tubes, chemical products and thermometers.



## Key points if you are a beginner ...

**Here are the key points to remember on color management. The rest of this page will be dedicated to those who want to go into more details.**

**Color management is a set of tools and concepts that try to preserve as much as possible, the same colors from the shooting to the final use : printing or Internet. All this to avoid those too often heard things : "Oh, the colors of my prints are very different**

from my monitor..." or "your colors are not like mine at home..." or even "Your monitor is dark !" and so on...

Color management thus serves to align all monitors, printers on the same color values, at least, close to it. The goal is for example to display a photo at home, a photographer place, or your neighbor with the same aspect ... For this, we will need to [calibrate](#).

The basis of color management is constituted by the calibration of the different devices that we will be used and in the first place comes the [monitor](#). The digital camera can be calibrated but only under certain conditions that cannot be of interested when starting. Then, remains to [calibrate the printer](#).

But how calibration works ? Calibration is used to know and then neutralizing the defects of a monitor, for example so that it displays the "right" colors, or in other words, the correct colors and if possible very close to all other calibrated monitors. The uncalibrated monitor can therefore have many display defects that calibration will attempt to correct. Once calibrated, all monitors, all printers must be close enough to each other in terms of colors and most importantly, you must have the satisfaction of saying : "Great, my print and my photo displayed on the display are identical or, at least, very close to each other".

Next key point : [How does the human eye sees colors ?](#) ▶

Color management : Here is a step that should not be neglected and yet is too often ignored by photographers and graphic designers, when they work their images on a computer. Yes, you will need proper tools - monitor calibrator or colorimeter, spectrophotometer, color target etc ... - to get a good color management but it is perhaps not that complicated ... This is just a little longer to explain than depth of field because there are many important concepts and new vocabulary. Indeed, none of our ancestors have told us about ICC profiles, gamut and Lab colors !



However, I hope to show you in the pages of this tutorial that color management is not reserved to some elite, but must be part of any photographer culture - amateur or professional - just like focus, depth of field or light measurement. Color management with ICC profiles is the technical basis of our new laboratory, our digital laboratory where the colorimeter and color target have replaced our thermometers and tubes.

In the process of accurate nature color reproduction, photographers, even amateurs, who sometimes made significant investments in their digital camera equipment for its qualities, are often unpleasantly surprised to see that the colors displayed on the monitor and the print that comes out of their printer are significantly different ! From one step to another of his color workflow, colors change. Each device introduces its own "deformations" when it succeeds to reproduce the color ! It is quite painful, who should be believed ? Why ? Is my monitor or my printer right ? Who is right ? What and how to fix it ? These are questions that I have asked myself because I thought I was wasting a lot of paper and ink away, even though I had the feeling of getting a correct result at the end. The problem : each time I spent a lot of time on each print before being satisfied. In these pages on color management, I will try to provide some answers and

explain how to control the color aspect of the images from one end to the other of the color workflow.

I address here all my warm thanks to Gerard Niemetzky and his team from Color-academy for their valuable advices during the first writing of this guide in 2004, and all those near and far people who have supported me. Since then, many others have helped me to develop it... So thank you all and enjoy your reading.



## **Color management problematic**

**In a perfect world (!), our eyes, our digital cameras etc... would all see the same colors ! In reality, for the photographer who works his images on a computer, it is quite different. But by the way, how many colors can the eye see ? How to go from one device to another with the same perceived colors ? How many different colors your monitor can really display ? And your printer able to print ? How to represent these colors with numbers ? What color distortions are introduced by a color reproduction device, even of high quality ? How to fix it ? Here is a sample of the questions that often arise when photographer works with digital devices ...**



**Color management** tools are here to simplify your work and allow you

to obtain a controlled result, during the processing of an image, from scanner or digital camera to inkjet or offset printing. Through the calibration of all the elements of the color workflow, as well as tools of our color management system - CMS - we may consider each device color defects to correct them and get a very high quality result throughout the processing flow of our photographs.

## Tips to understand ...

Since the beginning of the last century, we know that the human eye sees the world through color-sensitive cells lining the back of his eye. It is noted that there are two broad categories: rods especially sensitive to the amount of light and cones sensitive to color but with a singular peculiarity : these cells are especially sensitive to **Red, Green and Blue**. So for almost a century, we know that the human eye can only see a few colors directly but rebuild all others in his brain by the mixture of these three so-called **primary** colors. Since man sees in RGB, engineers made computers, monitors, digital cameras or printers work on this principle. So each pixel in your camera sees colors in RGB. To an RGB value corresponds a color. It's very simple to understand and implement. But then, if for a given device, a given RGB value actually corresponds to a color, the same value is not strictly the same color for another device. An example to finally understand the problem when it comes to RGB : television. Even if they receive the same television program - so the same RGB signal - they do not all display the same colors ! The color model is based on the model of the human eye but takes us into a weird world where a given RGB signal does not only match a single color for everyone but multiple colors. Then, is there an absolute color model, one where the colors are not described by the RGB values but something absolute ? This model has been invented and called the Lab color model. Lab colors are absolute colors, for which a

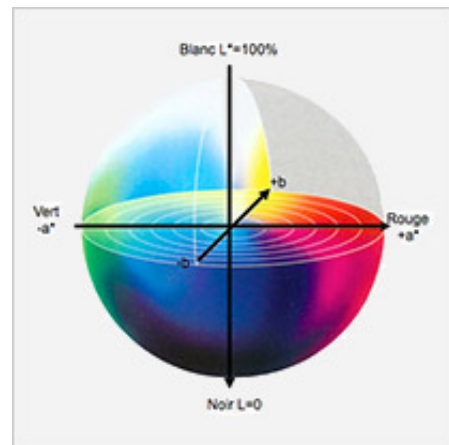


Lab value corresponds to one and only one color, that can be identified by its wavelength. The art of color management is to know, what RGB signal matches a given Lab color.



### Essential !

**The core of color management is based on all colors actually perceived by a "standard" human eye that is to say Lab color. Indeed, Lab color corresponds to one and only one absolute color for this "standard" eye. The calibration of each device will allow to know what signal RGB or CMYK color corresponds to the unique Lab color, knowing the fact that no device does it in the same manner. To display a color - a Lab color - a monitor will have to display a given RGB signal and another monitor, even from the same brand, another RGB signal. To a Lab color corresponds several RGB colors and it is essential. So vice versa, a given RGB value represents a multitude of Lab colors depending on the device that will reproduce it. So it is just needed to translate each RGB value of a given equipment to Lab colors, when assigning an ICC profile before sending them to the next device through a conversion - which change the RGB value to another R'G'B' value - ... to print, display the same Lab color with a CMYK or RGB signal of its own.**



**In color management, it is not an RGB or CMYK info that is transmitted, paradoxically, even if so practical and directly based on the human eye way of working, because it is too dependent on the characteristics of a device, but a Lab color - unique - absolutely independent of any device, color perceived by a "standard" human being. An ICC profile contains the color characteristics of each device and is in charge of achieving this work of correspondence !**

So, if your camera saw a red from the Lab colors, that "translates" it into its own RGB value, it will be possible to print this red, or a red from Lab colors perceived as close colorimetrically if not printable, thanks to the tools of color management - calibration, ICC profile creation, assigning ICC

profiles, conversion, etc..

Color management and its ICC profiles creation tools therefore make possible to know a lot about a specific device : if this device can actually see, print or display a color and if it is technically possible for it, how does it do that ? So in other words, with which characteristics or "defects", does it do that ? Whether it is possible or not, the information is contained in an ICC profile, its ICC profile. To create it, a colorimeter, a spectrophotometer for printers and a color target for digital cameras are used. So, an ICC profile is the identity card of a digital device.



## Quick summary of the color management guide

This guide on color management is divided into three parts : the **basic concepts and vocabulary** of color management, **calibration** of different devices - monitors or printers - and finally the **setting up** and use of ICC profiles with Photoshop.

And get used to the idea that your monitor calibration devices and other color targets are simply replacing your thermometers and tubes and all this without staying in the dark room !

Now, let's get started and try to know more about... [Eye and colors](#) ▶



# Eye and colors

The eye "sees" the colors in quite a weird way finally! To sum up, the light-sensitive cells covering the retina only see in blue, red and green. And yet, we see thousands or millions of colors. Everything seems to happen in the brain. And by the way, how many colors are we really able to see?



## **Key points if you are a beginner ...**

**Here are the key points to remember on eye and colors. The rest of this page will be dedicated to those who want to go into more details.**

**How does the human eye sees colors ?**

**The human eye sees colors through the light-sensitive cells at the back of the retina. it is lined with two types of photosensitive cells:**

- **cells sensitive to colors : cones,**
- **cells sensitive to light quantity (they see in B&W) : rods.**

**The cells sensitive to colors are in fact particularly sensitive to the color red, green and blue. So all colors are "constructed" by our brain and are not seen directly.**

**First of all, let's talk about colors, but how many color is an eye of a "standard" human being able to see ?**

**A "standard" eye can distinguish about 200 nuances per color. The human eye sees therefore approximately:  $200 \times 200 \times 200 = 8.000.000$  colors ! (Note that we are far from the billions of**



colors, that some adds on monitors or televisions are talking about).

Next key point : [colors and computer science ?](#) ▶

The eye is an extremely complex organ, fruit of a very long evolution. This is what enables us to see the world in colors and see millions of them. But how does it work? What is a color and how many different colors can the eye see? Why and when do we talk about gamma? How to represent it digitally? These are questions that I will try to answer now.

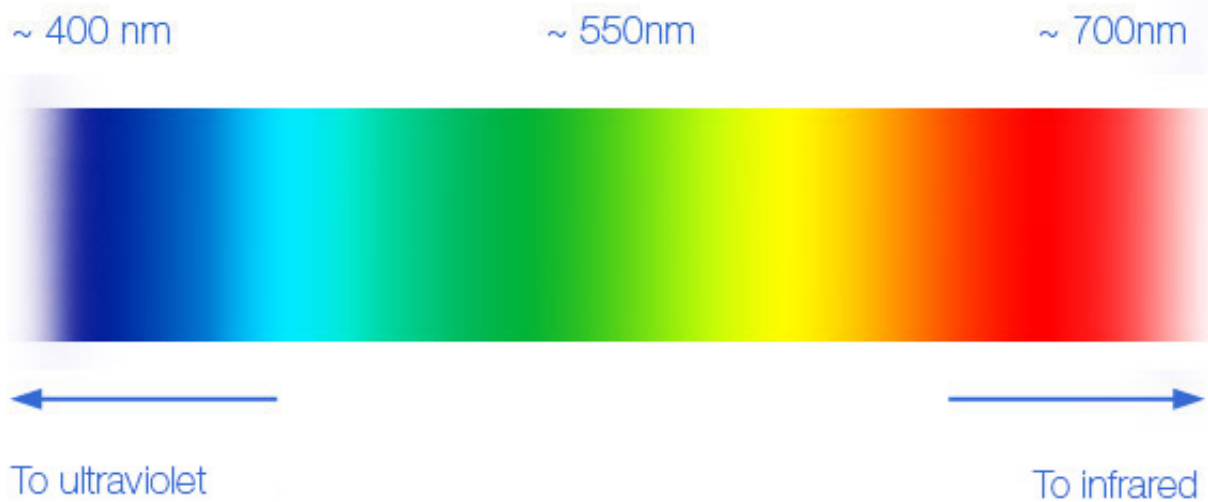


## **The eye and the vision of light**

**Before talking about how the eye sees colors, let's have a look at what light is.**

### **Properties of the light**

Color is a property of the light that is an electromagnetic wave. Like all waves, it can have different frequencies that give it its "color", when speaking of colors visible by humans. When the wavelengths are short - around 380 nm - we perceive them as blue-violet and when they are longer - around 700 nm - we perceive them as red. The whole set of visible waves is called the visible light spectrum. Beyond the visible light spectrum for humans, on the sides of short wavelengths, are ultraviolet, X-rays and gamma rays and on the side of long wavelengths, infrared and radio waves. Traditionally you can obtain a spectrum of the sunlight, if it passes through a prism or through water droplets. This creates a rainbow in certain weather conditions where one perceives all colors below.

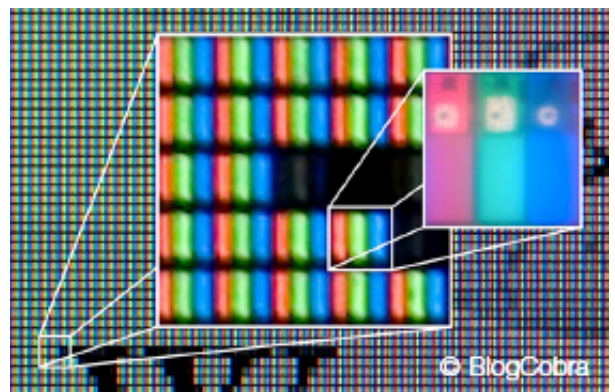


Light spectrum visible for humans, from ultraviolet to infrared.

## The eye

An image is formed by the cornea (transparent) and projected at the back of the [eye](#), on the retina. This one is literally covered with nerve cells - the photoreceptors - sensitive to the quantity of light - the brightness - thanks to the rods, but also to its quality - the colors - thanks to the cones. Cones (therefore sensitive to the colors) are not all sensitive to light color in the same way. Some are especially sensitive to red, others to green and finally the last kind to blue.

However, the eye sees all the colors of the visible spectrum - above - from red to violet in a continuous way, so it is through the mixture of these three colors that the brain is able to "produce", to build all other colors. That is why the RGB color model was

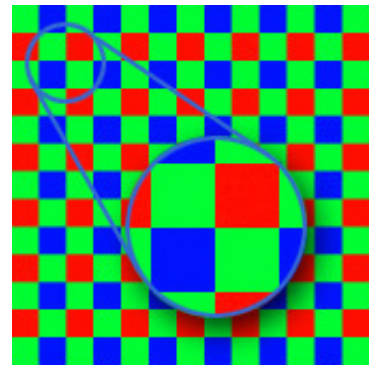


invented: to match the functioning of human eye. That is why monitors or colorimeters only have pixels in Red-Green-Blue or RGB and only see in RGB! They reproduce the human eye's way of functioning with three types of pixels. The screen just needs to turn on, more or less, each pixel of the display to reproduce ALL the colors! If you get really close to a computer monitor, you will see the RGB pixels separately but they are made small enough so that, seen by a human being at a normal distance, they are seen

as amalgamated, into a single pixel with multiple colors.

### **Fun fact!**

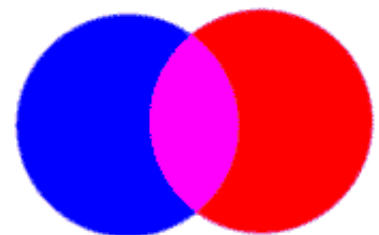
The eye is not sensitive to all colors in the same way, just like it is more sensitive to small differences in brightness in low lights than in high lights, by the way. Scientists noticed that the eye has a more extended sensitivity towards greens than towards the other two primary colors (R and B). That's why digital cameras sensors have two green pixels for a red and a blue pixel when you look at it with a magnifier. It's the same with screens or digital sensors. When you look at them with a magnifier or a microscope, you can see that they have two green pixels for a red pixel and a blue pixel.

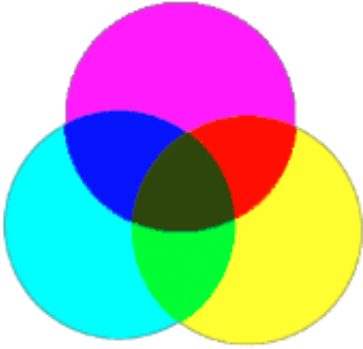


### **Millions of colors with three or four!**

A monitor or printer does not manage colors in the same way : the screen, like the eye, works with so-called additive colors - Red, Green, Blue or RGB to obtain white by addition as you can see in the center of this color animation below - while a printer works in subtractive mode - Cyan, Magenta, Yellow, Black or CMYK to obtain black by subtraction (below).

Concretely, with a screen that is thus working in additive mode, if one does not send any RGB signal to the pixels (0, 0, 0), the screen remains black. It is black by default. For white (255, 255, 255) each Red, Green and Blue pixel must be lit, as shown in the figure on the right. Other colors are obtained by changing the value of each primary color. To display yellow (255, 255, 0) for instance, the blue pixels must be turned off (the screen is yellow at the intersection between green and red as blue pixels are off). Only three colors require only one pixel. The three primary colors and their variations in brightness (from 0 to 255). All others, that is to say, the millions of others, will be a mixture of at least two primary color pixels, more or less bright.





With a printer, you start with a sheet of paper already white by default because it reflects all wavelengths of visible light equally. So here, it is the opposite, if you want black you will have to spray inks of complementary colors on this sheet, that is to say, Cyan, Magenta and Yellow which have the characteristic of absorbing each time a portion of visible light. In practice, you will also have to add Black Ink, as 100% of the other three colors do not create a deep black, due to impurities in the inks but a very dark brown. You can clearly see in the picture on the left that the center is brown and not black. Those inks projected in the same area will have the property of absorbing all light radiations. This area will thus now appear black. If you want the paper to look blue, then magenta and cyan must be projected over the same area. All light rays except blue will then be absorbed. Only blue wavelengths of light will be reflected there.

By convention, it was decided by the International Commission on Illumination - CIE - that the primary color red is a light with a 700 nm wavelength, green 546 nm and 436 nm for blue. Whatever the wavelength of their RGB pixels, screen manufacturers still try to reproduce colors as best as they can...

And finally, it is important to know how a color is "digitally" described. Typically, the colors are characterized by three or four digits, depending on whether you are working in RGB or CMYK, still with the aim to reproduce the functioning of the human eye. Therefore a color will be recorded as - 158, 128, 84 - in RGB and - 80%, 64%, 21%, 12% - in CMYK. But why these figures and to what color perceived by an eye does it correspond to?

**To be remembered!**

- **Light is an electromagnetic wave, which visible wavelengths for**

humans range from about 380 to 700 nm (from violet to red).

- The eye "sees" thanks to sensitive cells, some to colors and others to brightness only. The color-sensitive cells are called cones. They're especially sensitive towards red (ground), green (chlorophyll leaves) and blue (sky). There is not a cone for each color.
- Cones are sensitive to about 200 shades for each color, from the darkest to the lightest : it thus represents  $200 \times 200 \times 200 = 8$  millions different colors for a "standard" eye.
- By recomposing or mixing these three so-called primary colors, the brain "sees" eight million colors.
- Most people "only" see one to two million colors! And that is already a lot.

The next page is dedicated to the way IT processes these colors, as it is only able to operate with 0 and 1 - [Colors and computer science](#) ▶

[Next page 3/10 : colors and computers science](#) ▶



# Computers and colors

On the one hand, our eye and its complexity: it is able to see millions of subtle colors. On the other hand, our computers, so powerful nowadays. How do they speak the same language?



## Key points if you are a beginner ...

**Here are the key points to remember on computers and colors. The rest of this page will be dedicated to those who want to go into more details.**

### How computers code colors ?

**Computers only know 0 and 1, to work with. This is called a bit. So if colors are coded on a single bit, we only have two options : 0=off and 1=on. This does not give many nuances ! To have enough nuances - we have seen on the [previous page](#) that we need at least 200 nuances per color - so it is necessary to code the colors on at least 8 bits per color which gives 256 possibilities each time. So, colors are coded on 8 bits 3 times (for RGB). It is said that colors are coded on 24 bits.**

**Next page : [gamma of a monitor](#) ▶**

The eye is an extremely complex organ, the result of a long and slow evolution. This one allows us to see the world in color and see millions of them. But how does he achieve that ? What is a color and how the eye can see different colors? Why and when do we talk about gamma ? How to represent it digitally speaking ? These are questions that I will try to answer now.

## Colors in the digital era

How to get to code millions of subtle colors with 0 and 1, since that's all a computer can do (but it does it very very fast and repeatedly if necessary, whew!)?

## Colors and computers

Researchers have succeeded in modeling digitally the complexity of colors seen by a human being. They had to start from the basic way of working of a computer, that is to say, 0 and 1 (this is called a bit) and the human eye that sees in RGB on 200 levels of colors on an average basis. For that, they had to invent models based on these 0 and 1 to display, for example, one color or another on a monitor. These mathematical models are the bit and byte (a byte is 8 bits).



### Bit and Byte

**A bit has two possibilities : 0 or 1. It is written  $2^1$ . A byte is made of 8 bits, that is to say a sequence of eight 0 or 1. It represents  $2^8$  possibilities (8 choices of 0 or 1) or  $2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 256$  combinations!**



I will take a red pixel on my monitor as an example and assume that I only have these two numbers - 0 and 1 - at my disposal, because I have a very rudimentary computer! Either I send 1 (one small electrical current to my pixel) and I switch it on, or I send a 0 (no electrical signal) and it remains off. I thus have two possibilities: 0 or 1. 0 to tell the signal: switch it off and 1 to tell the signal: switch it on! However, I know that my monitor is capable of displaying the red pixel lighter or darker nowadays, with subtle differences, subtle differences my eye is able to perceive. The same is true for the other two colors G and B. The goal, let's not forget, is to display an infinity of colors! So I need more than a bit but then how many bits, how many figures do I need to code my signal?

- With one figure - 0 or 1 - I have 2 possibilities. My signal is coded on 1 bit, written  $2^1$ .
- With two figures - 00 or 01 or 10 or 11 - I have 4 possibilities of brightness level: off, dark, light, very light. My signal is coded on 2 bits -  $2^2$ .
- With three figures - 000 or 001 etc ... - I have 8 possibilities. My signal is coded on 3 bits -  $2^3$  or  $2 \times 2 \times 2 = 8$ .
- And so on... to what limit?

But after conducting tests on numerous human beings, other researchers of the CIE around 1930 found that, **in the best case**, 200 shades in a gradient of one color could be perceived as continuous, from the darkest to the lightest, as in the example below. There are at least 200 shades of blue in the gradient below (top one). If there were less, you would have the impression to see bands - known as tone breaks - in this same gradient, bottom one here.



And these are human beings who have an excellent acuity because after a test conducted in 1998, most people only see 2 million color shades. So on how many bits - how many digits - do I have to code my signal to have at my disposal at least 200 combinations per primary color ? The result is  $2^8 = 256$  possible values from 0 to 255. With 7 digits -  $2^7$  - I would have only 128 possible combinations by color. Incidentally, for many people it would have been sufficient! With 8 bits, I have  $256 \times 256 \times 256$  possible combinations (256 for each primary color) hence more than 16.7 million!!! Ideally, the human eye would actually need:  $200 \times 200 \times 200 = 8.000.000$  so it's even going to be too much... So, I have 16,7 million different RGB computer definitions to describe 8 million colors. As the  $2^8$  combination is unique, computer scientists gave it a special name: the byte. The byte is therefore based on the properties of human eye!



### Note about color definitions

Informations	
R:	200
V:	200
B:	200
8 bits	

**Needless to say that the eye can only perceive 200 shades per color in the best case, so it will perceive the same color if the monitor**

displays 200, 200, 200 or 200, 200, 201 or 199, 200, 200 hence three different color definitions, in this example, and I could even have gone further.

**Try it: take a color and just change it from one point on one, two or even three of its RGB componenets and you'll see that the difference is extremely subtle! The eye distinguishes 100 to 200 shades per color. That's why the word used is color definition and not color when a color is described with an RGB signal.**

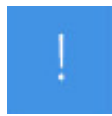
It is said that the signal is encoded in 24 bits -  $3 \times 8$  bits - so on three bytes as a byte = 8 bits. Each signal is a series of eight 0 or 1, three or four times for each RGB or CMYK color. An RGB signal will thus be written as 255, 112, 44, for example (the red being fully lit , green at 112 and blue at 44 hence quite dark).

## Colors and numbers!

Now that we know how to represent a color digitally speaking, let's send a given RGB signal, still the same - 255, 112, 44 - to different monitors (like the walls of monitors of household appliances stores). What happens there? None of the monitors displays the same color! Indeed, the RGB filters

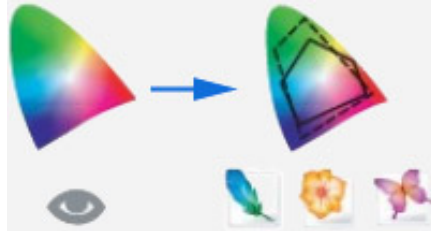


placed in front of each pixel of a screen will be different from one screen to another but even more between screens of different models or from different brands. The RGB color model does not allow to display the same color directly on several different devices. As we have seen in the introduction, a model had to be invented, independent from human eyes, their minor differences and different devices: the  $L^*a^*b^*$  model. The  $L^*a^*b^*$  color space was invented in 1976 by the CIE. A  $L^*a^*b^*$  color only matches a single color therefore a single wavelength. So for the same red pixel, displayed on each screen that was sent the same RGB signal, a one and only  $L^*a^*b^*$  color will correspond, slightly different each time.



## Very important !

To a given digital signal - so a given RGB triplet, in our example 255, 112, 44 - may thus correspond several different color feels for a person with a "normal" acuity, if it is sent to different screens for instance. Therefore, It is essential in color management and what follows to always have this notion in mind.



An RGB signal doesn't "really" represent a color - even if it is based on the model of human eye - but a digital piece of data (a color definition) which, sent to a specific device, is translated into a given color (a L\*a\*b\* color) that depends on the components that were used to make it. The RGB model is thus convenient to use since it is based on the functioning of the eye but isn't absolute at all, unlike L\*a\*b\*.

On the contrary, if I want to display the same color on multiple monitors, I will have to send them a different RGB signal! If I want to display a medium neutral grey (usually 100, 100, 100) on different monitors, I will have to send them different RGB signals, like x, y, z for the first one, x', y', z' for another rather than x, x, x as could be expected. As it is virtually impossible to know what value should be sent to a given monitor to display the "right color", they must be calibrated with a colorimeter and for each monitor, have a little file containing this valuable information: [an ICC profile](#). Therefore, ICC profile is the basis of color management.

## To be remembered!

- Computer science is about playing with 0 and 1. The smallest unite is called a bit. A bit stands for 2 possibilities: 1 = on or 0 = off.
- In order to code colors, a bit isn't sufficient: on or off because a multitude of color shades must be displayed. If a bit stands for 2 possibilities: on or off, then more bits are needed to code colors. 7 bits for instance would give 128 possibilities of shades ( $2^7 = 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 128$  possibilities) for each primary color (RGB). Colors must thus be coded on 8 bits in order to have more than the

**200 possibilities needed. It is even too much since it represents 256 possibilities with 8 bits.**

- **"Digital" colors are coded on 8 bits (255 levels where 200 would be sufficient, but we are stuck with that, due to computer structure): as this value is strong and important, since it allows to code colors that humans see, the computer scientists gave it a name: Byte.**
- **As colors are coded on one byte for each RGB component, it is said that colors are coded on 24 bits.**
- **A couple of RGB values does not represent a color in itself but only a color definition: a color definition may then represent many different colors depending on the color space that we'll see later...**

How represent one color perceived by a standard eye for a digital couple then, if for a given monitor, I have to send it an xyz RGB signal and not xxx, to display a neutral color? Here comes CIE again to answer this question. This is what we will see with [color space and color model](#), in the next page. But before that, I want to clarify another important notion which is the notion of gamma of the eye or of a monitor - The [gamma of the eye or a monitor](#) ▶

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# The gamma

Our eye, as our monitors, "has" a gamma! It simply means that our eye reacts to light in a nonlinear way. What?! In fact, our eye is not sensitive to the same increase of light when it is in a dark room and when it is exposed to direct sunlight. Light a second candle in a dark room and you will see more light BUT not twice more light. That's right! Finally, light the same candle in the same room but in broad daylight: it does not change much and yet you bring as much light as in the dark room. Surprising, right, even if you never pay attention to it?



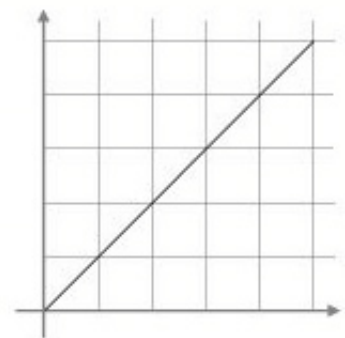
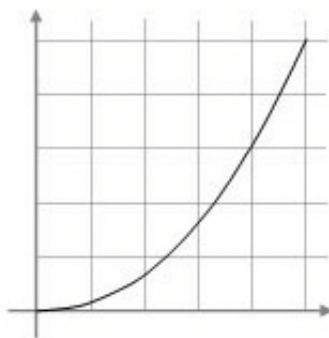
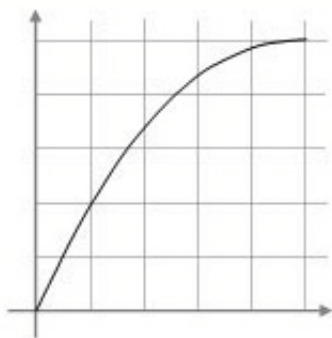
Image

X

monitor

=

Our picture



## Key points if you are a beginner ...

**Here are the key points to remember about gamma. The rest of this page will be dedicated to those who want to go into more details.**

### What is Gamma ?

**The eye reacts to light in a weird manner. This reaction to light is not regular - it is said to be non linear. What does that mean ?**

- **The human eye is more sensitive to small variation of light in a dark environment than in a bright one.**
- **If you light two candles instead of one in a dark room, you will not perceive twice more light, but only more light. The eye response is not linear.**

**That's what gamma expresses.**

**But usually we talk about gamma for a monitor and not for the eye?**

**It is precisely to try to reproduce the behavior of the eye that monitors have a gamma.**

**Hopefully, everything is done automatically in our computers and there is nothing to do, except in specific cases that are of no interest for beginners and they will therefore not face!**

**Next key point: [color spaces](#) ▶**

It is especially when talking about monitors that the notion of gamma is used. Although unfortunately its content remains quite uncertain, it is now important to pay closer attention to this vocable to understand the eye and human vision and thus choose your monitor's gamma with all parameters in sight: 1.8 or 2.2, the two most famous gammas to calibrate your screen and to question the so peculiar rendering of an HDR photo?



## **Vocabulary and general notions**

The vocabulary of color management is full of new words compared to the vocabulary that was used in a lab for film-based photography: now we're talking of gamma, response curve...

### **Gamma**

The notion of **gamma** - of an eye, of a monitor or of a scanner - is a concept that comes up regularly in the vocabulary of color management, particularly when calibrating the monitor. It is simply a mathematical curve (a function) that enables to know the connection - the correlation -

between an input signal and the response of a sensor, for instance, our eye. This function is written as follows:

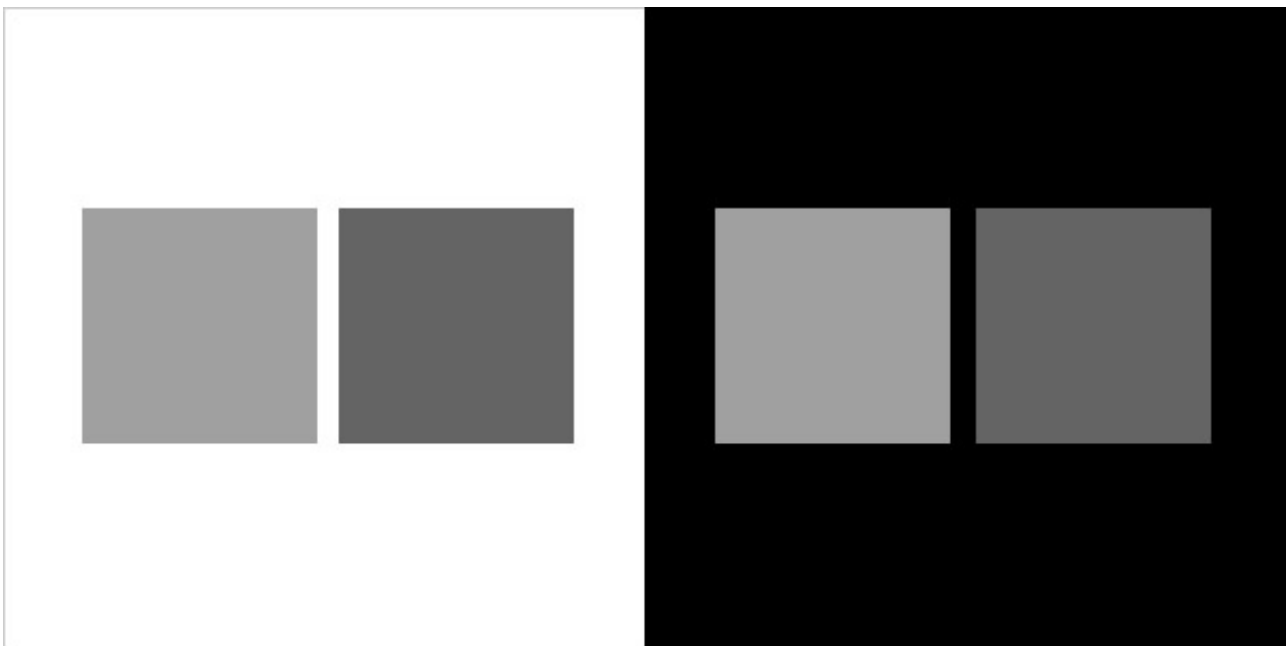
$$\text{output signal} = \text{input signal}^{\text{gamma}}$$

(The output signal equals the input signal to the power of gamma)

Indeed, our eye has this singular characteristic not to have the same sensitivity (in quantity) in low light and high light. The same difference in brightness (eg 10 lumens) will be seen in a dark environment, but not at all or almost not in a bright environment. The eye is much more sensitive to small differences of brightness in low lights than in high lights. If you light a second candle in a dark room, you will see more light but it will not even be noticeable in a room in broad daylight. But in both cases, you will have added the same amount of light.

Therefore the response is not linear.

Finally it should also be noted that this non-linearity is different depending on the light environment, so this "gamma" differs depending on the lighting ambiance, as shown in the figures below.



Contrast and light environment: the two grey squares have the same RGB values of 160 and 100 on a white background on the left and on a black background on the right. It clearly shows that the contrast between these

two squares is more important on a white background!



Summary! The gamma of the eye is continuously changing depending on the light around and the contrast of the scene viewed. It is thus different on a foggy day and in plain sunshine or in front of a screen and when it looks at a photo print. It varies between about 2 and 3, with the famous 2.2 when watching a screen.

Here's one surprising specificity about the human eye but it is rather a specificity of the human body and not only of its eye. This characteristic enables the human body to feel important differences without saturating its sensorial sensors too fast.

### Dynamic of the eye

Why? The reason is very simple. To adapt to different light environments while continuing to see something without saturating the nerve cells too fast, the eye has a necessary appendix: **the iris**. It can open up (slowly) and close (almost instantly) when the light variation is too important - you can feel it when you leave a room where you stayed long enough in summer, for example. Under these conditions, the iris measures approximately one millimeter in diameter and lets few light pass through, while at night, after a good quarter of hour of adaptation, the iris fully opened measures six-seven millimeters in diameter. But for a given iris diameter (from 1 to 7 mm), the eye is able to see about 14-16 equivalents of photo stops out of the range of 24 stops. The absolute range of the eye is thus 24 stops, but thanks to the iris, you can only access 14-16 stops at the same time. Remember that the best digital cameras today are capable of shooting a maximum of 11 to 13 stops, like for instance the famous Nikon D810 but





also the Pentax 645Z or also the Hasselblad 50C!

So why do HDR images have such a characteristic rendering?

Well, quite simply, because the gamma of the eye watching a monitor isn't the same as the gamma of this same eye when it was in front of the scene shot. Since we're trying to reproduce using this technical process called HDR technique and because it is "technically" possible to merge multiple images together (it isn't uncommon to merge 6 photos with a diaphragm gap between two shots) and it is possible to "recover" a "crazy" dynamic of over 16 diaphragms that we're trying to watch with a 2.2 gamma hence not adapted to view over 16 diaphragms. The images thus doesn't seem very contrasted, weird-looking. HDR, in fact!



So in other words, a photo with an important dynamic - over 14-15 diaphragms - will always have this typical rendering displayed on our screens with fixed gamma.

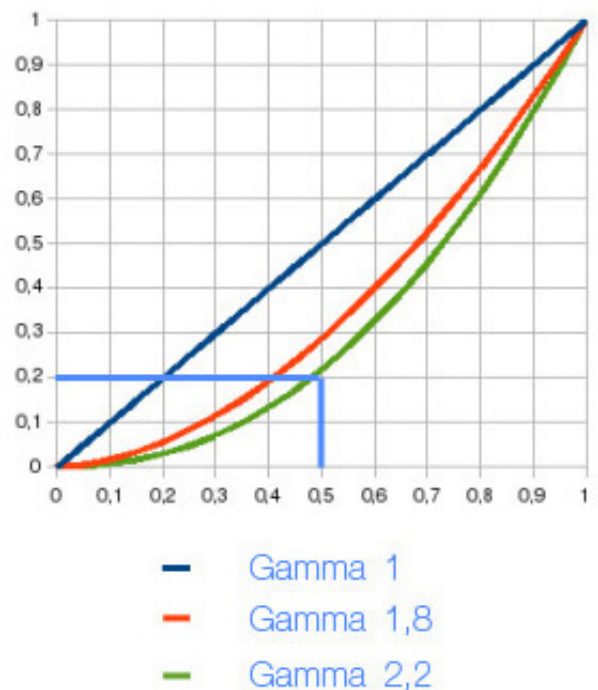


HDR rendering with only one photo in RAW format! The dynamic of certain recent camera bodies with Sony sensors - Nikon D810, Pentax 645Z, Sony A7R2, etc. - is so important - about 13.5 diaphragms but just under the limit of 14/15 diaphragms - that when you'll move the cursors "High lights recovery" and "High shadows recovery" in Camera Raw or Lightroom to the maximum, you bypass this limit and end up with an HDR image in one photo. What it must be with the brand new PhaseOne diaphragm, announced at 15 diaphragms!!!



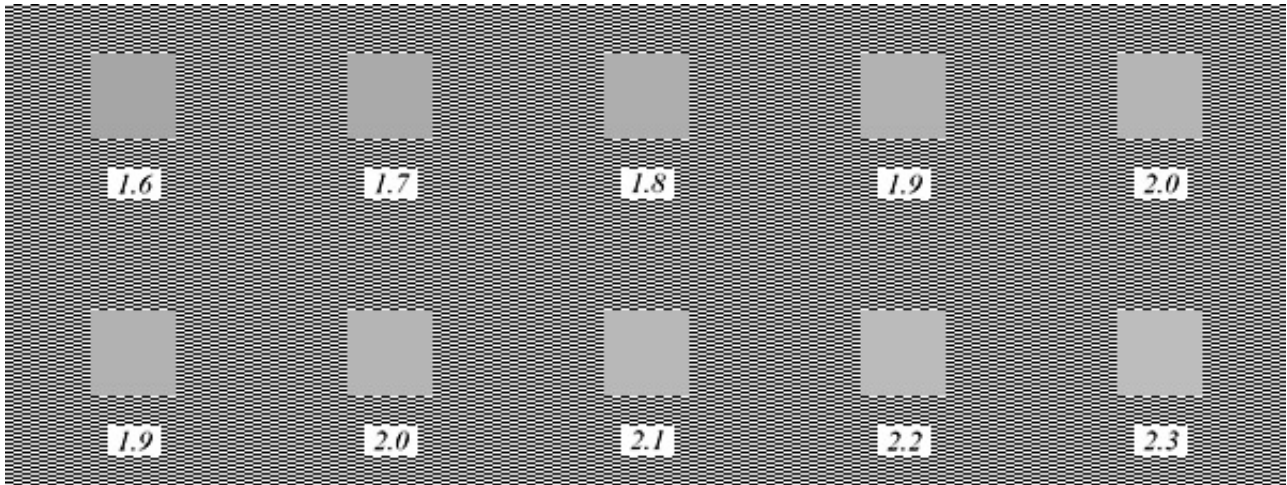
## Response curves and gamma

So, if I send to my eye a light signal located exactly between 0 and 255 (minimum and maximum levels that can be seen), hence at 128, it will have the sensation of seeing a dark grey of around 0.2 on a scale from 0 to 1 and not 0.5 as one might think. This correction is thus applied to the signals that are sent to graphic cards to fit this specificity of the eye. Only raw files - RAW - of digital cameras have a gamma of 1 because their sensors have a linear response to the light they receive (blue curve). This is important to know if you are shooting in RAW.



Control of the gamma of your monitor

When getting close enough to the monitor, you can see that some samples seem to blend into the checked image used as a background. If you get far enough from your monitor - about a meter - you'll see that one or two samples seem to disappear into the background of the image and the area seems to become uniform. At this viewing distance, you just have to locate the area - so the gamma - which seems the most homogeneous and where you no longer distinguish the patches from the background.



Look for the patch that fades into the background of the image. This is a fun test when you compare it to the gamma chosen during calibration. There is often a slight difference, not really annoying though.

#### **To be remembered!**

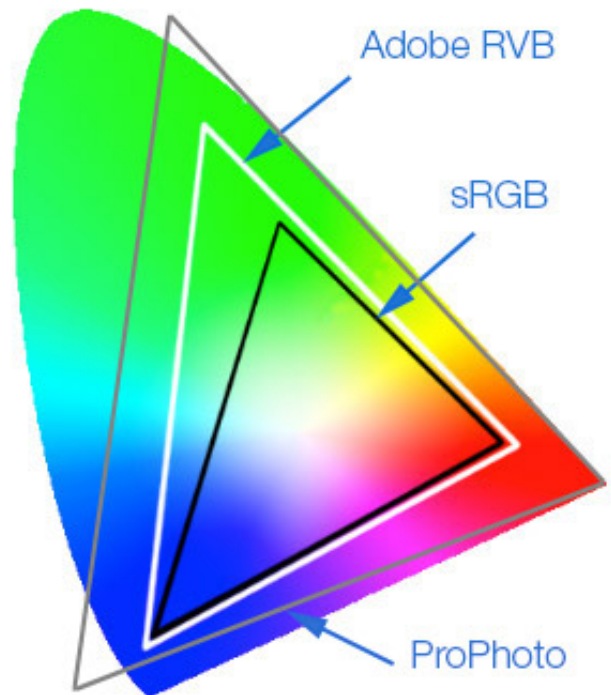
- **The gamma of the eye varies a lot depending on its light environment.**
- **It is close to 2.2 when watching a monitor. That is why most of the monitors are at 2.2.**
- **It is close to 1.8 when reading a book. Graphic art monitors, for printing professional for instance, are thus often at 1.8.**

Let's keep on going with the specific vocabulary of color management:  
[color spaces](#) ▶

[Next page 5/10 : colors spaces](#) ▶

# Color spaces

A color space is a set of colors also called gamut. The gamut of a monitor represents all the colors it is able to display. The gamut of a printer represents all the colors it is able to print. There are two types of color spaces: the ones relative to a device (and we're talking about ICC profile then) and the ones created by engineers so that they don't depend on a device and among which the most famous are sRGB, Adobe RGB 98 or also ProPhoto. The largest, representing the set of colors that a human being can see, is called  $L^*a^*b^*$  space. All the others are smaller because technical limits keep devices from reproducing so many colors, for now at least. Then why did we invent so many?



## Key points if you are a beginner ...

**Here are the key points to remember on color spaces. The rest of this page will be dedicated to those who want to go into more details.**



**Note ! The concept of color space is not simple and is primarily dedicated to advanced users, or those who really want to know what happens in Photoshop when retouching colors. All softwares, like Photoshop or Lightroom, take care of everything, they choose the right options and you will have nothing to do. So do not panic !**

## What is a color space ?

**A color space is a set of colors. This is called a gamut. All colors a human being can see is called  $L^*a^*b^*$  color space. This is the largest color space. There are many other, smaller, that of YOUR camera, your monitor, your printer ... In fact, your smartphone, your camera do not succeed to photograph all the colors that you**

are able to see. But do not worry, they see the major ones and it is quite enough already. The rest is for the purists or really specific cases.

More importantly, a camera, a monitor or a printer see, display or print colors with defects (often small but real. These are technical limitations). Color spaces of those devices are limited and imperfect. It's the ones, color management will try to correct.

Finally, there are others, specific, because they do not depend on a device but are virtual, ideal and perfect. You may have heard of sRGB. This is the one of your images on Internet. But we need one more thing to correct the defects of our devices ...

Next key point : [ICC profiles](#) ▶

The concept of **color space** - or colorimetric space - is very important in color management. The most important is your images'. The famous [Photoshop workspace](#) is often presented as being very important as well but it only is in a particular case: when your image doesn't have an ICC profile at the opening in Photoshop! Let's have a look at that now ...



## Colorimetric models

A color space represents a plurality of colors, visible for a human being or a device. This set is also called **gamut**. There are several color models or color spaces : RGB, CMYK, L\*a\*b\* or CIE xyz. It is said that some models are **dependent** upon devices and others that they are **independent**. Finally, some are called **workspaces**. Why ? Which is the one to choose in photo editing software? In your camera? From which one can we represent numerically a single color, that is perceived by a standard human eye, to answer the questions above?

## The starting point: CIE xyz & L\*a\*b\* spaces

Colors come in about eight million different shades for a "standard" eye (standard but still powerful!). CIE and mathematicians needed to

mathematically represent a three-dimensional graph (i.e. a volume), two of which appear in the figure below. The figures below might look familiar to you: that's the chromaticity diagram and the  $L^*a^*b^*$  space. They represent all the colors that can be seen with a human eye and will therefore be put to use all the time thereafter.

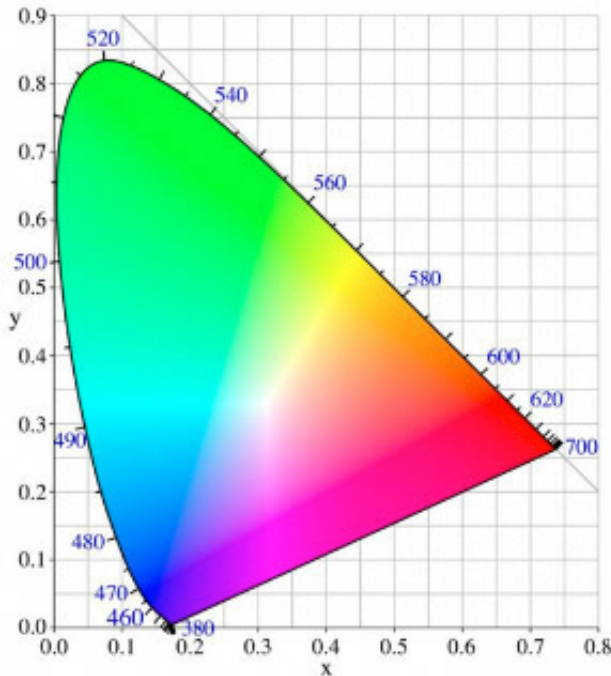
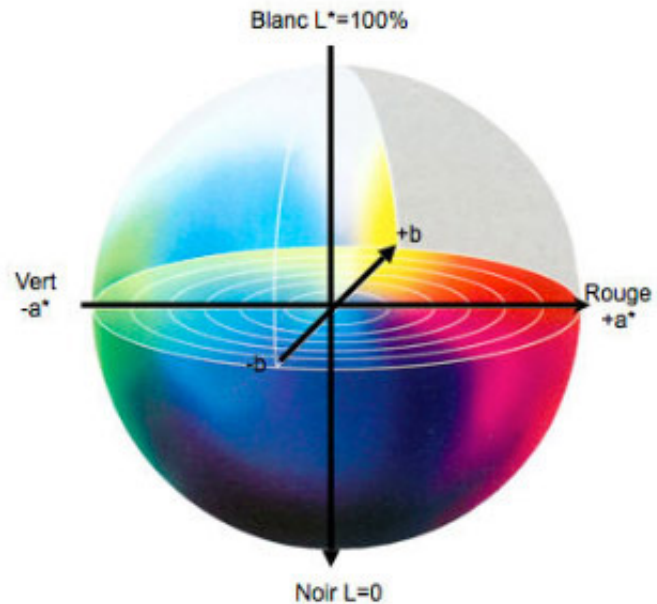


Diagram of chromaticity



Lab color space

Here are two different ways to represent the same thing: the colors a human being is able to see. Note: in the diagram on the left, the representation is more accurate to the "way" the eye sees colors since the green surface is twice larger than the red and blue as seen in the previous page.

But why are colors represented in so many different ways?

The aim of color management is, to make it short, to keep the same colors from one device to another: I want to see the color I shot first on my monitor and then on my print! But everything gets complicated then since these three devices don't "see" colors the same way. They all have different defects and they don't all "see" the same most saturated colors. So each device has its own color space, also called ICC profile.

To share the same color from one device to the other, it is thus necessary to alter slightly the RGB values to take into account the defects, or

characteristics of each device. This is called a conversion. Behind this conversion lies a complex mathematical formula. But mathematicians have invented several mathematical formulas because none, single and unique, could fulfill all the complex specifications of human vision. In some circumstances, they use one and in other circumstances another. Each mathematical formula has its "color space" and its characteristics (assets/drawbacks).

Note that not all these mathematical formulas needed to use RGB values.



Visual analysis of the figures above: in the chromaticity diagram, green is over-represented compared to red and blue, but really, the eye is twice as sensitive to this color. It is the model that comes closest to the human eye. In the  $L^*a^*b^*$  space, a color equals one point. Depending on the mathematical "work" to do, mathematicians rather use one color space or another.

CIE spaces are the largest color spaces, as they represent all the colors we can see but they represent colors differently. **Since they do not depend on a device but really on the modeling of the human eye, they are said to be independent.**

In **the CIE xyz space**, each color is represented by three coordinates: XYZ (Z as depth, so the brightness of each color) as shown in the figure above. These values, admit it, don't speak for themselves but are very convenient to use in a mathematical formula!

The  $L^*a^*b^*$  color space, as for itself, is an absolute colorimetric space, as CIE XYZ, but represented differently. This is also this absolute color space that is used by Photoshop and Lightroom, by the way, as a basis for color management in these programs. It is equivalent to the cash desk to make an analogy with the different currencies of all countries. This is the same as for money changing euros into dollars through an intermediary, the change rate, in order to keep the same absolute value of money in your wallet. Even if you had 100 something in a country to buy gold, you would have 30

in another country, but you could also buy the same amount of gold. 100 ≠ 30 in numeric value, but between the two countries, it has the same value in gold. Here the gold would be the equivalent of the L\*a\*b\* space value, 100 and 30 being RGB values.

Instead of describing a color with XYZ values, the L\*a\*b\* space describes them with L, a and b values. L for the brightness level (0 to 100), a for colors from red to green and b for colors from blue to yellow (-128 to +127). Last point, these color spaces are neutral because they have been defined by a human brain.

And finally, since it is not so convenient to work in L\*a\*b\* values, engineers invented spaces based on RGB values, much easier to use! Then why isn't there a one and only RGB space?

### **Other color spaces: RGB / CMYK spaces**

As you probably noticed, RGB or CMYK values haven't been mentioned any time with these two giant color spaces. However, us photographers almost always work with these spaces, just like our eye. L\*a\*b\* and CIE XYZ spaces are not convenient enough when working, for example, in Photoshop, so other color spaces have been invented based on RGB or CMYK color spaces. Here, colors are represented by RGB values and not esoteric XYZ or L\*a\*b\* values that don't speak for themselves at all! Adobe RGB 98, sRGB, Don RGB, ECI RGB or Prophoto spaces or even my monitor's or my printer's space are RGB color spaces. Here you might want to ask: then why didn't they invent a one and only RGB space as broad as L\*a\*b\* because what can do more can do less!

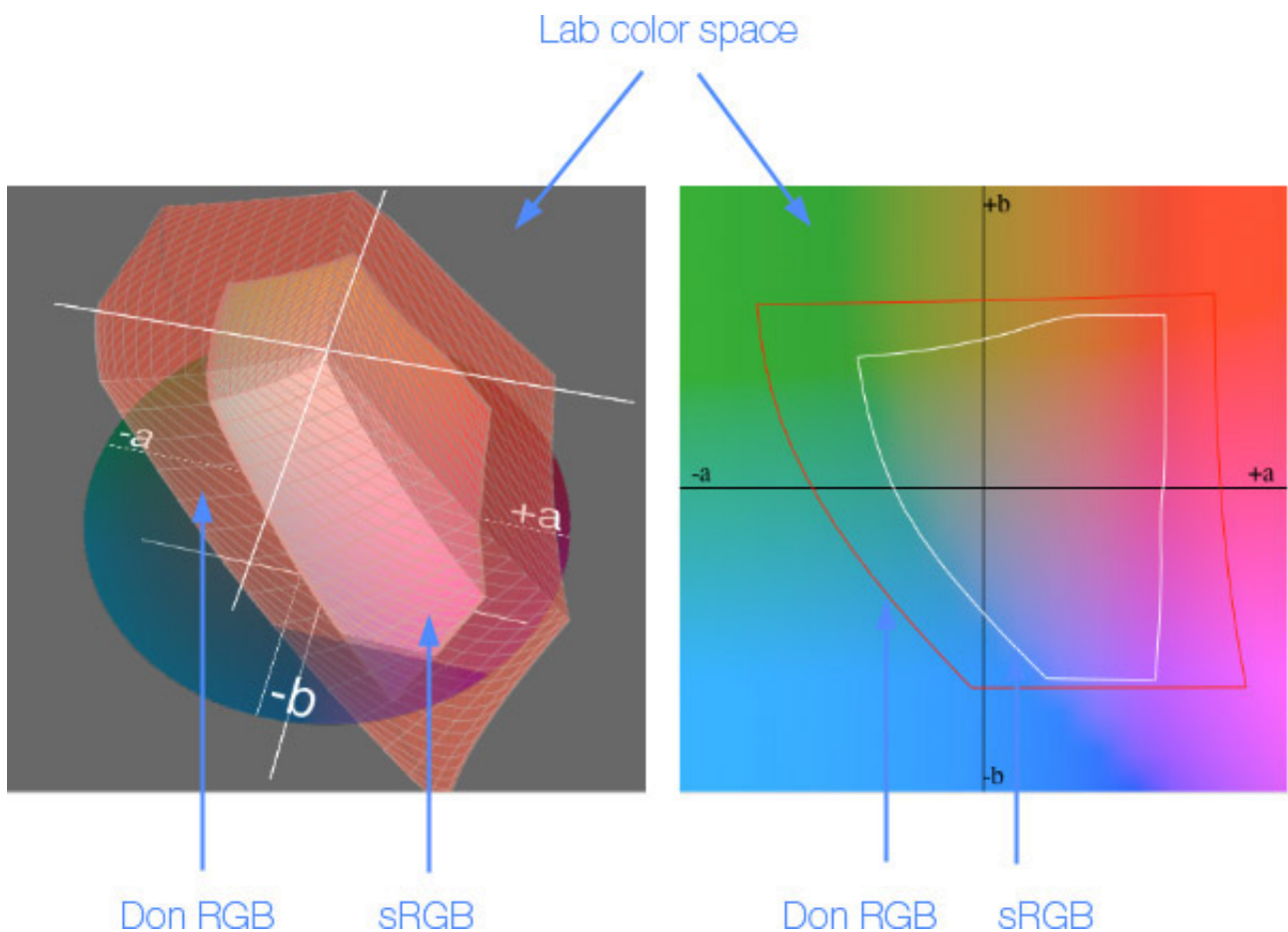
First of all for historical reasons. When color management was implemented in personal computer in the nineties, their power was absolutely not equivalent to their power nowadays. And treat as much information per pixel was completely insane considering processors and graphic cards back then!

Secondly, for technical reasons: was it really useful, and is it now? Well there's no camera, monitor or printer that is able to reproduce as many



colors as a human eye nowadays, so there's no point in working with eight million colors all the time... So come what may, there was no reason to invent an RGB space as broad as the  $L^*a^*b^*$  space. Then why didn't they invent a one and only RGB space, but smaller? Quite simply, to fix numerous problems and because each device has its own, bigger or smaller.

Another important point is conversion. When you send the RGB values of a photo to a printer, they're modified to take its characteristics into account (or said less diplomatically, its defects). This change is called a conversion. And when the conversion is performed from one very wide color space (a camera for instance) to a much smaller color space (a printer's), there are important risks to see tone breaks in the final print. It is thus better to work in an RGB space that is a bit bigger than the final space. We'll also see that later.



It is clearly visible that even the wide DonRGB is much smaller than the  $L^*a^*b^*$  space. This one is today quite close to the gamut of an inkjet printer on glossy paper.

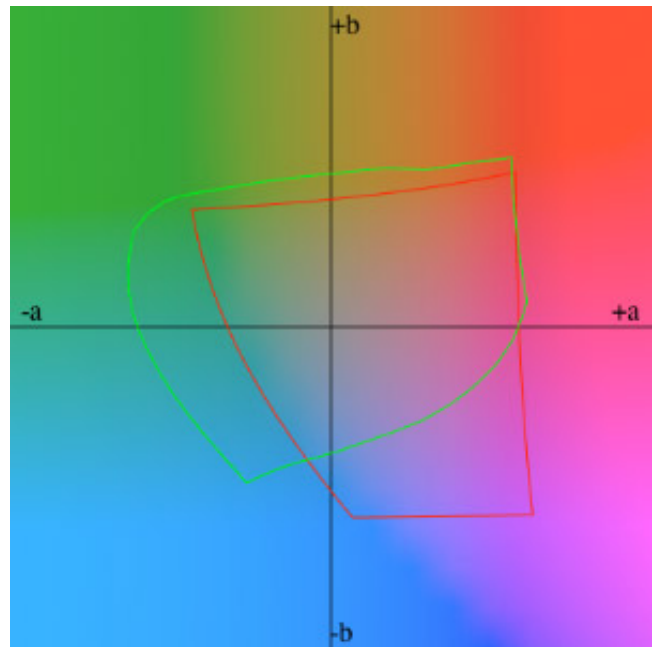
## Dependent / independent of a device?

Everything would be perfect in the world of color management if all monitors and printers could reproduce or display all the colors that a human being can distinguish and even more without introducing defects! But unfortunately, that is not technically possible or would be too expensive...

The set of colors that a device can reproduce - its color space, also called **gamut** - is always smaller than the  $L^*a^*b^*$  space, due to technical limitations. When a device is given to see, display, print a one color, it is impossible to know, as long as it has not been calibrated and characterized (i.e. compared to a reference, using a specific device or as long as it does not have an [ICC profile](#)), what it actually perceived, and what it can display or print. The limits of each device's color space, that can only be known through its calibration, are represented in the figure below, and are the result of:

- monitors: min/max brightness & maximum saturation of each pixel (so directly linked to the quality of the RGB filter used);
- printers: black color depth / paper whiteness & saturation of the dyes or ink pigments.

In the figure on the right, the  $L^*a^*b^*$  color space is represented by the colored square and the limits of other spaces by continuous lines of different colors. The green line represents the gamut of a printer on glossy paper and the red line the gamut of a Graphic Art monitor, close to sRGB. Both are significantly smaller than the  $L^*a^*b^*$  space and it is clearly visible that the printer is



capable of printing cyan/green that the monitor is unable to display! In terms of surface they are about four times smaller than the  $L^*a^*b^*$  space, what means about two million colors. But there is another characteristic of devices color spaces that can not be seen here: their defects. If you take the  $XXX$  RGB value, hence three times the same, the color won't be represented at the intersection of the lines  $-a+a/-b+b$  but very slightly apart. Grey values are in fact slightly colored: it is their defect that these two lines (green and red) don't show in this figure. And each device has its own, slightly different every time. Please note, by the way, that these differences have decreased a lot from 2000 to 2016.

So, on paper and in this representation, the difference related to the defects of each device regarding the color spaces DonRGB, sRGB, Adobe RGB 98 doesn't appear and yet devices color spaces are said dependent. Please note, finally, that they're always in RGB.

Color spaces relative to a device

A color space relative to a device describes :

- all the colors that it can acquire (scanner, digital camera...), display (monitor), or reproduce (printer) compared to  $L^*a^*b^*$  colors. This color space is also called the GAMUT.
- All its "defects" or colorimetric characteristics more accurately.

During the calibration and characterization process of a printer, for example, the calibration device measures all colors it is able to print, but also how it does it. Those are called its characteristics. In other words, does the printer print colors right! For instance, it is asked to print an  $L^*a^*b^*$  color and it prints a slightly different one. This difference and the way to fix it are contained in the ICC profile.

To do so, it is given to print reference colors - a reference chart - and it is going to print different ones!! This information - differences between the color that should be printed and the color that is actually printed - is placed in a special file: the [ICC profile](#), that we'll study in details in the next page. Moreover, no printer is perfect and no calibration device either. Even though they are insignificant, errors in the ICC profile will be real. However, with a good equipment, it is obvious that perfection is so close that we can easily consider the colors are fully corrected and neutralized.

## Color spaces not relative to a device

In a space that is not relative to a device, the color space is the result of a calculation rather than a measurement. It is broader or smaller but neutral. **The same percentage of RGB gives out a perfectly neutral grey.** This is the case, may I say it again, of the  $L^*a^*b^*$  color space but also of **sRGB, Adobe RGB 98, DonRGB, ECI-RGB, Prophoto ...** The **sRGB color space**, for example, was created as the lowest common denominator in the world for computing and digital imaging. ALL MONITORS AND PRINTERS IN THE WORLD KNOW HOW TO REPRODUCE IT. As it does not contain all the  $L^*a^*b^*$  colors but only about 90% of the ones present in our photographs, all recent devices know how to deal with it. We will see in the chapter on [image conversion](#) why it is important that the RGB color spaces be significantly smaller than the  $L^*a^*b^*$  color space and why, therefore, we created smaller colorimetric space than the  $L^*a^*b^*$  color space and yet of different sizes.

### To be remembered!

- **A color space is a broader or smaller set of colors, with more or less defects. The biggest of all is the  $L^*a^*b^*$  color space (colors a**

human being is able to see) and the best known is sRGB, the smaller common denominator to all devices on the market.

- **There are two main categories of color spaces:**
  - **The ones relative to devices:** it means the set of RGB colors that a camera, a monitor or a printer is able to interpret, display or print. It is smaller than the L\*a\*b\* space and most importantly, it contains all the defects and technical limits of the device. There are as many devices color spaces as there are devices. They're also called ICC profiles.
  - **And the ones that are not relative to devices:** they are virtual, more or less large and they are perfect. They do not depend on one device and are therefore perfect colorimetrically speaking. There are thus much less than ICC profiles. A good color space is not necessarily a very large color space. The most well-known are: sRGB, Adobe RGB 98 and ProPhoto. Independent color spaces are mainly used as color workspaces in Photoshop and especially in your images.
  - **The right color space is the color space you need!** If you're shooting or working with very saturated colors, using the HDR technique for instance, I need wide gamut spaces as they're called, broader than sRGB, like ProPhoto. If you like "normal" colors though, not especially saturated, sRGB will be just fine! Trust me, try it and you'll see!

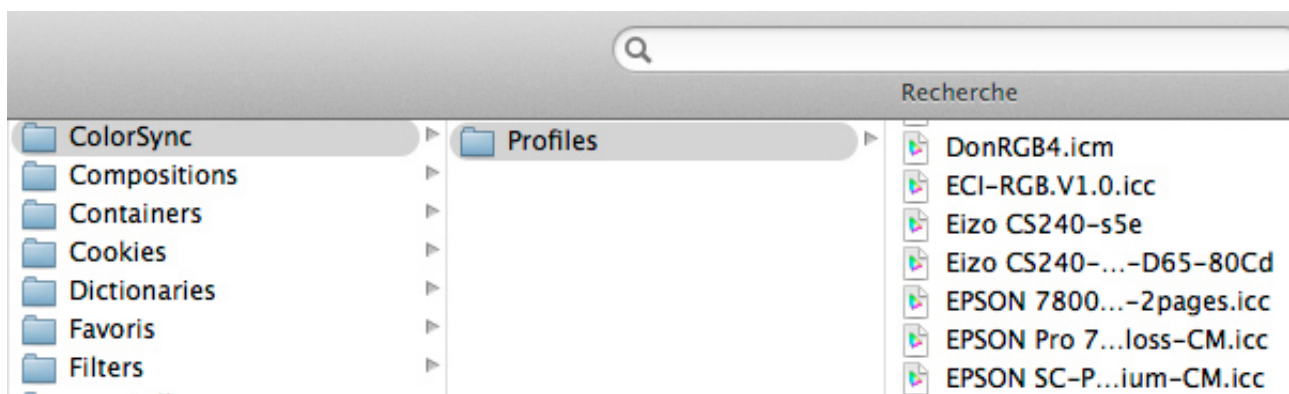
As we have talked about them on this page, it is time to go further on [ICC profiles](#) ▶

[Next page 6/10 : icc profiles](#) ▶



# ICC profiles

It is compulsory to understand what an ICC profile is in color management: it is the color ID of a device or a picture. ICC profiles are mainly used to display the "right" colors of a file. The ICC profile is created when calibrating a device. Two things are important and we'll take an example to explain them: during the calibration of a monitor, you want to know if it renders colors properly and how many of them it can display. All this information is gathered in ITS OWN ICC profile. Same for the pair printer/paper. Software managing these ICC profiles will thus use them to display or print colors correctly.



## Key points if you are a beginner ...

**Here are the key points to remember on ICC profiles. The rest of this page will be dedicated to those who want to go into more details.**

### What is an ICC profile ?

**An ICC profile is the color ID of a device. It contains two essential information :**

- **the color space or gamut of this device, so all the colors it can display or print,**
- **the color "defects" of this device. For example, reading the ICC profile of a monitor, Photoshop knows how to fix the colors so they are correctly displayed.**

### How to get an ICC profile of a device ?

**An ICC profile is obtained by calibrating the device. monitor is calibrated with a [monitor calibration colorimeter](#), a printer with a spectrophotometer, etc ...**

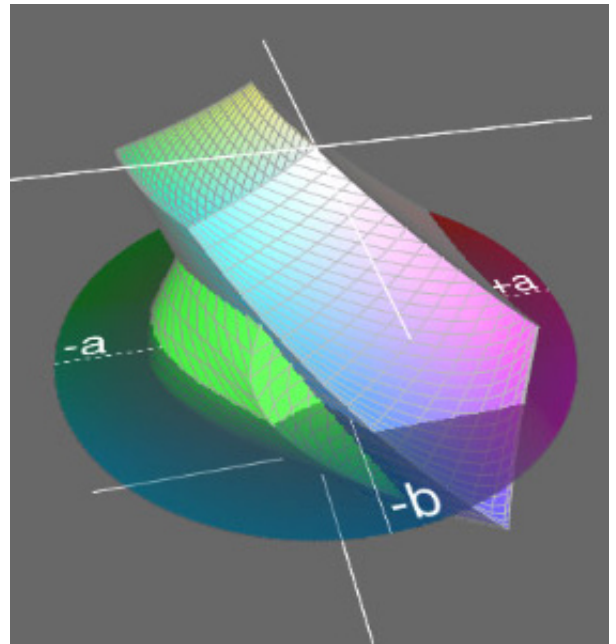
**Is there a difference between a generic profile (delivered by your**

monitor manufacturer for instance) and a custom profile created by yourself or done by a distant service provider ?

Oh yes there is! Calibrate your monitor on your own, calibrate your printer yourself or have it done if it is too expensive. The result has nothing to do with the one you get with a generic profile, even if, I agree, generic profiles have made much progress.

Next key point : [assign an ICC profile](#) ▶

**ICC profiles**, calibration tools and conversion engines - CMM for Color Management Module - form the cornerstone of a good color management. For a color reproduction device to work properly, you must first know how it works by default. This is to take into account its possibilities and of course its characteristics, as seen in the previous pages. This is what we want to know during calibration.



All these details will be contained in a specific file: **an ICC profile**. The only thing left, will now be to use it with the tools of color management to keep the same colors throughout your color workflow !



What is an ICC profile?

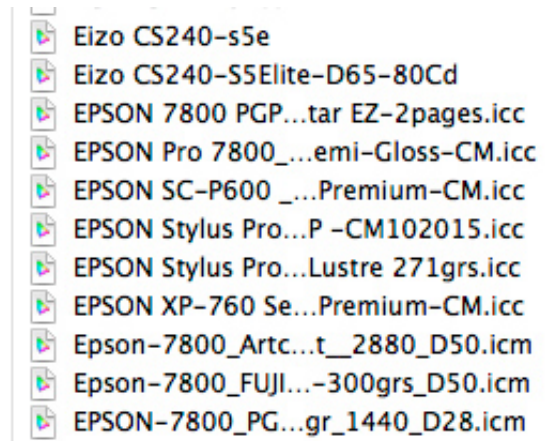
It is thus a short file linked to a color reproduction device. Each device, in color management, must have its own ICC profile. It contains many pieces of information about the colors of the device. It is also described as the color ID of a device.

It is a gamut AND a color ID

First of all, it is a color space (as seen in the [previous page](#)), but a bit specific because it depends on a device. This is a sort of color ID for an

image or a color reproduction device, as we saw in the previous page, since it contains its color characteristics, including:

- All the colors that can be reproduced by a device or contained in an image. In this sense, it is a color space and therefore a **gamut**. In other words: can this or that color be reproduced by this device?



- But also to what  $L^*a^*b^*$  color does each RGB color value correspond to. In other words: is the device reproducing colors correctly? These matches (between RGB and Lab colors) are contained in a special table: a matches matrix table (in other words, an ICC profile). To an  $L^*a^*b^*$  color seen by the camera corresponds another RGB value and then we know what R'G'B' values to send in order to display or print the color (meaning the  $L^*a^*b^*$  color) you want.

So the more accurately the ICC profile creation program works, the more values will this table contain (rows and lines). However, the more accurately it will work and the more information will the table contain hence will the ICC profile be big. Theoretically, the matrix table would contain 8 million matches for the 8 million colors of the  $L^*a^*b^*$  space.

But practically speaking, no device can "manage" eight million colors like the human eye and moreover, there's no real interest in analyzing all the colors that a device can see, display or print. One color from time to time is enough to create a good ICC profile! These are its color characteristics, in other words, its defects and the way to correct them!

An ICC profile is therefore directly linked to a device - unlike a pure color space. It is the color characteristic of a device measured by a given tool in known and precise calibration conditions. As a matter of fact, the process of creating the profile is known as **characterization**. So the ICC profile created depends directly on this measurement tool, the profile creation program and of course the calibrated device.



## The ICC profile depends on a device

There are two kinds of ICC profiles:

- Either it is the ICC profile of an input **device** (camera, scanner,...), or either of an output device (printer etc..). Then on the one hand, it is the description of all  $L^*a^*b^*$  colors it is able to reproduce hence to see - its **Gamut** - AND on the other hand, the transformation rules of the original file so that the colors can be transcribed or displayed correctly. The aim is to "eliminate" or correct distortions induced by the device.



Its Gamut is smaller than the  $L^*a^*b^*$  space and is therefore contained in it. But while the  $L^*a^*b^*$  space is absolute because it does not depend on a device, the space of a device corresponds to the results of a measurement and therefore depends directly on the quality of it. We saw on the previous page that a same RGB (x, x, x) value does not give a neutral grey without calibration.



### **Important...**

- **A color space is just a gamut and an ICC profile is a gamut AND color characteristics proper of a given device.**
- **The big difference lies into depending or not on a device.**

Does an image contain a profile or a space?

An image, when it leaves the camera, contains the profile of this camera but it is instantly and automatically converted into a neutral color space. If you're shooting in JPEG, you have two possibilities: sRGB and Adobe RGB

98, and if you're shooting in RAW, you often have ProPhoto (very broad) in addition. I explain it all in this page.

## **Difference between an ICC profile and a color space**

Well there is not really ! These are two different aspects of the same thing which may, however, contain more or less information. It's a bit like a cylinder : either you look from the top and you say that it is a circle, or you look at from the side and you say it is a rectangle !

We choose to talk about color space when it comes to workspace - which must be balanced (neutral) - and talk about ICC profile when you want to signify the gamut AND the "deformations" of a given device measured during its calibration, that is to say its characteristics. **A color space is only a gamut, and, an ICC profile is a gamut AND color characteristics specific to a given device.**

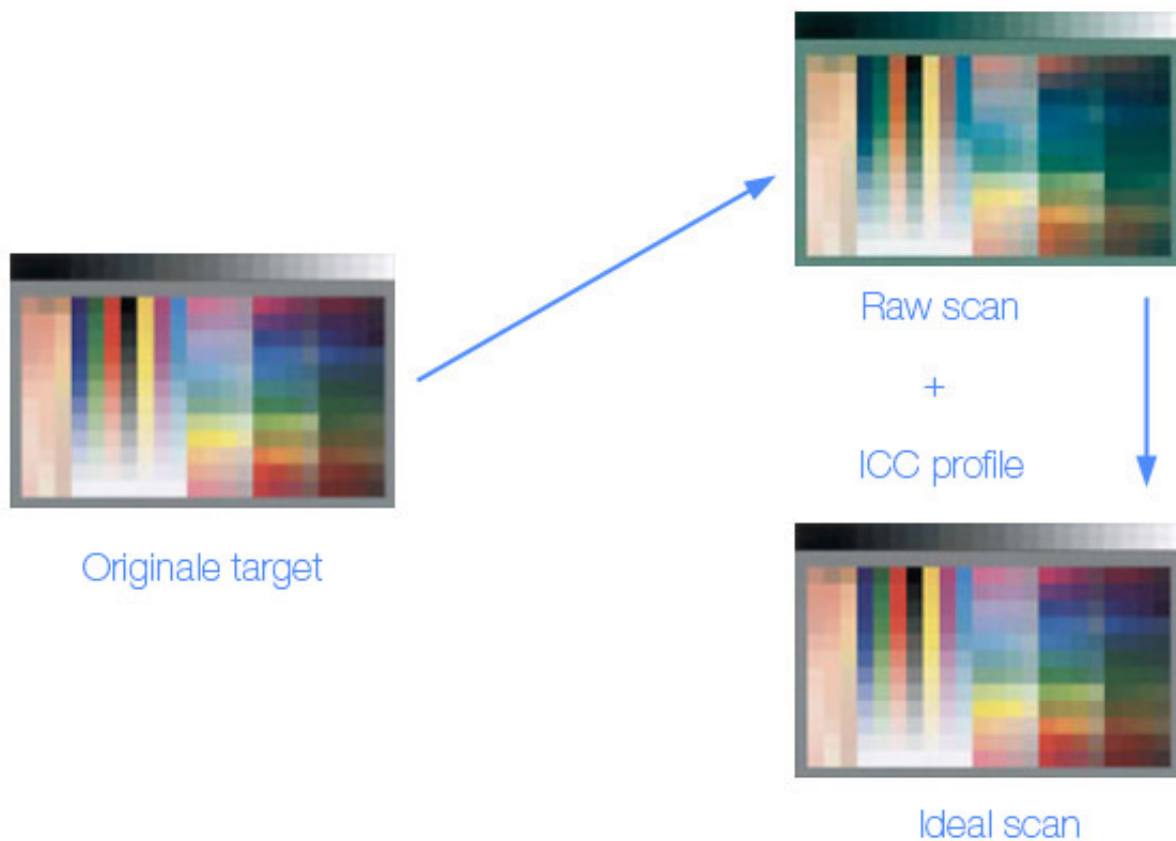
The biggest difference stands in the dependence or independence to a device.



## **To sum up, what is an ICC profile used for?**

It is used to render a right vision of colors for each device. Without a profile, a color reproduction device reproduces them with more or less defects and once "profiled" or calibrated, it will render them correctly as if by magic! An ICC profile enables any device to recover a visual acuity!

Let's take the calibration of a scanner as an example, because it speaks for itself. When you watch the raw scan in Photoshop, without an ICC profile, you can see that the image is far from the original. In our example, the scan looks greenish. The creation of the ICC profile of the scanner and its assignment at the opening of the photo in the same program enables, as if by magic, to recover the true colors of the original.



The scanner "sees" the colors a bit green but once calibrated, you just have to assign THIS scanner's ICC profile to the image it produced and everything goes back to order.

What happens concretely? Thanks to this device's ICC profile, a program like Photoshop knows that when the image file contains an RGB value, like for instance 128, 140, 128, hence with a predominant G value (hence the greenish aspect), the scanner scanned a neutral grey all the same (128, 128, 128) and it should have the RGB value 128,128,128 and thus display a neutral grey. Well Photoshop is going to read the matricial table of this scanner's ICC profile and it then knows that when it must display the RGB value 128,140,128 it needs to display the La\*b\* color 54,0,0 instead (equivalent in RGB to 128,128,128) and it will then send to the screen a corrected RGB signal like maybe 128, 116, 128 to take the defaults of the scanner in the greens into account in this example.

An ICC profile is thus used to display the "real" colors of the image without taking RGB values that are "really" read into account. An RGB value of 128, 140, 128 will thus still be displayed as a medium grey and not as a greenish grey here.

Even if the difference between the ideal result and reality was particularly

impressive at the time when scanners were widely used, it is now true, at the time of "all digital" since the shooting, that external devices WITHOUT calibration are a lot less far-off from true colors.

**To be remembered!**

- **An ICC profile is the color ID of a device! The ICC profile contains the gamut (the whole set of colors of a device in comparison to the L\*a\*b\* space) and its "defects" of color (it's an image!).**
- **It gives back its "eyesight" to any device: monitor, printer, camera, scanner.**
- **An ICC profile is created during the calibration of a device. So, when you are printing a photo on a calibrated printer, the color management program that Photoshop is going to read the printer's ICC profile in order to know what RGB values it must send taking its characteristics - what I'm calling defects - into account. Without an ICC profile, it would have sent other RGB values and the print wouldn't have looked good.**
- **So no ICC profiles, no color management!**

The processes of creation of ICC profiles and the rules of ICC profiles management will be seen in other parts of this color management guide. In the next page especially, we will go into the notions of ICC profiles assignment: [assign an ICC profile](#) ▶

[Next page 7/10 : assign an ICC profile](#) ▶



# Assign an ICC profile to a photo

"Assigning a profile" is a notion both fundamental for color management and not so easy to vulgarize. Nevertheless, I am going to try through this page to give you the basics, because that's where everything starts...



## Key points if you are a beginner ...

**Here are the key points to remember on assigning an ICC profile. The rest of this page will be dedicated to those of you who want to dig into more details.**

**First of all, it is important to understand that assigning an ICC profile to an image is only done once !**

**When you open a picture in Photoshop without any embedded ICC profile, it cannot be displayed correctly. You have then to assign an ICC profile and if possible the right one.**

**That means you absolutely need to know from where it comes from : internet, scanner, camera in sRGB mode or Adobe RGB 1998 mode ...**

**It is as if you were finding a bank note on the floor. You see 100 written on it but you do not know the country it comes from. Before using it in France, you will need to go to an exchange office, so that they can tell you from which country that money is and change it to Euro.**

**The action of knowing from which country that money is like assigning a profile to the picture.**

**Remember that assigning a profile is only done once. Once you know the country of the bank note, you do not need to question yourself a second time ! Then, you can go through multiple profile conversion (see next page) to go from one device to another (as if you were travelling from one country to another).**

Next key point: [photo conversion](#) ▶

Since there are wider or smaller [color spaces](#), [ICC profiles](#) for each external device, what we now need to know is how to communicate the right color, the "same" color as much as possible from one device to another, while taking their characteristics into account. Communicating the "right color" starts with assigning the right ICC profile to an image. Let's now see why and how...

If I were to sum it up! It is quite like in a bureau de change: you find a 100-something bill on the floor (a currency you've never seen before) and you want the equivalent in euros so you go to the bureau de change, which will enable you to identify this famous bill (and accessorially make you rich... or not!). Before giving you the equivalent in euros, it is first necessary to know where it comes from... because that's what will give its absolute value (relatively to a global standard that could be gold). It is the same for images...



## Why is it necessary to assign an ICC profile or a color space to an image?



**This paragraph is one of the most important of this site. A corner stone!**

Assigning an ICC profile or a color space to an image enables it to be displayed correctly, to display the "right" color hence the real  $La^*b^*$  colors. Let's take the history of an image file back from the start...



Important note! I'm going to take the shooting of a photo as an example. Whether it is taken with a smartphone, an "amateur" camera or a

professional camera body, it is always shot as a RAW file.

All cameras, even smartphones, don't know how to shoot a photo in anything other than RAW. The RAW file is thus internally developed by a sort of mini-Photoshop in order to provide you with a nice JPEG file. Color management and the "profile assignment" then "conversion to a color space" session is thus done transparently for the user but is automatic. Without color management, no colors, even in a smartphone!

My RAW file is thus a digital negative. With pro cameras or some amateur ones, you can get this RAW file to develop it yourself in a demosaicing program like [Camera Raw](#) or [Lightroom](#). We'll see how it works a little later. But let's start with a smartphone or an amateur camera because they deliver a JPEG file directly, without other possibilities by the way, allowing exception. But they are necessarily shot as RAW files that will be internally developed by a sort of mini-Photoshop in order to give you your image under the form of this famous JPEG file.

So how does it work? In two steps, invariably... following this analogy: you find a 100-something bill on the floor. You don't know which currency it is. Of course you can't use it in your favorite stores! So first you need to figure out what it is. What currency is it? In color



management that would be the "assignment of a profile". OK, so it's 100-something hence completely useless in France! You need to change them into euros following the change rate of the day hence in reference to a universal value - let's say gold. In color management this standard is called the La\*b\* color space. It is called "conversion". In photo, assigning an ICC profile doesn't change the RGB values of the file. It's just that the RGB values are displayed "correctly" and not in a matter-of-fact reading. Then it is converted to another currency, for instance in euros, and it becomes 10 euros - hence still with the same absolute value - but 100 became 10. La\*b\* colors are identical but the RGB values of the file have been changed.

## 1 - Case of a JPEG photo: assigning the camera's ICC profile to the image directly inside the camera

The camera's mini-Photoshop must read the RGB values contained in the photo and translate them into the "right color" hence its "ideal"  $La^*b^*$  colors. A 255, 0, 0 RGB signal must be displayed with a red but what  $La^*b^*$  red? It is thus done reading the ICC profile's instructions. Let's imagine you shot a perfectly grey wall. Your JPEG



photo should be perfectly grey at this place and your file should thus have RGB values like 128, 128, 128. But your camera has a few defects and the RGB values saved in the file are rather like 128, 138, 126. If you display these values in Photoshop, you'll have a greenish/yellowish grey instead. How disappointing! But since your camera's manufacturer knows it has defects, he calibrated it so he inserted its defects in its ICC profile meaning in a table (a matricial table) where he inscribed: I give you a neutral grey 128, 128,128 and you save it as 128, 138, 126 in the RAW file hence with an ugly color predominance! So the table is here to tell you that if you have an RGB value of 128, 138, 126 you should in fact display a 54, 0, 0  $La^*b^*$  color and not a weird grey.

The RGB value in the file is still 128, 138, 126 BUT the camera acted like it's 128, 128, 128 to display it. Assigning an ICC profile only has one use: make sure that the RGB values are interpreted correctly and thus displayed without trying to get a match between the RGB values and their "logical" display. An RGB value of 128, 138, 126 doesn't have any reason to be displayed as a medium neutral grey without an ICC profile. An ICC profile doesn't change the file. The RGB values of the RAW file remain identical but are then interpreted correctly. It is just a sort of user manual, a post-it stuck to the RAW file to tell it how display/see its RGB values correctly.

All of this results in the fact that an ICC profile only needs to be assigned



once in the life of a RAW file. Many conversions can then be made for this or that printer, this or that screen but the assignment only happens once. In the history of a JPEG photo, it is thus directly done into the camera body or the smartphone.

Then the RGB values of the file and its display are going to have to be matched. Indeed, the eye sees a nice neutral grey but if you place the pipette on this grey in Photoshop, it indicates 128, 138, 126!!! It doesn't match! This alignment is called [conversion](#) and we'll see this in details in the [next page](#) ▶.

## **2 - Case of a RAW file you develop yourself**

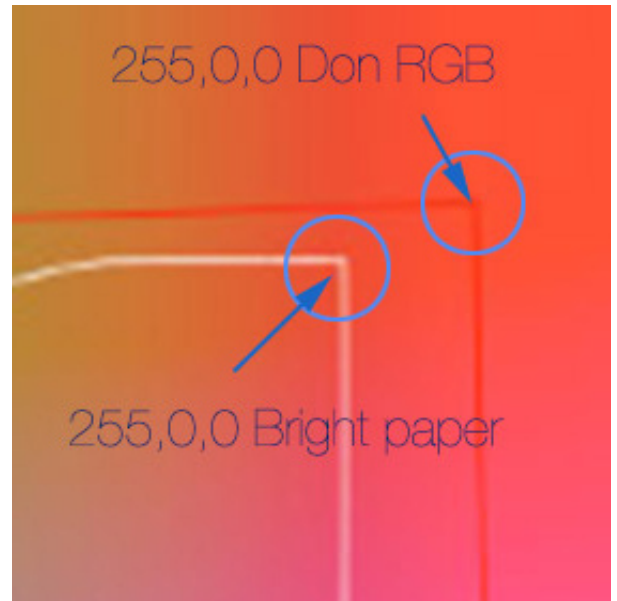
As I'll explain a little later in this page and in my pages dedicated to [color management in Camera Raw](#) or [Lightroom](#), the assignment of an ICC profile is also done automatically when opening your RAW file in the demosaicing program. To display your photo "correctly", it reads the file's Exif data, saw with what camera it was shot and thus assigned this camera's ICC profile stored in its database - Adobe get their hands on all cameras on the market and calibrate them themselves in order to establish each one's ICC profile - to display the "right" colors hence the ones the camera body is supposed to have shot and not the ones that are "logically" inscribed in its RGB values (a 128, 138, 126 is displayed "as if" it had read 128, 128, 128 hence with a nice grey without any predominance while the RGB value does have one).

## **3 - Case of an image from the internet without an ICC profile...**

When you open it in Photoshop - this program can manage colors so it will detect that there's no ICC profile assigned to this photo, but it needs one to display it correctly - it will offer you to assign a profile to this image thanks to a dedicated menu. You'll only have to let it know that this image's ICC profile is most probably sRGB. We'll see that in details in the pages dedicated to [color management in Photoshop](#).

## 4 - Last precision - the "true" color: RGB values and L\*a\*b\* color?

In order to see clearly why a same RGB value corresponds to a different real color - hence a L\*a\*b\* one - différente, I projected four different color spaces or ICC profiles on the L\*a\*b\* color space. You can see here the top right part (towards red values) of this projection. The angle of each color space or ICC profile corresponds to the most saturated red value since its RGB



values are: 255, 0, 0. But you can see that **this same color definition** isn't projected at the same place in the L\*a\*b\* space hence really corresponds to "real" different red colors.



Note on use - If you have the feeling that these 4 red points are displayed in the same shade of red on your screen, it is only due to your screen's gamut that doesn't enable to distinguish distinct shades for such saturated colors. One same RGB value (255, 0, 0) and yet four different real hence L\*a\*b\* colors in this example. To know which one's the right one, we only need the associated ICC profile or color space of an image file for instance and to assign it. The RGB value is then interpreted correctly and is displayed with the "right" L\*a\*b\* red.

## 5 - And by the way, what happens if you don't assign an ICC profile to an image?

Without an ICC profile assigned to the image, it will be displayed arbitrarily following two possible rules - because it can't be otherwise:

1 - In a program that doesn't manage colors - It will be displayed in the

screen's color space, quite simply, hence differently on a screen displaying sRGB or Adobe RGB 98 like it is more and more common to see since the RGB values of the file are directly interpreted by the screen.

Example: If the image comes from a camera that was set in JPEG and Adobe RGB 1998 but the ICC profile has been lost and the image opens in Windows or Mac OS explorer (that don't manage colors), the image will be displayed by default according to the screen's color space (hence still nowadays most of the time in sRGB).

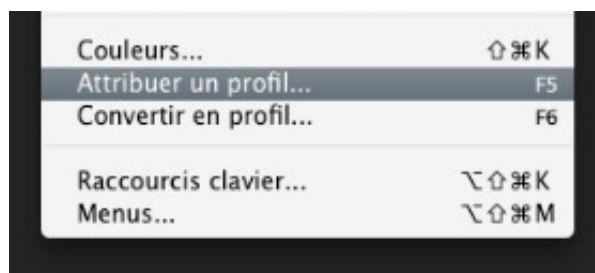
2 - In Photoshop if you don't activate color management - which is what happens by default even if it can seem weird! - Here, the image will be assigned [Photoshop's RGB workspace](#) as ICC profile(sRGB by default).



## How to assign an ICC profile to an image in Photoshop?

It can be said that there are two main cases:

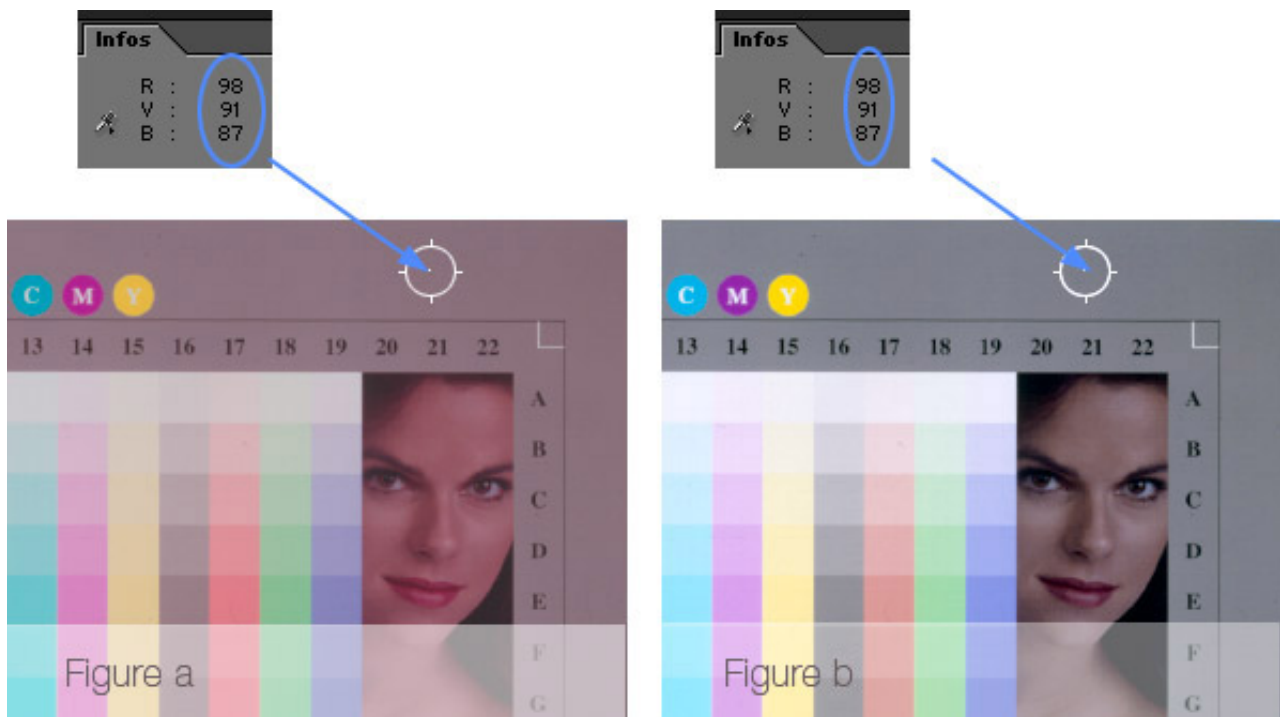
### Opening a "classic" image file in Jpeg, Tiff, PSD, etc.



When you open a JPEG, TIFF or PSD image without an ICC profile (so more accurately without a color space) in Photoshop (unlike a RAW file as we'll see later) Photoshop warns you and asks you to choose one if you chose to activate color management in this program (see [color preferences in Photoshop](#) for more information and examples in images). It is either done directly at the opening of the image, either once the image is opened Photoshop via the menu Edition / Assign a profile...

Let's take an example with an image coming from my old scanner that I open in Photoshop with the right settings on my calibrated screen:

So I open this image - an IT 8 test card - coming from my scanner (figure. a below). To understand well, I chose to open it without an ICC profile (figure a below on the left) - I didn't assign my scanner's ICC profile at the opening of the image - but since Photoshop necessarily needs to assign an ICC profile to an image to display it, it will force its assignment and in this case assign what is called its RGB workspace. Here the image opens in Adobe RGB 1998 since I'd chosen this color space as RGB workspace back in time. So the image is displayed with arbitrary default colors, as if it were an Adobe RGB 1998 image. Each pixel contains RGB values that are interpreted in this color space. In the image on the left below, you can see that the greys on the test card are reddish. Indeed, in the color space Adobe RGB 98, the RGB value 98, 91, 87 is reddish. For my image to recover its "true" colors of display, I need to assign it the "right" profile, its own one! In the photo below on the right, I assigned my scanner's ICC profile to my image and my greys are neutral again! It's magic. And you'll notice that the RGB values are still identical. **The RGB values in the info palette don't change BUT the colors displayed, the L\*a\*b\* colors, do change!** The assignment of an ICC profile only changes the display of a photo for given RGB values.



The image that was assigned the right ICC profile displays correctly, quite simply, here on the right!

To do so, I used the menu Image/Mode/Assign a profile in Photoshop until PS CS2 and the Menu Editions/Assign a profile for PS CS3 and next. Taking into account the characteristics (defects) of my scanner by reading its ICC profile, Photoshop now knows that for this device, a signal of 98, 91,87 must be displayed as a neutral color, a neutral grey and not a reddish one. The image has recovered a normal contrast in the operation, by the way.

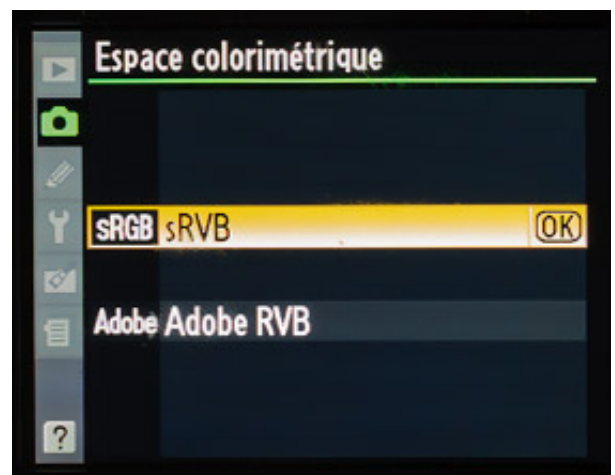
Now my image has an ICC profile that depends on my scanner and that enables to display it correctly taking into account my scanner's colorimetric characteristics. However, there's a big inconvenience! **There's no match between what I see and the "logical" RGB values anymore.** That's what we saw in the page - [Dependent/independent profile](#) -. To get a match again, I need to change color space hence ICC profile or more accurately here [color space](#) since only them are neutral. It is called a conversion and we'll see in the [next page](#) what happens then...

## Opening of a RAW file

The case of RAW files stands a bit apart and I would add that there are also two subcategories:

- when RAW files are directly developed in the camera or the smartphone (as we saw before),
- and when they are demosaiced in a dedicated program like Photoshop's famous Camera Raw or its equivalent in Lightroom.

Let's re-affirm that all cameras, even compact ones or smartphones, can only shoot photos in RAW format. They never shoot Jpeg directly even if the files that are saved on our memory cards are Jpeg files. In fact, the RAW file is demosaiced internally, with a "mini Photoshop" hence a "mini"



Camera Raw to deliver a Jpeg, more convenient for the vast majority of users. The process is as follows: the RAW file is "opened" by the mini-Photoshop installed in your camera. For the colors to be correct, the camera **assigns** the right ICC profile to the file, of course the one that the engineers incorporated in the camera. Logical! Then the same micro-program converts the file in a neutral color space, in most cases the famous sRGB (as we'll see more into details in the [next page](#) and as shown in the figure below).



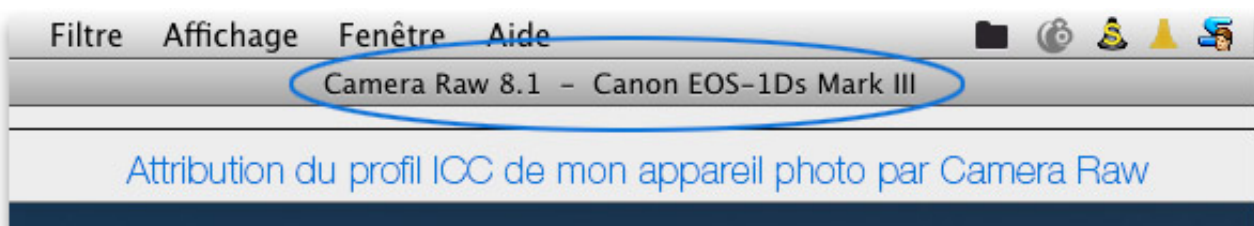
### Choose sRGB or Adobe RGB 1998 in the camera?

**First, this choice is made through the menus of the camera when this one is already quite an evolved one, and this ONLY APPLIES TO JPEG FILES! If you choose RAW + JPEG on your camera, the sRGB or Adobe RGB 1998 color space will only be applied to Jpeg files. The choice of a color space for RAW files is made in the demosaicing program and you're choosing it. This has two assets:**

- You get to choose,
- and above all, you'll choose from more options. In Camera Raw, it is possible to choose the broad ProPhoto for instance, sometimes useful in certain cases!

**Help you choose between sRGB and Adobe RGB 98: [My recommendations to choose your workspace](#)**

And there's still the case that can be interesting when you're trying to optimize the quality of the files shot by your camera: **demosaicing RAW files yourself in a demosaicing program like the famous Photoshop's Camera Raw, Lightroom or also DXO and Capture One.**



In this case, the program **MUST** assign the camera's ICC profile at the opening of the file and this automatically in order for the colors to be

correctly displayed. To that extent, these programs all have a complete database of all cameras on the market that are able to deliver RAW files with their ICC profile. When they read the file's EXIF data, they know with which camera it was shot and thus how this camera "sees" colors. Here's the reason why, when your program isn't up-to-date, you can't open files from most recent cameras. Since they can't assign them an ICC profile because it hasn't been created yet (the camera hasn't been calibrated by Adobe yet), the program can't open them. The big asset of demosaicing programs is that it is possible at the next step, which is conversion to a neutral color space, to have other options than the classic sRGB or Adobe RGB 1998.



### **Calibrate your camera or not?**

**As we saw for [printer calibration](#), generic ICC profiles, meaning created by the brand for a given printer model, can't work when you're looking for the best quality for your equipment. The reason is very simple:**

**It is very complex and above all, expensive, to make all printers of a same model rigorously equal from a colorimetric point of view while it is so simple and cheap to calibrate them one by one later for an optimal result.**

**It should be the same for cameras! But Camera Raw or also DXO apply the same ICC profile to all the bodies of a same model... Here's why more and more photographers calibrate their camera themselves... even if it's not as easy as for a printer...**

Let's follow on generalities about colors with the [conversion in ICC profile](#) ▶

### **To be remembered!**

- **What is the right color? It is an  $L^*a^*b^*$  color hence an absolute one. A  $L^*a^*b^*$  corresponds to one color only.**
- **Assigning a profile is used to give a colorimetric meaning - a "true" color - to a photo's RGB values. When assigning an ICC profile to an image, each RGB value (of each pixel for instance) becomes the "right"  $L^*a^*b^*$  color. If a photo is assigned the right ICC profile, it will display the "right" colors, the ones that should**

have been seen if the camera had been perfect!

Imagine you find a 100-something bill on the floor. You don't know this currency. You go to the bureau de change and the first thing the agent is going to do is identify this bill, give it some sense. Once you know what it is, you'll be able to ask for a conversion of this currency into yours in order to be able to use it in shops. For a value of 100 at the start, you might only get 40 in your currency but the absolute value will be the same. For colors, it represents the same  $L^*a^*b^*$  colors but different RGB values!

- Assigning a profile is thus only used ONCE, at the very beginning of the history of this photo, for instance in the camera or in Camera Raw if it's a RAW file. A 100-euros bill is worth 100 euros. It isn't worth 100 dollars. Then it will undergo numerous conversions in order to keep the same absolute value but this time in a different currency...

- The assignment of the right ICC profile for cameras is done automatically:

- . Either directly in the camera body if you're shooting in Jpeg,

- . either in your demosaicing program like DXO or Camera Raw.

If your camera's recent and you didn't update your program hence its cameras database, you just won't be able to open its RAW files because it won't be able to assign it the right ICC profile because it won't have it! No profile = no "right" colors!

- The assignment of the right ICC profile to an image downloaded on the web is done manually at its opening in Photoshop by assigning it the likeliest color space, sRGB.

What's coming next, logically, is the conversion of a photo or more exactly the conversion of the RGB values of a photo in different R'G'B' values, corresponding to the same  $L^*a^*b^*$  color: [Convert an image](#) ▶

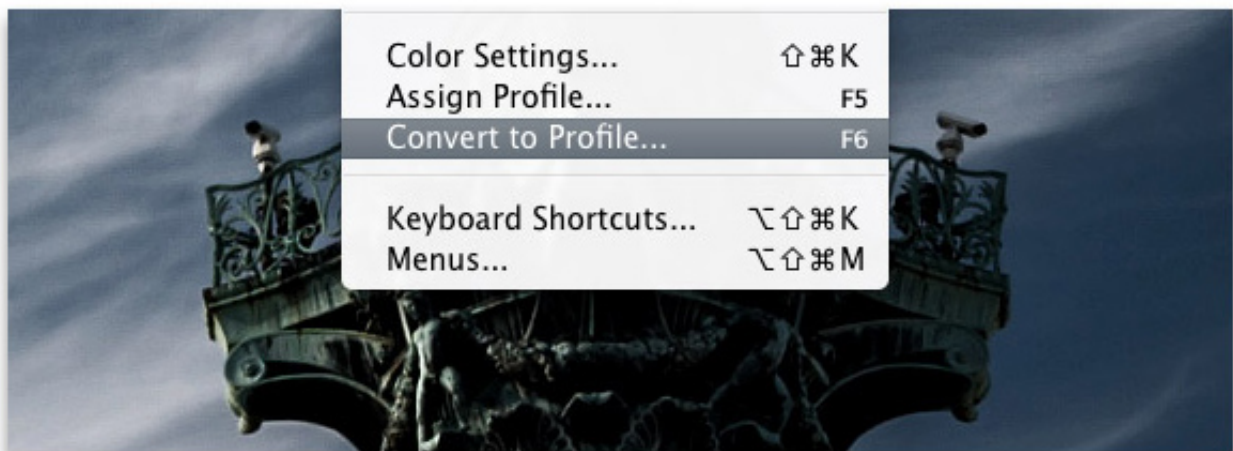
[Next page 8/10: image conversion](#) ▶





# Convert an image: why, how?

Here again, it is a vocabulary that is specific to color management. The conversion is necessary if you want to keep the same colors (L\*a\*b\*) from one device to another. An image is converted when its RGB values are changed to others slightly different in order to take into account the defects of the destination device. If you are new to color management, the most important is to know that Photoshop can take care of everything. But what a satisfaction, if you take the time to learn to do it yourself: your prints, your images on your website will be even more beautiful!



## Key points if you are a beginner ...

**Here are the key points to remember on image conversion. The rest of this page will be dedicated to those who want to go into more details.**

**Since you want to keep the same color on your monitor and your print for example, the RGB values displayed on your monitor should be changed to take into account the "defects" of the printer. This modification of values to other RGB values is called a conversion.**

**This is exactly the same as in an exchange office : you have 100€ in your pocket and you change it for 80\$ during the day. You have 100 something then only 80 of something else, but it is the same (the same color in the end !).**

**This conversion is very complex and fortunately done automatically in Photoshop, if you use the color management tools of the software.**

**To achieve this, you need two things : a picture WITH its ICC profile and a destination device with its ICC profile (the one of the printer for instance). If one of the two ICC profiles is missing, it is impossible to achieve it. And you will also have to choose the conversion mode which I explain next page...**

**Next key point : [conversion modes](#) ▶**

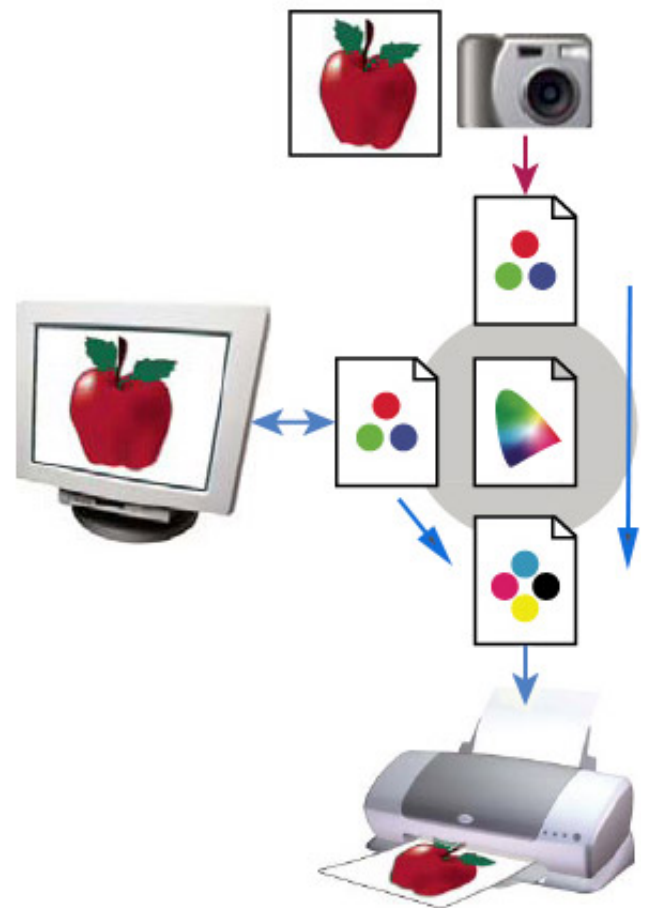
Since there are larger or smaller [color spaces](#), [and since there are also ICC profiles](#) for each device, the problem is now to know how to communicate the right color, the "same color" when it is possible, from one device to another, taking into account their characteristics. The communication of the "right color" and change of the corresponding RGB values is called **conversion**. Let's see how and why now... knowing that it is kind of similar to a foreign currency exchange office: you have \$100 in your possession (as if you were in a given color space, the image's) and you want the equivalent in dollars (to print your file correctly with a given printer and paper) and it is the exchange office and daily exchange rate (the equivalent of the  $L^*a^*b^*$  space) that will provide you the equivalence through a conversion... coincidentally, it is also called a conversion when it comes to money.



## **How to communicate the "right" color?**

Let's start with a little bit of history. Over 20 years ago, an international organization, the International Color Consortium - ICC - founded by Adobe, Microsoft, Apple, Agfa, Kodak, Silicon Graphics and Sun invented and installed, first on an Apple computer, a fabulous tool: Colorsync. ICC profiles were thus invented in 1993 - or ICM profiles for Microsoft ® - and conversion tools that necessarily accompany them. But in 1993, the tool Colorsync was only a conversion tool and not an ICC or ICM profile creation tool. They were still to be invented!

In fact, all these ICC creation and conversion tools only show good performances since 2000 for the general public, that is to say since Photoshop version 6 and since companies like MonacoSystems or X-Rite created great profile creation programs at affordable prices and quality sensors. It is thus quite recent!



What is the "right" color?

We now know that the "right" color is in fact a  $La^*b^*$  color and thus the "true" color perceived by a camera for instance. But this "right" color is transcribed in RGB value for obvious practical reasons but since the perfect camera doesn't exist, it is unable to see them correctly directly. So each RGB value supposed to retranscribe these  $La^*b^*$  colors is marked with a little mistake. This mistake is measured during calibration of said camera, and kept available on a little post-it now accompanying this photo and that is called its [ICC profile](#). To display a photo correctly, we saw in the [previous page](#) that this ICC profile had to be assigned to this photo. Its RGB values are then correctly interpreted and thus displayed with the "right"  $La^*b^*$  colors.

But we also saw in the previous page that it was possible to face an annoying technical problem. The RGB values that can be measured with the pipette in an image don't match the colors displayed anymore. We took as an example a neutral grey (128, 128, 128) but retranscribed in the image with the RGB values 128, 138, 126. Thanks to the assignment of an ICC profile, we saw that the image then displayed correctly because Photoshop, thanks to the ICC profile, knew that for this camera, a value of 128, 138, 126 should in fact be displayed 128, 128, 128 hence in a neutral grey. But this didn't change the fact that with the pipette, the RGB values showed a

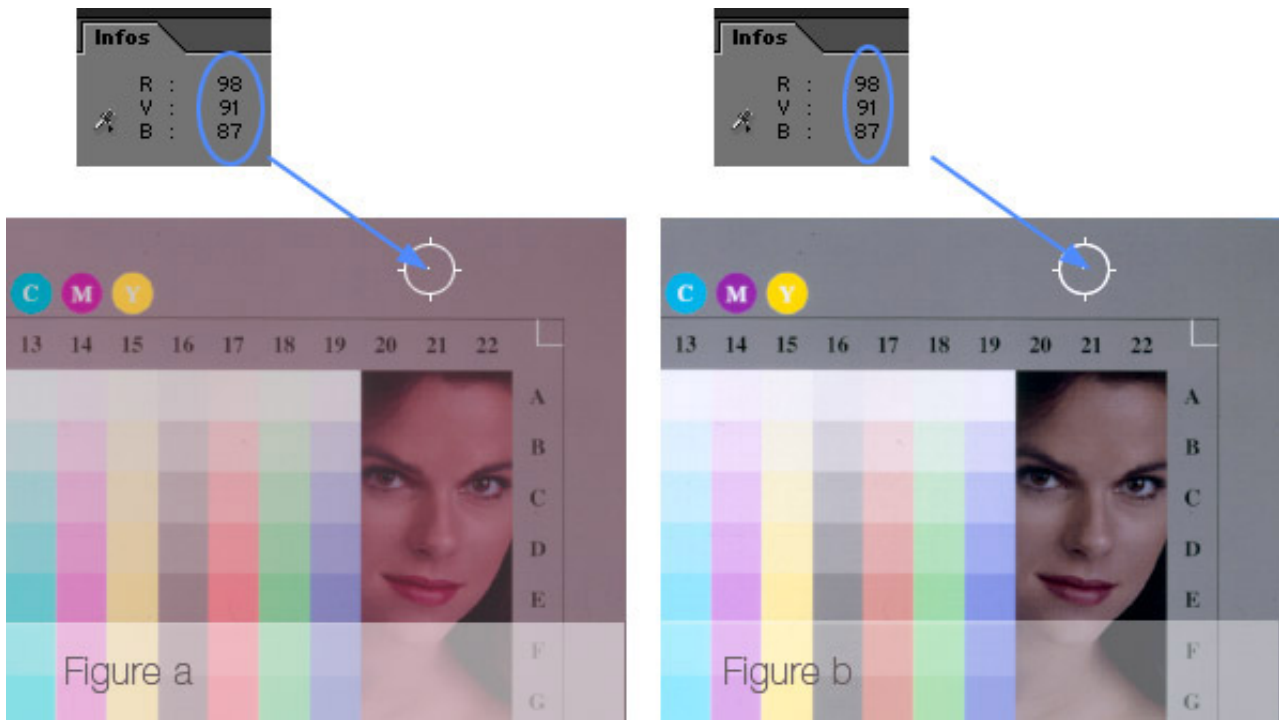
predominance. So there's a "logical" problem at this step in color management between what the pipette measures and what the eye sees. The pipette measures a grey marked with a predominance and our eye sees a neutral grey. There's one more operation to go through for everything to be back to "logic". This operation, as you'll probably have guessed, is called a conversion.

What is a conversion and how is it performed?

Convert an image is thus used to change RGB values this time - and not the colors displayed - into other R'G'B' values WITHOUT changing - or as little as possible - its L\*a\*b\* colors so that the colors of a photo are, for instance, printed as accurately as possible, keeping into account the defects of the printer this time.



Let's go back to our example of the previous page - our IT8 test card - dedicated to the assignment of a profile to understand all of this better. We'd opened the image file of this test card (figure a. below) in Photoshop. The image displayed in Photoshop on the left is an image displayed without a profile to understand the whole process. Well not exactly without a profile because Photoshop necessarily needs to assign it one (ideally its own). But without one of its own, it will force the image to use one at all costs and will thus assign it what is called its [RGB workspace](#). If you "just" read the RGB values in the grey parts in figure a (on the left below), they read 98, 91, 87. But in the color space Adobe RGB 98, it does correspond to a reddish dark grey since the R value is predominant. So at this step, our scanner file was assigned an ICC profile by force but since it's not the right one, the image displays weirdly. It is thus time to assign it its own! And when it's assigned the right ICC profile - mon-scanner.icc - everything about the display goes back to normal (figure b. on the right below).

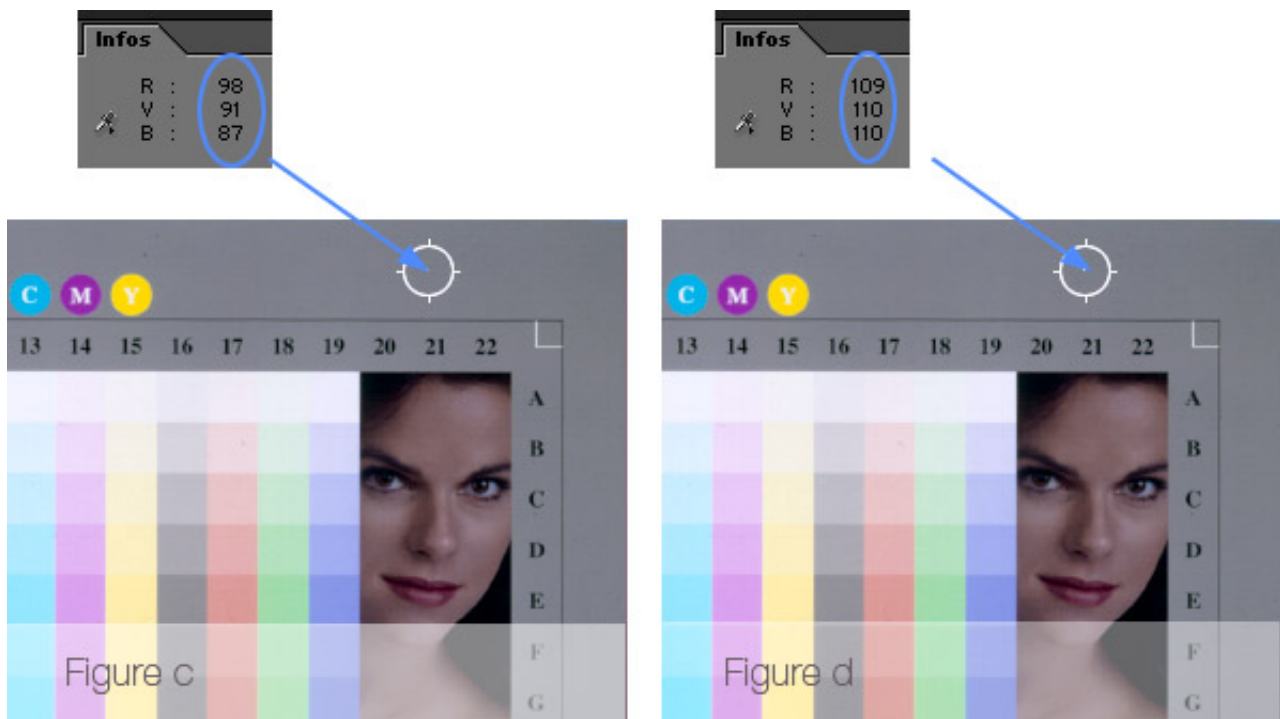


But my image that is now displayed correctly bears a huge handicap. The neutral greys displayed don't match at all the RGB values that could legitimately be expected in the info palette when I place my pipette on it. I see a perfectly neutral grey but the RGB values match a reddish gre (98, 91, 87). I thus have to perform this famous second operation that is called a conversion this time, in order to match the colors displayed with "realistic" RGB values. For that, I need to convert RGB values into other R'G'B' values but this time without changing the  $L^*a^*b^*$  colors displayed.

In figure c below on the left, identical to figure b above on the right, I see my image displayed correctly but still with my scanner's ICC profile. Via the menu Image/Mode/convert into profile in Photoshop until PS CS2 or via the Menu Edition/Convert into profile in the next versions of Photoshop, I'm going to convert the RGB values of this image in a rather broad color space like the well-known Adobe RGB 1998 (figure d.) This time, the display of  $L^*a^*b^*$  colors doesn't change BUT the corresponding RGB values change (R'G'B') to become "almost" neutral 109, 110, 110. It is called balancing my image. In the color space Adobe RGB 1998, the RGB values 109, 110, 110 are expressed as a neutral grey since it is a neutral space.

Once converted into a neutral space, I have a visual match between my

image and the RGB values.



Now that my image is displayed correctly and in a neutral and broad color space, I can edit it as much as I want - possibly with the pipette.

In fact, each device, each image, etc. does have its own ICC profile that a program like Photoshop is able to interpret. It can [assign a profile](#) to an image or "translate" colors, which is called converting an image, from one device to another. Devices are thus able to communicate through the CMM - color conversion engine - and their ICC profile. Since Photoshop version 6, it is called: ACE color engine. It didn't exist before this version of Photoshop (hence a long time ago!).

To work well, the CMM needs to know which ICC profile is assigned to an image - source ICC profile - to know which  $L^*a^*b^*$  colors it's dealing with for given RGB signals and to which device it should send it - destination ICC profile -, hence convert it in R'G'B' signals.

The CMM is the central element and is based on the  $L^*a^*b^*$  colors (the universal standard) and not on RGB or CMYK signals because, as we've seen several times before,  $L^*a^*b^*$  colors are absolute. **It knows which or which other  $L^*a^*b^*$  color it is supposed to transmit as information (hence absolute) and not each or other RGB value**

**(relative) thanks to the ICC profiles and know which RGB or CMYK signal it matches for this one and this one only.** It will thus translate this  $L^*a^*b^*$  color, a different RGB value for each device - even if they're quite close, obviously -, into another R'G'B' or C'M'Y'K' signal for the destination device to reproduce the same  $L^*a^*b^*$  color. And the best part is, if it can't do it directly, it will replace it with a different one without betraying the perceived visual impression. It's where its main strength lies! This operation of "translation" is called a conversion and there are four different ways to perform it depending on the rendering you're expecting. We'll see that in details in the [next page](#).

When must a photo be converted?

It is necessary to convert an image at least a first time in its history to match what the Photoshop pipette measures and what is given to see. Then, we'll perform or the image will undergo automatically other conversions to change the RGB values of our photo - hence still without changing its colors or as little as possible - to broadcast this image on the internet (sRGB color space), to be displayed correctly on our calibrated screen (this is done on the fly in the graphic card) hence keeping into account its own display defects, or at each print.



Important! When you convert an image into a neutral color space, you need to choose it a bit broader than the camera you used's ICC profile. It's why there are many of them, from the smallest sRGB to the broadest ProPhoto RGB.

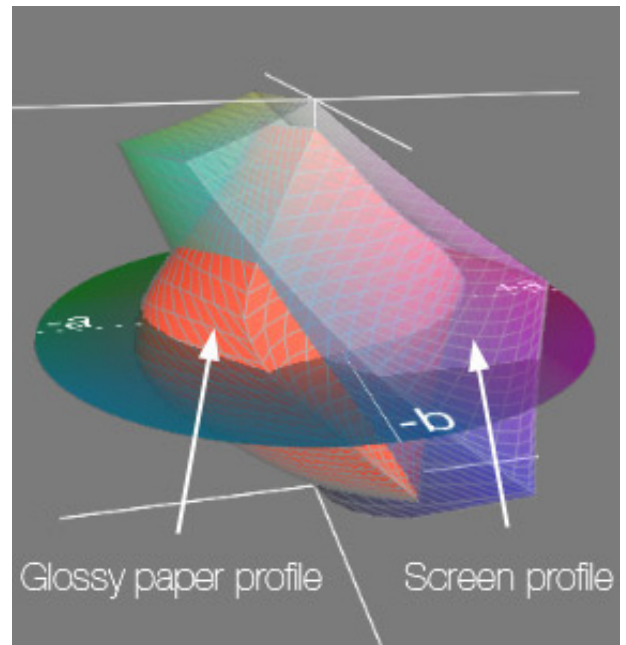


**What happens during a conversion?**

We just saw in the paragraph above the different roles of conversion. When you choose to perform a conversion, what does really happen to the RGB values of my image? How does the conversion tool, the CMM, keep L\*a\*b\* colors as much as possible, that is to say, the visual sensation of the picture, if the target device does not allow it as it is unfortunately often the case with printers? A conversion is a kind of translation which aim is not to alter the original...

## Large or small color spaces

As we already saw in the page dedicated to [color spaces](#), devices color spaces or workspaces are more or less wide. Some are so large that they cover all the others (ProPhotoRGB or certain digital cameras). Some are so small that they are included in all the others as for certain printers on matt paper. But sometimes, some are a little bit larger towards a specific color and vice versa



for another. This can clearly be seen in the illustration on the right. Globally, the color space contained in the ICC profile of this printer/paper pair is smaller than the gamut of the monitor except towards blue-green colors. These colors are printable but not visible on the monitor (not displayable originally hence displayed with less saturation). This is more often the reverse case you will face, by the way.

In other words, some colors can be contained in the original file, but not be printed. So two scenarios can be observed:

- Either original colors are printable (in the destination gamut),
- Or original colors are not printable (out of gamut).

In the first case, if the colors in the photo are printable, conversion is only



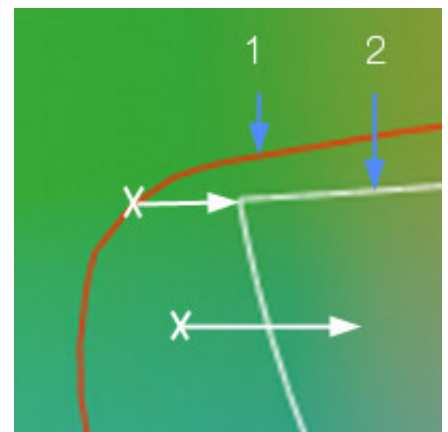
used to change the RGB values of the image to get the same colors on the print. So far, so good! But what to do in the second case or if the gamut of the image is much larger than the gamut of the printer or... the opposite?

Unprintable, really?

Of course not! In fact, they're "replaced" by the closest color(s) - see the next page about conversion modes - hence the most saturated color(s) of this screen. On a print, colors don't disappear either! They're just printed with the closest and most saturated colors that this printer and its inks can manage to produce. So where there was originally a color gradient on screen (for instance), you might end up with a color block, and a less saturated one moreover, on the print. In fact, with glossy papers, it is more often the opposite!

What to do with non printable or out of gamut colors?

Suppose the profile of your image is profile 1 (in red) and your printer's is 2 (in white). Your image has greens and yellows that the printer won't be able to reproduce because they are said to be out of its gamut. No combination of CMYK can exactly reproduce this  $L^*a^*b^*$  color in my image. What should I do then? The conversion consists into forcing, these greens into the printer's color space so that they're printed anyway, even if normally the printer wouldn't be able to, as with a shoehorn! But the visual impression must remain as close as possible to the visual sensations of the original image. To complete this shoehorn task, color management and conversion tools use four conversion rules - among which only two are used by photographers:



- Relative mode
- Perceptual mode.

They are discussed in the next page: [relative mode and perceptual mode](#) ▶  
There will inevitably be losses, but a good rendering engine will reduce them to a minimum (the losses!), without altering the visual sensations of the original image. Photoshop's is particularly powerful if you choose the correct conversion mode. Obviously some image editing programs, much cheaper, also feature edition tools like the clone tool and others of high quality, but none has such a good color management. Unfortunately, this comes at a price...



### **Notes about color spaces**

**It is perfectly imaginable to think that a one and only neutral color space such as Adobe RGB 98 could be sufficient to make conversion from the ICC profile of a device towards a neutral color space, but then why have so many been created, more or less broad, like ProPhotoRGB, sRGB? Well, the answer stands in two main and simple reasons :**

- **On the one hand, it is only justified by the fact that digital devices not only do not reproduce all  $L^*a^*b^*$  colors but additionally do it in very different ways. However, when a color of a photo - so one seen by your camera - is unprintable, conversion should find a way to recreate the color on your print so that it looks like your original. But, the more differences there will be between the original and the capabilities of the printer, the bigger the risks of having the original colors changed. Color management tools do not deliver miracles! A printer on matte paper does not have the same gamut than on glossy paper.**
- **Secondly, the larger the color space, the more colors it contains, therefore the more the computer work is important. But computers did not use to have the computing power they have today. Do not forget that Colorsync was created in 1995 ...**

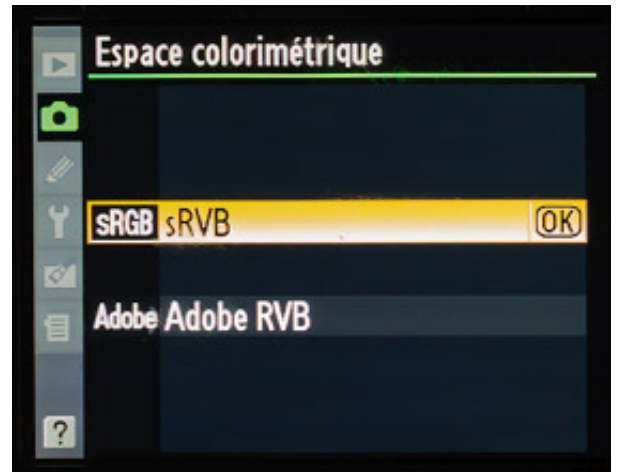
**... And concretely?**

Conversion can be performed in three different ways:

- Directly in your camera body (in JPEG),
- In your demosaicing program (Camera Raw, Lightroom, DXO, Capture One, etc.) in RAW,
- In Photoshop (all types of image files).

## 1 - In your camera body (in JPEG)

The assignment of the ICC profile of your body must have happened automatically in your camera body. Conversion towards a neutral color space like the famous sRGB will also be performed directly in your body, to the condition that you're shooting in JPEG. For that, you'll have to go into the menus of your camera and choose your color space from two options (very seldom, three):

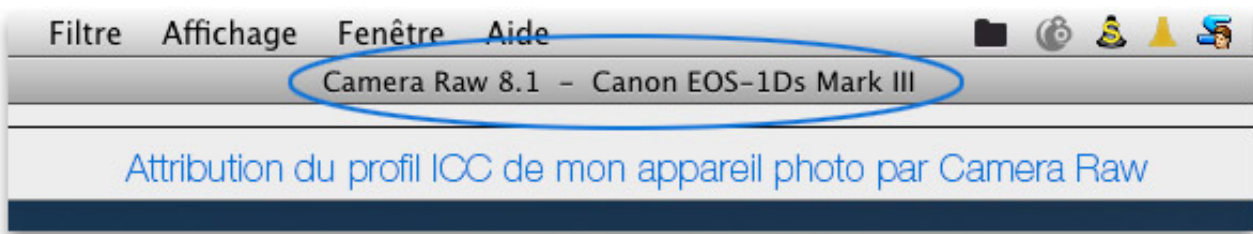


- sRGB (by default),
- Adobe RGB (or Adobe RGB 98 but it's the same).

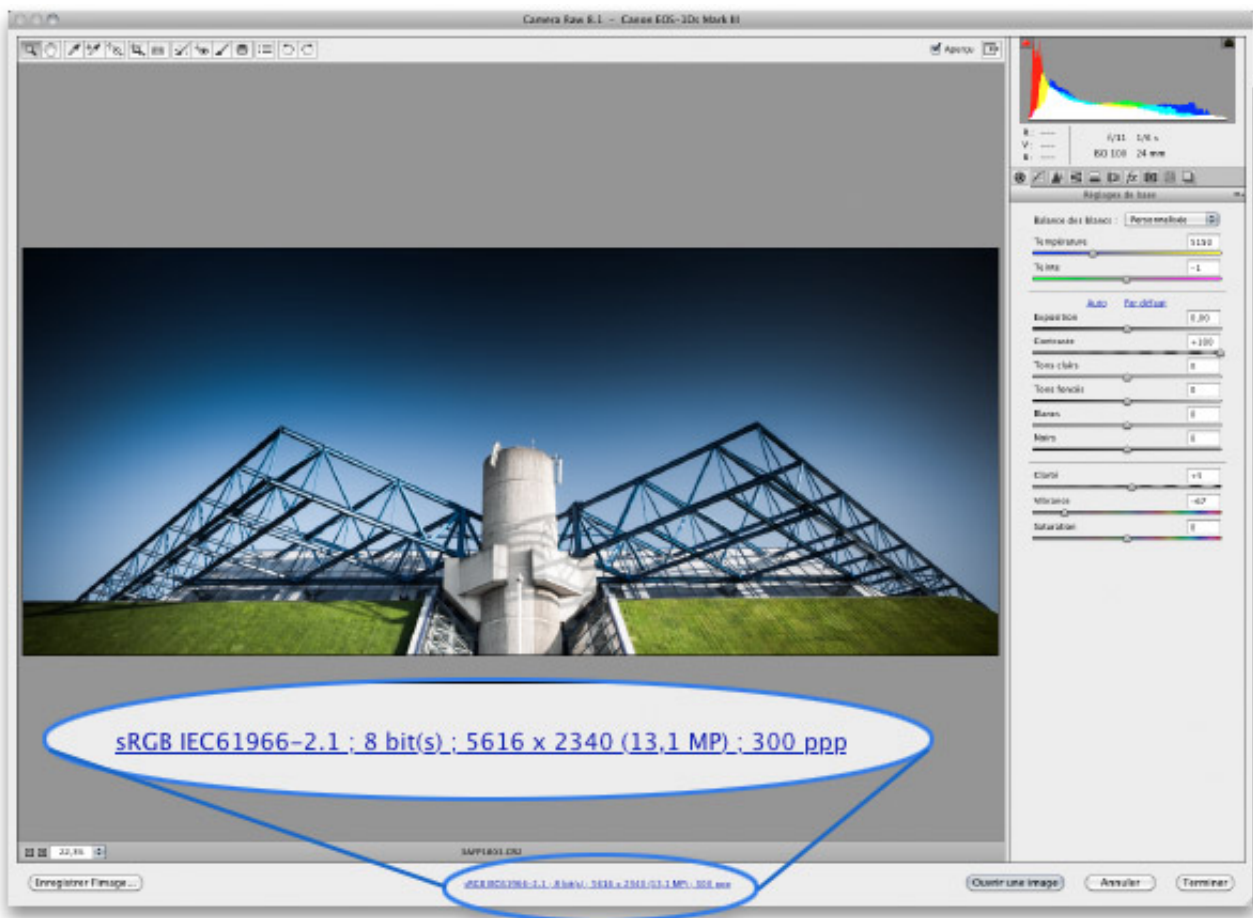
Caution! This choice only applies to JPEG files, even if you're shooting in RAW + JPEG.

## 2 - In your demosaicing program (Camera Raw, DXO, etc.) for RAW files

The assignment of the ICC profile of your body applies automatically at the opening of your RAW file in your program. You have nothing to do and you can't do anything at this stage! If your body isn't recognized by your software because it is very recent or you haven't updated the database of your program, you just won't be able to open your RAW file.



Once opened with the right ICC profile, you need to choose your destination color space, just like on your body (see above), but with an important difference: you can choose from more options among which the very interesting and useful ProPhoto, in certain situations. Example with Photoshop's Camera Raw below:



Right at the bottom of the window, you can choose the destination color space. In Camera Raw, you can choose between the classic sRGB, the bigger Adobe RGB 98 and Colormatch RGB and the very broad ProPhoto.



Important update! Since the update of Photoshop CC to 14.1, it is now possible to choose your destination color space from all these profiles! If

you installed them on your computer, you can thus choose DonRGB, Best RGB, Melissa RGB, etc. and not just between 4 possibilities and moreover, you can now choose the conversion mode. (Until then, the default choice was relative, which is quite logical). The situation is thus perfect now and finally leaves us the complete choice of color management in Camera Raw.

When you'll click the button "Open an image", your photo will necessarily have this color space.

### 3 - In Photoshop...

Conversion with Photoshop is treated in a dedicated page: [color management with Photoshop](#) ▶

#### **To be remembered!**

- **A right color (L\*a\*b\*) can be "translated" by a great variety of RGB values, depending on the device. An RGB color is thus not a "right" color but only a color for a given device hence in a given color space.**
- **To be sure to communicate the same color (meaning the same L\*a\*b\* color), two devices must exchange RGB values thanks to a conversion: the RGB values of a color are converted hence translated into R'G'B' values for another device hence for this same L\*a\*b\* color.**
- **So this conversion tries to keep the look and colors of a photo even if some of the colors are unprintable, for instance.**
- **There are two "ways" to solve these issues of unprintable colors: relative and perceptual conversion modes, studied in the next page.**
- **This conversion can also be performed first in your camera if you're working in JPEG, in your demosaicing program if you're working in RAW, and then in Photoshop or your photo editing program.**

There is now a last point to talk about when dealing with image conversion, and one that I just mentioned: [perceptual and relative colorimetric conversion modes](#) ▶

# Convert an image: perceptual and relative conversion modes

You're in the heart of color management when you want to print or share photos. Conversion and conversion modes are thus very important concepts. You need to choose one of them BEFORE you print or share your picture because the rendering may be significantly different BUT it depends a lot on your photo. In most cases, the differences will indeed be imperceptible. Let's see this...

## Key points if you are a beginner ...

Here are the key points to remember on conversion modes. The rest of this page will be dedicated to those who want to go into more details.

### How many conversion modes exist ?

There are four different conversion modes, but only two of them interest us :

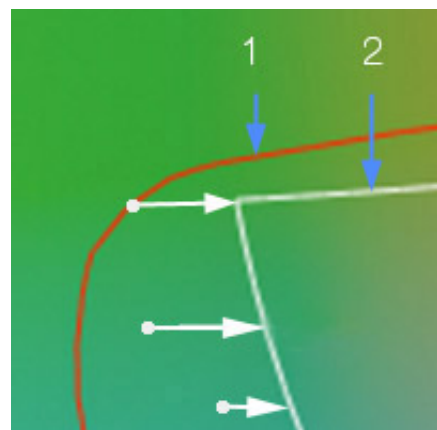
- Relative colorimetric,
- Perceptual (sometimes called photo rendering).

### What is a conversion mode for ?

During the conversion of RGB values of a photo to R'G'B' values of the destination device (eg Photoshop to the printer), it may exist colors from the original image which can not, for example, be reproduced. The printer does not have enough saturated ink. What should be done with these colors? Whereby change ? The two modes of conversion will take care of this but in two different ways.

In relative colorimetric conversion mode  
In this mode, all original unprintable colors, because too saturated in the source image, are replaced, by the printer, by the nearest and most saturated ink color printable. All other colors do not change.

What is the consequence ? Imagine you have photographed a beautiful red dress using a flash. The red will be very

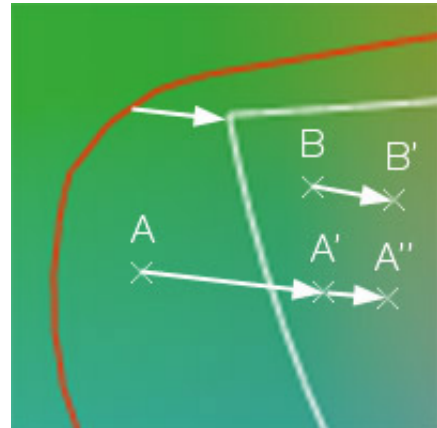


saturated. The camera has photographed all the nuances of the drape. However, the printer does not know how to print all these so saturated nuances. In relative colorimetric, all these reds will unfortunately be printed with the same red. The dress is going to lose a big chunk of its nuances, so its drape. The photo will be flat.

#### In perceptual conversion mode

This conversion mode tries to keep all the drape of the dress, so will print all shades of red but with less saturated colors, at least the more saturated of the printer.

What is the consequence ? always with our dress, the drape is kept here, but all colors are changed. The general perception of the image is preserved but some other perfectly printable colors will also be desaturated or slightly modified. That's why it is called perceptual. This mode keeps the drape, but at the color truth cost.



Then, which one is to be chosen ?

Firstly, there is no ideal conversion. Each image has its most suitable conversion mode. If you know how to do it (and I explain it on my page dedicated to [print with Photoshop](#)), you know that you can choose the conversion mode for your picture BEFORE printing. If you hesitate and as it works very well in most cases, I recommend the relative colorimetric mode. This is the conversion mode by default of Photoshop and that is fine with me.

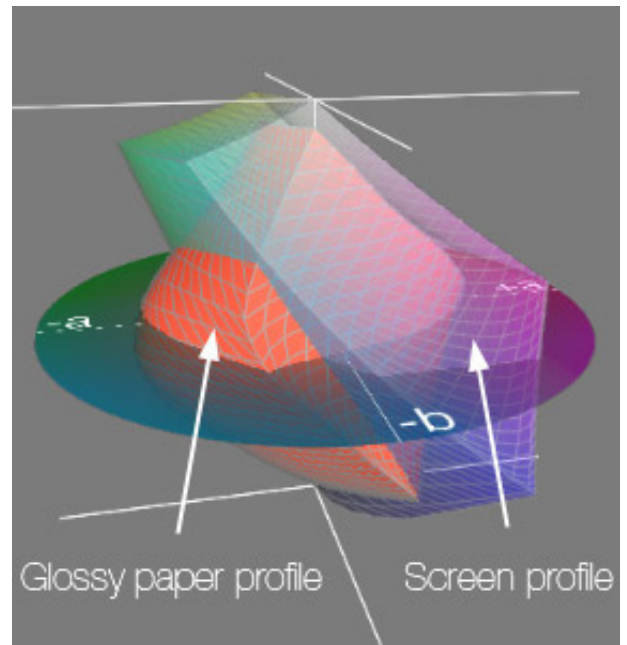
Next key point : [what is calibration ?](#) ▶

We have seen on the [previous page](#) the different roles of conversion. When we choose to perform a conversion, what is really happening at the RGB values of my image ? How the conversion tool, CMM, offers the best La\*b\* colors, that is to say, the best visual sensation of the picture, if the targeted device does not allow it as it is unfortunately often the case with printers ? The conversion is a kind of translation which aims not to distort the original ...



## Why is there a need for two conversion modes ?

As seen on the page dedicated to [color spaces](#), color spaces of devices are more or less wide. Some are so large that they cover all the others (ProPhotoRGB or DonRGB). Some are so small that they are included in all the others. But sometimes, some are a little bit larger for a specific color and vice versa for another. This is clearly seen in the illustration on the right.



Here, the color space contained in the ICC profile of this printer/paper set is smaller than the gamut of the monitor except in the blue-green colors. These colors are printable but not visible on the monitor. This is more often the reverse case you will face.

In other words, some colors may be contained in the original file, but be not printable. So two scenarios are observed :

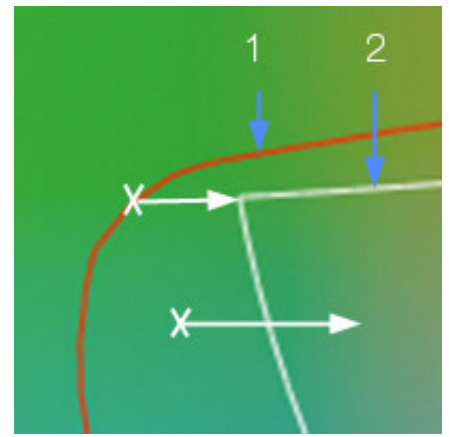
- Either original colors are printable (in the destination gamut),
- Or original colors are not printable (out of gamut).

In the first case, if the colors in the photo are printable, conversion serves only to change the RGB values of the image to get the same colors on the print. So far, so good ! But what to do in the second case or if the gamut of the image is much larger than the gamut of the printer or ... the opposite ?

**What should be done of non printable or out of gamut colors ?**



Suppose the profile of your image is the profile 1 (in red) and that of your printer the profile 2 (in white). Your image has greens and yellows than the printer can not reproduce because they are said to be out of gamut. No combination of CMYK can exactly reproduce the color Lab of my image. What should I do then ? The conversion is to force, as with a shoehorn, the greens into the printer color space so that they will be printed, even if normally the printer would not know how to do so ! But the visual impression must remain as close as possible to the visual sensations of the original image. To achieve this task, the color management and conversion tools use four conversion rules - only two of them are used for photographers :



- The relative colorimetric
- The perceptual

They are discussed below. There will inevitably be losses, but a good rendering engine will reduce them, without altering the visual sensations of the original image. The Photoshop one is particularly powerful if you choose the correct conversion mode. Obviously, some image editing softwares, much cheaper, are also having edition tools, such as clone tool and others of high quality, but none has such a good color management. Unfortunately, this comes at a price ...

## **Rendering modes : relative colorimetric or perceptual**

When a conversion is performed in Photoshop, you need :

- An image with an ICC profile;
- To Choose the destination device ICC profile - your printer and your paper -
- But also, as seen, the rendering mode (Rendering intent).

What is it ? Just how colors are managed out of gamut when converted. Are we deleting colors out of gamut - destructive but logic - are they replaced by other colors but which one ? What happens to the colors used for the replacement ?



### Note on conversion

**The conversion takes care of changing the RGB values - origin to destination - and the rendering mode (Rendering intent) handles to know what we're doing of out of gamut values - preserve, remove, replace or change -.**

Let's have a look at it now ... According to the rendering mode selected, the conversion rules will change. There are four of them : perceptual, relative colorimetric, absolute colorimetric and saturation. Best suited to photography is very often, in my opinion, the **relative colorimetric mode**, but the most "logical" because supposedly more linked to photography is the **perceptual mode**. I will now describe them.

An example may illustrate the problem : Imagine that I want to print an image. It has the profile of my workspace - red line on the illustration on the right - and I know that my printer is much smaller for the greens and yellows - white line -. Colors of my original, around the point A should be unprintable - Lab color associated is not printable. Never the less, I



want to try to print these colors, so I have to convert my image into another space, the destination - inside the white line - to read the right RGB values BUT HERE THE RIGHT RGB VALUES DO NOT EXIST AS NOT PRINTABLE. In the case of the point B which is common to both areas, and the Lab color associated belongs to both spaces - the LAB color can be converted into other RGB values. Under these conditions, how to

print those yellows and greens of my image that are outside the reproducible area of the printer and not completely distort my image when printed ? What is the printer doing of colors out of destination gamut ? Are they just deleted ? In addition, on my original image, the distance between A and B points gives me a certain visual "sensation", how to keep it after the conversion ?

But there are several problems :

1 - If greens out of the color space, so normally unprintable, are placed in the space of the printer - inside the white line - many colors will actually be "overlaid". Perfectly printable colors that belong to my original image, would be replaced by initially unprintable colors. One might think then that the only option open to us is to keep the color B and eliminate A. In other words what does one decide to keep and eliminate?

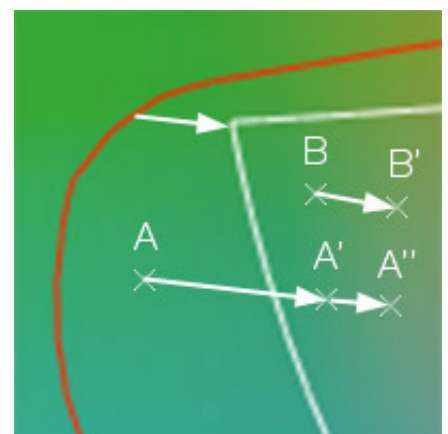
2 - Also, if I put the color A on the color B and red line colors on those of the white line, it will be impossible to differentiate them, although they were different in the original space.

3 - Finally, I remind you that the yellow-green point A was at a distance of yellow-green point B in my original image, which gave me some visual sensation.

To solve these problems, mathematicians have invented conversion rules they called rendering intents.

## In perceptual rendering intent

The ACE conversion engine of Photoshop will work hard ! It will indeed be placing the greens out of space, so not to completely remove the nuances and keep my visual impression (my visual perception). To make a conversion respecting the visual sensations of the original image, the ACE conversion engine of Photoshop will proceed in two steps. It will first of all "set" the colors of the red line (the limit of the space



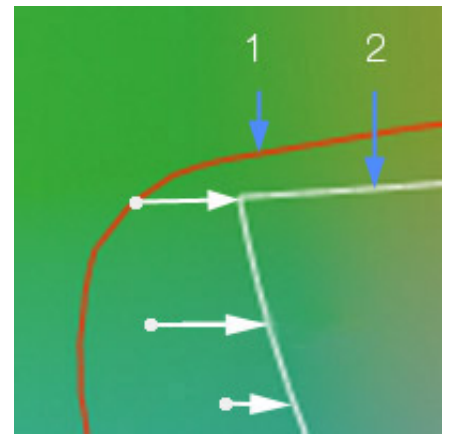
Perceptual mode

of the image) on the white line (space limit of the printer) as the colors of the white line are the closest visually of the red line colors. The colors of the red line are the most saturated colors of my original image and the white line colors are the most saturated colors of my printer. Then, to keep a close visual sensation of the original image, it will **slightly and gradually** "shift" colors within the space of the printer as shown in the figure above. B will shift to B' and so on ... B being "liberated", Photoshop can put an out of gamut color in its place. As this cannot be done indefinitely, without having colors disappearing on the "other side" (red colors side), it is wiping out a few nuances of the original image **in the gamut** as it "pushes" colors inwards, while trying to retain the same visual perception. That is why this mode is called perceptual. The image will lose some of its original colors but the visual sensation remains very close to the original image.

Summary : The red line goes to the white line. Color A disappears because unprintable and is replaced by A', the nearest printable color. A' is replaced by A". From time to time out of gamut colors really disappear because the volume of color of the red line can not physically go into the white volume. The relative distance between A and B - A 'and B' therefore being smaller - is conserved as much as possible. That is why an image should be worked as long as possible in the original color space. This is the only way not to lose information. Conversions, in this rendering mode, are destructive because **all colors are changed**, even those that were printable. Conversions need to be limited in number and done at the very last moment. Finally, the converted image will appear slightly desaturated and slightly less contrasted, if the color space of the printer is really too small for these colors. Then simply apply a level layer or contrast layer to find - almost - the Lab color from your original image.

**In relative colorimetric rendering intent**

The ACE conversion engine of Photoshop works much less because it is then simply a matter of removing all colors out of gamut ! The Lab colors shared by the two color spaces remain unchanged. **So, if the colors out of gamut disappear, other colors are not changed at all, which was not the case in the perceptual rendering intent.** This mode is therefore perfect when the original image contains very few colors out of gamut or when a printable color should not move at all.



## How to choose between perceptual and relative colorimetric?

The most important thing is that there is not a better way of rendering than the other, it depends on the photo to convert and more precisely of Lab colors contained in the file. Reminder : in nature, the colors are not always very saturated and that is why the choice of working only in sRGB is not "catastrophic". While it is fashionable to work in larger color spaces to show that you know a lot about color management, I find even smarter to stay in sRGB in most cases because the sRGB color space already contains enough colors, to be only rarely forced to work in a larger color space. Each picture taken does not contain millions of colors and all photographers do not take pictures of the turquoise seas or dresses of designers with intense reds !

So if your original image has little or no out of gamut colors for your printer, they will not be "lost" by a **relative colorimetric rendering intent** ! It is then the most appropriated mode because it does not change - so do not deform - the colors within the gamut. Coincidentally, this is the one that works best in most cases, which is perfect ! Even if you work in ProPhotoRGB, it is surprising how this rendering mode often works very well. Your image was not necessarily containing a lot of colors out of gamut for the printer, whose gamut is much smaller.

If your original image contains a large amount of unprintable colors, then it may be wise to use the **perceptual rendering intent**. Certainly it changes all the values of your file but it has a much better preservation of some materials, of some relative distances between two colors as explained above.

## **How does it get actually materialized ?**

Where the **relative colorimetric rendering intent** could transform unprintable colors into a solid color without any nuances since all colors out of gamut are "deleted" or in other words replaced by a single color, the closest printable color, the **perceptual rendering intent** tries to keep those nuances, even if it has to replace them with others, very similar visually. I'll try to show you, I hope, with the illustrations below !



1 - Original photo



2 - Photo convert to relative mode

3 - Photo convert to perceptual mode



One point is very interesting : if you look at the whole picture EXCEPT the circled area, you will see that the picture does not "move" between the original, the perceptual and relative colorimetric rendering intents. The "movement of colors" will take place for some colors only !

In this example, you should have a look at the yellow color of the wall on the left, the twilight colors of the sky near the horizon and finally, the colors in the circled area. On the original **(1)** the sky is saturated with shades of blue, more or less dark and more or less saturated.

The converted image with the **relative colorimetric** rendering intent **(2)** show the disappearance of many nuances in the sky - circled area - while the rest of the image remains unchanged. The blue out of gamut color of the sky in the circled area cannot be kept the way they were. And where

there were nuances in terms of saturation and brightness, there is a flat area !

On the image converted with the **perceptual** rendering intent, we are less moving away from the original. While the blue sky in the circled area is also less saturated than the original, it retains brightness nuances as on the original. The result is closer to the original image. The rest of the photo in the common gamut is preserved.

### **Remember !**

- **There are two color conversion modes. The Relative colorimetric and the Perceptual rendering intents.**
- **There is no ideal mode. Each picture has its best conversion mode.**
- **If your photo have really saturated colors (for instance the red dress drape) it will be a good idea to verify before printing that the perceptual rendering will deliver better results than the classical relative colorimetric rendering.**
- **Photoshop and Adobe Suite, by default, use the relative colorimetric rendering intent and in most cases, it is just perfect that way. You do not always photography highly saturated colors.**

Finally, the order in which we will calibrate our color workflow is very important. You have to start with your [monitor calibration](#). Then you will deal with your scanner (if needed) and your [printer calibration](#). But before going any further, I would like to spend some time on defining some more words : [calibration and characterization](#) ▶

[Next page 10/10 : Calibration and characterization](#) ▶





# What is calibration ?

Even if our eyes are wonderful partners to show us the world, they're unfortunately completely unable to help us calibrate our color workflow. However, achieving a good color management between the pictures displayed on our monitor and their prints or when sharing them on internet, cannot be done unless you go through the calibration process. At the very least, I "highly" recommend you to calibrate your monitor, because it is relatively cheap and easy to do and also to calibrate your printer or to have it calibrated by a professional if you find it too expensive to do yourself.



## Key points if you are a beginner ...

**Here are the key points to remember on calibration for your color workflow management. The rest of this page will be dedicated to those who want to go into more details.**

**In order to have the color management work you need to calibrate your different devices : [calibrate monitors](#), [calibrate printers](#) ... Thereby you get all the ICC profiles of each device.**

**Calibrating a device consists of two different steps :**

- **Calibrate devices : that means placing your device in a known and stable way of working,**

- **Characterize devices** : thanks to monitor hardware calibrators or spectrometers for printer, you will precisely know how they behave (or in that case misbehave) and how to correct defects.

**monitor calibration** consists of using a colorimeter, also called **hardware calibrator**, to determine the right luminosity, contrast (this process is impossible to achieve with your eyes) - also called gauging phase -, and to have those defects being written by a software in an ICC profile (kind of identity card) - also called grading phase or calibration -.

In order to achieve this process, the software will display colors on the monitor that the colorimeter will measure.

A monitor colorimeter or **hardware calibrator** is therefore essential and remain cheap nowadays.

**Printer calibration** consists of choosing a paper, inks - the equivalent of the gauging process - print a reference color target and measure thanks to a spectrometer the reality of the colors printed.

In order to create the ICC profile of your printer, you just need the software to compare the printed colors to the colors that should have been printed.

Those calibrating kits are expensive, but you can go for the alternative of having it done by a professional for a limited amount of money.

Next key point : **Calibrate a monitor** ▶ Next key point : **Calibrate a printer** ▶

The whole color management process is based on this essential step: calibration and characterization of each device of your color workflow.

Thanks to calibration of each device, hence to the consideration of their color characteristics, you will be able to keep the "right" color, the L\*a\*b\* color from one device correctly interpreted by another one.

Thanks to calibration you will obtain an **ICC profile** for each one of them.



Calibrate / characterize: what for?

The calibration process consists of two different steps: first **calibration**, then **characterization**. During the first step, you make sure the device runs at its best, at least in a known and stable way (it is called fixing the device to given working conditions)



and during the second step, you are going to measure its characteristics - its color ID hence its distortions, would I be tempted to say, even if it is not completely right.

To characterize a device, you display known colors on the monitor, print a known color chart and then run a program controlling the measurement tool that will read them to create an ICC profile specific to this device in these working conditions. If you change contrast values on your monitor for instance, you'll modify its calibration and will have to go through characterization again to create a new ICC profile.

## **Calibrate**

It means aligning on a control measurement (standard meter, second of an atomic clock). For a monitor, for instance, it is to set once and for all the conditions in which your ICC profile will be generated, meaning luminosity, contrast, gamma and color temperature. For a printer, it is choosing ink, paper and printing definition.

## **Characterize**

It means taking down the color characteristics of a device - screen, printer, etc., hence which  $L^*a^*b^*$  color is displayed or printed when a known RGB or CMYK signal is sent. For a printer, it means making sure it is printing the "right" color, as if no deformation or defect had occurred - but of course, it is an image! The control tool in color management, is called a color chart for a printer and a light wave length for a monitor.



The aim of calibration and characterisation is thus to know precisely:

- What the color characteristics of a device are or how a device is "distorting" colors in a more schematic way, even if it is not exactly what really happens - what color it really "sees" for a given RGB signal - in order to be able to "correct" it afterwards using an ICC profile that will induce adjustments compared to the standard;
- AND what colors a device is able to reproduce - called color space or gamut - depending on their technical characteristics, meaning will a color be printable or displayable on a monitor?

For that, the ICC profile creation program sold with sensors and colorimeters will compare a colored chart which characteristics are precisely known, meaning the one and only  $L^*a^*b^*$  color of each colored patch, to the color actually printed by the printer or to the light wave length displayed in RGB on the monitor.

Unfortunately, the calibration/characterization process can only be achieved with sensors or colorimeters, hence with accurate measurement

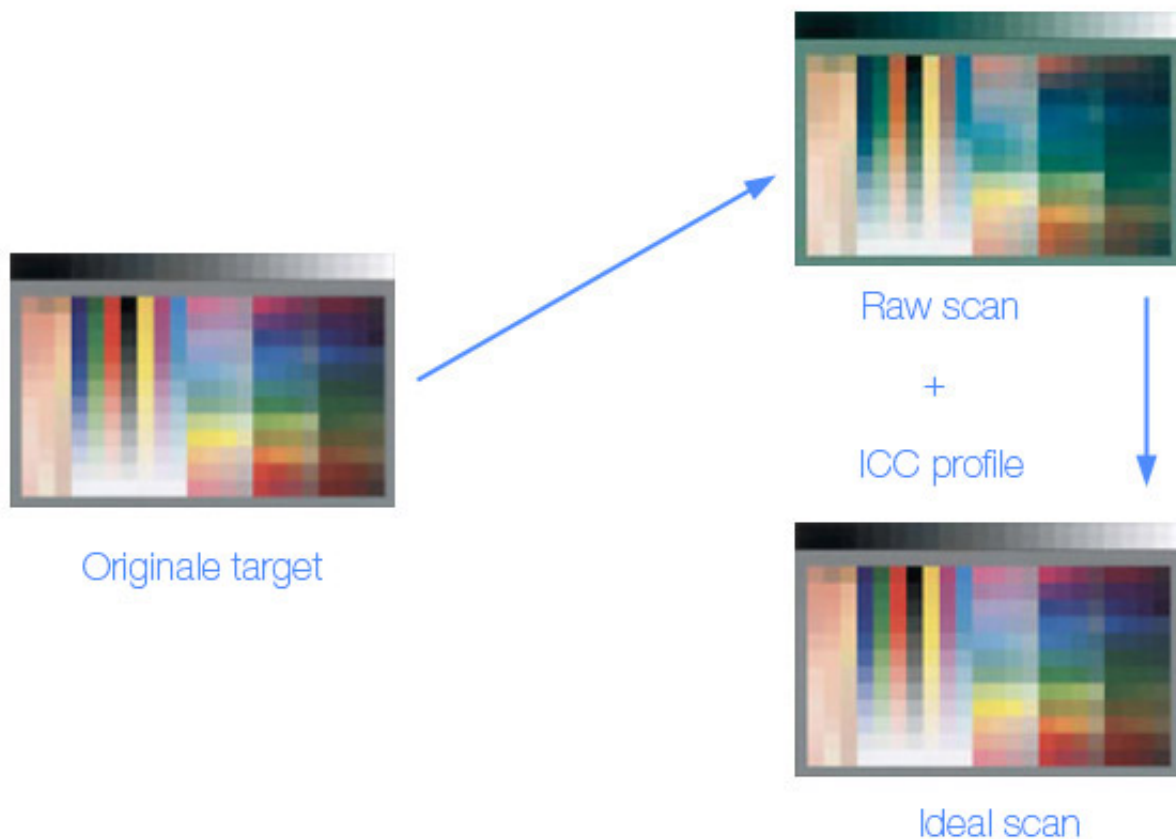
tools. It is unfortunate for the cost, even if the situation has changed a lot and keeps on evolving.

In the end and after correction, in order to take into account the device's defects, you will have to, for instance, project a different quantity of CMYK inks for a standard eye to see a neutral grey on a print !



## Concrete example !

Example of a scanner calibration / characterization process :



What we do is we make the scanner "see" colored patches - some of them neutral grey, while knowing the color characteristics of each one of them (CIE XYZ or L\*a\*b\* values). However, when you visualize them in Photoshop on a calibrated monitor, they appear to have, in that example, a green color predominance, far from the original color!!

If you check the RGB values of the greys with the eyedropper tool, for instance, you will be able to check that they are not all the same - 128, 128, 128 should be displayed but 120, 138, 128 for a neutral grey is actually displayed. So this scanner sees green where it should see neutral grey !

That is why an ICC profile is dependent on a device and should not be chosen as workspace in Photoshop. An RGB value of 128, 128, 128 in the color space of this scanner appears to be slightly greenish. We then [assign](#) the right ICC profile of this scanner to this picture and everything goes back to normal regarding the way this one displays colors on the monitor. The ICC profile corrects the defects of the scanner.

### **So what is calibration for?**

**Calibration enables to know exactly how a device sees colors in order to be able to fix the differences with the standard thanks to color management tools. The ICC profile informs the rest of the color workflow of its own characteristics. By the way, we should be using the word characterization here as it is about marking down the characteristics of a device. So the necessary conclusion is:**

**CHARACTERIZE!**



## **How to?**

It is really important to stress here that the quality of human vision is such that it is possible to distinguish subtle variations when it comes to comparing two colors. A "standard" human eye is able to see a difference of 1/100 to 1/200 between two color nuances, as explained in the [color page](#). But unfortunately, as for audition, really few people have an absolute vision. Almost no one is able, without a reference, to know which  $L^*a^*b^*$  color he is looking at with only one color before his eyes.

It is impossible for a "standard" human eye to know, without any comparison support, if this red is a red of 700 nm

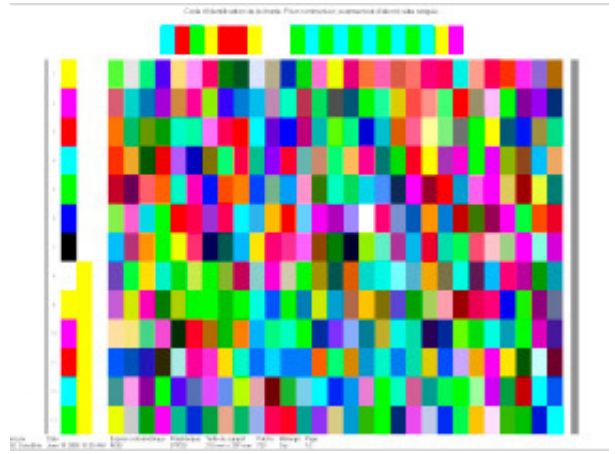
of wave length, hence a precise kind of red in the  $L^*a^*b^*$  color space. You will thus need a tool. A tool to measure or characterize.

As I said in the introduction, it would never come to your mind to put your finger in a test tube to evaluate the temperature of a liquid!

This tool is called a colorimeter or spectrophotometer and measures the wave length of the light. It is used to measure the colors a scanner x or y is able to digitize, a printer is able to print or a monitor is able to display. Charts and other references have been created for this purpose, accompanied by the program controlling the colorimeter and creating ICC profiles, that contains all the characteristics of the device.



What happens concretely during characterization? As an example, I am going to perform a printer calibration. First step will be to print with **all the settings by default** the color target - picture on the right - which is made of a multitude of known colored patches, that's to say, for each of them, the calibration software, which is also an ICC profile creator, knows the CIE XYZ coordinates.



The printer prints the chart as it is and delivers a print of this file. My ICC profile creation tool is now going to read, thanks to the colorimeter, the RGB values of each patch really printed and compare them to the expected  $L^*a^*b^*$  colors. The difference between the  $L^*a^*b^*$  color and the printed color is saved into the ICC profile matrix. From now on, for any picture printed on this device, with this paper and these inks, **I will have Photoshop convert the RGB values of my image into RGB values compatible with my printer and its ICC profile.** The image file to be printed will be transformed in order to take into account my printer characteristics, which I call defects!

Hopefully, once characterized, all devices are ready to be used as if they were natively able to replicate colors accurately. That being said, since it is a measurement, the quality of the ICC profile generated is directly related to the quality of the characterization device and to the software controlling it. It is only using his experience that a color management specialist will be able to say which system is efficient or not, since this device will deliver consistent results on different color workflows. In any case, even if those measuring devices are not perfect, they will always be better than a human eye, even an expert one!



**Temporary conclusion!**



Nowadays, thanks to color management tools in Photoshop and calibration kits on the market, it is possible to get surprising results to achieve a work of quality, knowing what you're doing and possibly what you're missing without leaving it to chance. For instance, when the monitor is calibrated, you know where to look if you're experiencing a printing issue at home or with a lab printer, even if you do not have the ICC profile for this printer/paper/inks. Considering how much can be saved on paper, inks and above all time, I still believe those calibration kits are not so expensive, considering how they help. The great thing is the ability to share identical color files with others and, in any case, respectful of the quality of the pictures delivered by your digital camera !

#### **To be remembered!**

- **Calibration is a must! And nowadays, affordable and easy to perform.**
- **At the very least, calibrate your monitor with a [Spyder5Pro](#) or a [Colormunki Display sensor](#).**
- **If it's not done already, avoid first price sensors which will deliver not great a result in the best case and a bad result most often.**
- **Printer calibration can be done remotely for a small sum of money in comparison to the price of a calibration kit.**

On the following pages, I will go through the calibration of each device, starting with the most important one, the monitor : [monitor calibration](#) ▶

[Next chapter : calibrate your monitor](#) ▶



# Why to calibrate your monitor?

**Because it is essential, quite simply! And why is it so? Because it is the starting point of the work you perform on your pictures, because you want to get the best out of them and your eyes are unable to accurately support you in this process. You should be convinced by now!**



## **Key points if you are a beginner ...**

**Here are the key points to remember on monitor or display calibration. The rest of this page will be dedicated to those who want to go into more details.**

**The monitor is our main working tool at home. And this main working tool is not always accurate when displaying colors, unless you spend more than \$2,000 in it, and things consequently improve.**

**Moreover, monitors have three main drawbacks for us who edit images: when they leave the factory, they're always too bright, too contrasted and the image is too cold. I could also add that their image depends a lot on the angle at which you're watching them (because of their technology).**



**But nowadays, as it wasn't always the case, powerful and affordable tools exist (less than \$250) to solve those issues. We are thus going to calibrate our monitor using a tool much more efficient than our dear human eye: a calibration sensor, also called colorimeter.**

**Obviously, this can only be done with a colorimeter, because to give you a simple example, how do you want to adjust precisely a monitor luminosity at 100 Cd/M<sup>2</sup> to the naked eye... Certain people are granted the absolute pitch, but I don't know anyone with an absolute vision!**

**Next key point : [how to calibrate your monitor?](#) ▶**

At least do your self a favor: perform a display calibration with a monitor sensor, a colorimeter. You have no idea how it will change your way of working! Considering their current cost, you don't have any excuse not to purchase one anymore! Just ESSENTIAL for someone working with images on a computer, screen calibration cannot be done efficiently



without a colorimeter (sold with ICC profile creation software). Prices have really dropped down since Spyder4Express or [Colormunki Smile](#) colorimeter can be found at a price around \$100 nowadays (versions I don't recommend though) and "Pro" versions are just a bit more expensive,

around \$170. This is excellent value for money. The references today are [i1Display Pro from X-Rite](#) or [Spyder5Elite from Datacolor](#), and cost \$250 incl. taxes. It doesn't seem too expensive to me compared to the price of digital shooting equipment, and to the money spent on ink cartridges and paper, or even more the price of a powerful computer, regarding its interest.

Monitor calibration is performed in two steps :

- calibration or gauging in itself;
- characterization next.

It is only during that second step that the monitor's [ICC profile](#) is created (device characteristics). At first, I am going to clarify those two terms. Even if I am going to put an emphasis on calibrating with a colorimeter, I will also explain in a second time why it is not only essential, but also very different from calibrating to the naked eye or using a print. Then [in the next page](#), I will answer the question "how to?" and in a third part, I will benchmark almost all [calibration sensors on the market](#). Then, I will end up with a summary where you will find [all my purchasing advice for calibration sensors](#) depending on each device category: laptop, iMac, iPad, office monitor, graphic arts monitor.



## **The problematics**

Calibrating a monitor consists in performing three REALLY IMPORTANT adjustments... and making one important choice!

- On the one hand, neutralize color predominances hence display defects of the screen,

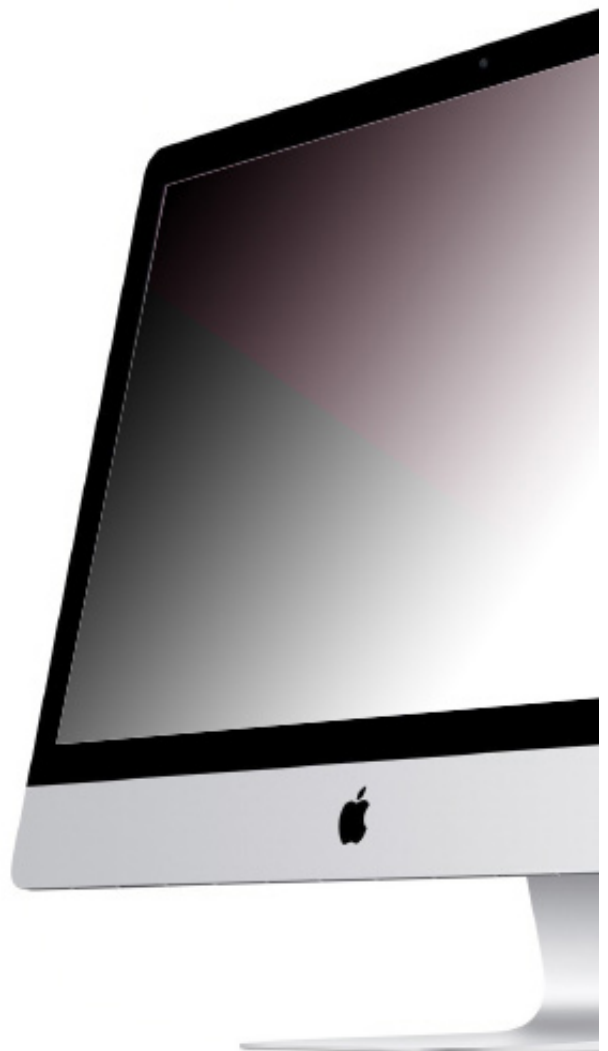
- On the other hand, adjust your monitor's settings to enable to display the right luminosity and contrast level,
- Ensure that the monitor displays the widest possible range of colors,
- And finally, make the right choices of monitor technology!

**Under no circumstances can those adjustments be performed to the naked eye, because even if the human eye is very good for comparison, it is also theoretically quite bad in terms of visual acuity.**

### **1 - Correct color predominances and optimize color range**

As seen in the pages dedicated to [generalities about color management](#), all color reproduction devices reproduce them with alterations that are proper to each and any of them. We would like our monitor to display a neutral grey, but it displays a grey with an unexpected color predominance, without even taking the printer's defects into account, etc. Calibration will thus consist into sending to the monitor a serial of RGB signals which absolute color we perfectly know ( XYZ values in CIE XYZ color space or  $La^*b^*$ ) and to measure with a colorimeter - also called colorimeter - how they are really displayed.

For instance: if I try to display a 128, 128, 128 RGB signal on a non calibrated monitor, there is very little chance I will see a perfectly neutral grey appear (even if things are better since 2012). Most probably, it will display a grey with a slight color predominance (reddish, greenish, etc.).



The sensor will measure the "real" color displayed (hence its L\*a\*b\* value) and place the information in a special file: the ICC profile of this monitor. With the created profile, Photoshop, for instance, will now know how to modify a RGB signal in order to display the right L\*a\*b\* color, in this case, a neutral grey. It means that when willing to display a neutral grey, 128, 128, 128, the graphic card will have to send a signal like 124, 128, 128 in order to take into account the monitor characteristics, here a defect in the reds. By doing this, the monitor will display the largest color range possible. On top of that, you'll see how your sensor can help you with additional adjustments in the next step.

### **The "bad" surprise of wide gamut monitors**

**A new monitor generation appeared: wide gamut monitors. Those monitors are able to reproduce at least 98% of the Adobe RGB 98 color space and can even reach 110%. However we have our habits with our monitors displaying sRGB only.**



**Almost all icon colors will appear very saturated in the task bar or in the Dock before and after calibration. Mac OS and Windows can't manage colors. You will only enjoy the benefits of your monitor calibration in programs featuring color management, like Photoshop or the Viewer. Your images will be beautiful in Photoshop and highly saturated/contrasted in the Windows or Mac explorer...**

**As for the web, it will depend a lot on the browser you're using. A real mess, still in 2014, but I go into further details about it in my page dedicated to color management on the web (July 2016).**

## 2 - Adjust monitor brightness

A point also often neglected is **screen brightness adjustment**, so that **the brightness of the picture displayed on screen is close to the printed one**. This adjustment can not be achieved with to the naked eye, just like color predominance correction, and requests a calibration device which is going to measure precisely the real monitor brightness level depending on the instructions you'll be giving to your program. It is the gauging phase.



Caution! The monitor gamma by default is also an important parameter. If you decide to buy a graphic art monitor, it is likely to have a 1.8 gamma. Calibrating it at 2.2 isn't very useful, and it could even be worse! Your monitor can have a good brightness level but a 1.8 gamma and you will still get too dark prints. Not so easy to deal with that! We will come back to that point later on.

## 3 - Adjust monitor contrast

Another point that is also often neglected the monitor contrast adjustment. Contrast adjustment is used to set the black point level for your monitor. This can clearly be an issue for laptop monitors calibration that never feature this setting. The colorimeter will have to perform it automatically.

## 4 - Are all monitors equal?

I invite you to read this page where I give you purchasing advice, my opinion on choice criteria (especially for screen technology for photographers) as well as my point of view on things...

## Recommendations to choose your monitor for photo edition

Let's now have a look at the two steps of calibration process for a monitor: **calibration** and **characterization**, or the report of its precise **colorimetric** characteristics.

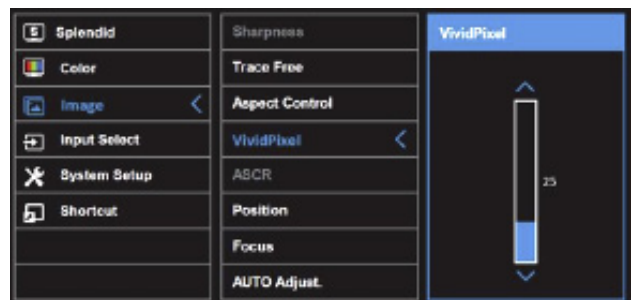


## Calibration & Characterization

As I already said several times before, the calibration process is in fact a two steps process: a **gauging** followed by a **characterization** (except for isolated cases like the [iPad](#)).

### Monitor calibration or gauging

In order to make sure that this color reproduction device that is a monitor is working in optimum conditions, we'll have to calibrate it, or rather gauge it, meaning that its basic functioning must be optimized and it must be placed in known and preferably stable conditions. For a monitor, one of the color workflow tool we are talking about in this page, the calibration process is used to set once for all:



- Maximum monitor brightness or white point;
- Contrast;
- Gamma;
- Color temperature - in Kelvins -;
- And possibly minimum monitor luminosity or black point.

This operation also called gauging can be done in two different ways



depending on the quality of the monitor purchased, **but always using a sensor:**

- With a non graphic art monitor, this is to say almost all monitors, this is done through the monitor menu and the colorimeter which, during this stage, operates as a gauging tool. A collection of colored icons appears on the monitor to enable calibration. One of the most important points is to know if the software offers the possibility to control the maximum and minimum quantity of light that it has to display precisely. This one should ideally be close to 80/140 candelas per m<sup>2</sup>, depending on the luminosity of your working environment, so that the luminosity of your print will be very close to the luminosity of your picture on the monitor. This can only be done with the help of a measuring device. A human eye is absolutely unable to achieve such a process without elements of comparison.

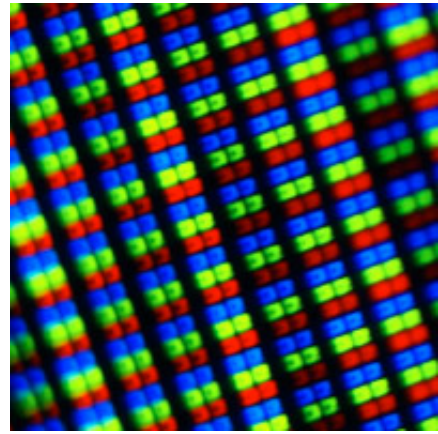
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### **Funny remark!**

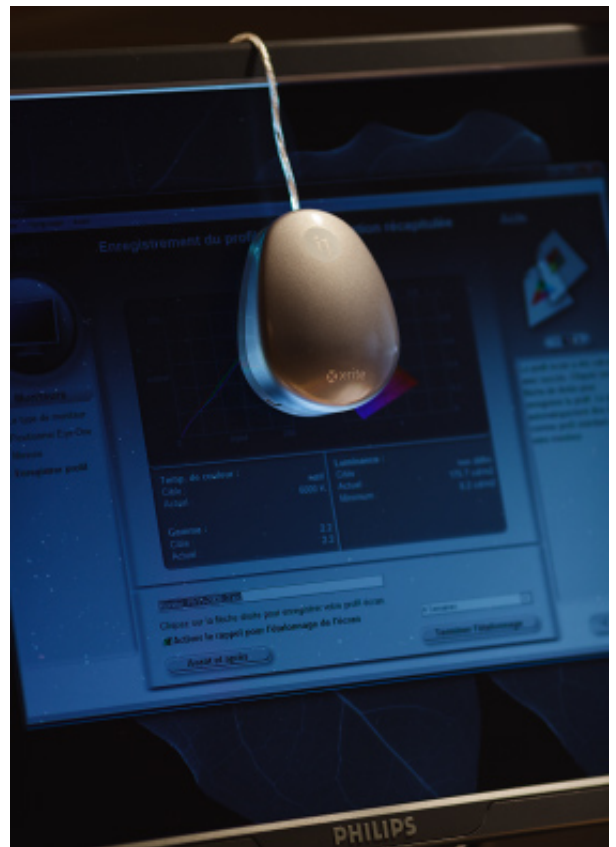
**As I told you in the first page of this file - [introduction to color management](#) - light wave lengths fixed by CIE for three primary colors are 700, 546 and 436 nm. To produce these colors precisely, a monitor lights up pixels of less than 0.30 mm (non retina screens hence around 90 dpi) in front of which RGB filters have been placed. The quality of the filters will determine the quality of the monitor. However, as it is a built-in technology, these filters cannot be changed. You can light them more or less, but you cannot change them! So if the monitor has a blue filter emitting at 438nm instead of 436nm, it is absolutely irretrievable. There is no way to transform this color and it goes the same way for the two other primary colors. But then, what is the colorimeter measuring and what is an ICC profile for, if the three primary colors are not ideal and cannot be changed?**

Well the answer is quite simple! The colorimeter measures precisely what the color is - light wave length - of the RGB filters of a monitor at first ( possibly at different luminosity levels depending on the type of ICC profile creation software). Now, we know that colors multiply to infinity (between 2 and 8 millions depending on your visual acuity), therefore the three primary colors are only three colors among millions - a bit more if you consider the different levels of luminosity possible for each of these three colors - the monitor will have to display. But all other colors are always a percentage of three or two primary colors. So it will be easy to slightly change the percentage of those primary colors to, finally, correctly display any color. Only the three primary colors will never be correctly displayed by this monitor, if it has a defect. It is pretty funny and almost crazy: display colors correctly with three corrupted basic colors !!! And yet...



## Characterization

It is during this second step that the [ICC profile](#) of the monitor is really created, in accordance with the settings optimized during the previous step, meaning during calibration. We are now going to measure the color characteristics of the monitor placed in "ideal" working conditions or at least known and precise conditions (ideal meaning that the monitor wouldn't need to be profiled anymore). Then, the calibration software send a series of RGB signals to the monitor and the real colors displayed are analyzed and compared to the ideal colors -  $L^*a^*b^*$  - of the ICC consortium using a monitor sensor - also called colorimeter.



Caution! If you perform the characterization with your eye, you will only perform a comparison and not a measurement. So, this step is impossible to perform with free gauging tools based on color patches comparison. In the end, the software will create a color identity card of the device by measuring :

- The color space it is able to reproduce compared to the L\*a\*b\* color space (also called gamut); it is the result of white point, black point and maximum saturation of the filters placed in front of each pixel of your monitor;
- And how it is displayed - what RGB signal for which L\*a\*b\* color.

Very important: all color alterations displayed on screen compared to L\*a\*b\* colors will be carefully saved in a special file, the [ICC profile](#) of this monitor. When the graphic card will want to display a certain L\*a\*b\* color, it will know exactly what "amended" RGB signal has to be sent for the color to be displayed properly, taking into account those characteristics. An ICC profile can thus be quite a large file because it contains an impressive number of information. The number of colors possibly displayed on a monitor is indeed incredibly high - a very good eye can distinguish, let me remind you, almost 8 million colors! Using your eye for such a process can only lead you to an approximate result even if sometimes this can do the trick as a monitor gamut is not very wide - even if new technologies using LED for instance increased it. Even if it is still often close to sRGB, more and more monitors are now able to display Adobe RGB 98, noticeably wider, what explains why calibration devices are changing these days, by the way. Many photographers had a lot of problems with the first generation of LED monitors, a technology that is now under control (summer 2012).

### **To be remembered!**

- **Monitor calibration with a good calibration sensor is mandatory and totally affordable nowadays.**

- **Never buy first price colorimeter (Spyder4Express ou Colormunki Smile) not recommendable and not so much cheaper than Pro or Elite version, that are perfectly working.**
- **Pro or Elite version can be misleading: there are no pro or amateur sensors; there are colorimeters that work very well with any monitor and colorimeters that are so basic that they will often deliver a calibration of poor or unstable quality. It is thus hard to recommend them. "Even" amators shoul buy "Pro" sensors!**
- **Calibrate your monitor between 80 and 100 Cd/m<sup>2</sup> if you intend to have your work printed and calibrate at 120/140 Cd/m<sup>2</sup> if you are essentially editing your images for the web.**

[Next page 2/5: calibrate a monitor ▶](#)



# How to calibrate your monitor?

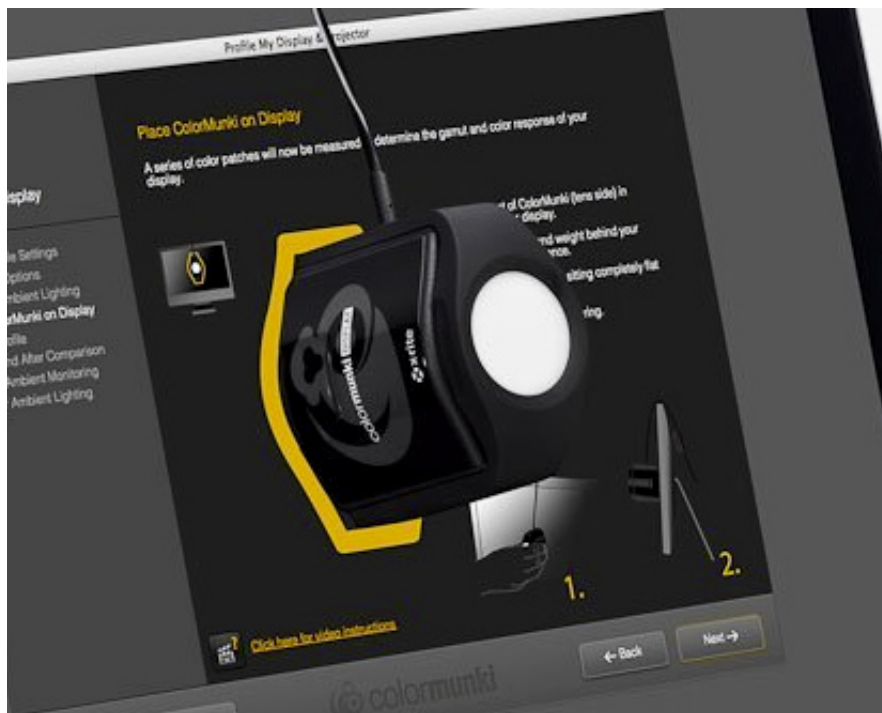
Now that you are convinced about the importance of calibrating your monitor with a calibration colorimeter, I am going to help you do it through this page, and especially to help you choose the right target values (gamma, color temperature, brightness...).



## Key points if you are a beginner ...

**Here are the key points to remember about monitor calibration. The rest of this page is aimed at those who want to learn more.**

**We saw that using a calibration colorimeter, or colorimeter, was absolutely compulsory to calibrate your monitor. Without it, it is impossible even to set brightness or contrast values of the screen. And I'm not even talking about color predominances... Screen calibration has to be performed with a calibration colorimeter.**



**There are several colorimeters on the market: they're distinguished by the quality of their components and of their calibration software. Prices range from single to double: from \$100 to \$250.**

**Colorimeters with glass filters are much more stable in time (since 2011, X-Rite colorimeters are guaranteed 3 years). Other colorimeters feature gelatin filters (colorimeters Datacolor and Colormunki Smile). The old generation of colorimeters, like the famous Eye One Display II with gelatin filter, ages and no longer works almost overnight, so be careful. At June 2016, if you own an old colorimeter (three-four years max.), I really recommend you to change it for this reason.**

**Monitor technologies evolve as well as color filters in colorimeters in order to adapt and deliver the best results. Of course, this requires a new investment (every five years averagely), but I really recommend you to change your old colorimeters, especially if you also changed monitor technology.**

**Recent monitors = recent colorimeters!**

**Next key points: [My recommendations to choose your colorimeter](#)**

In the first part dedicated to [monitor calibration](#), in the previous page, we defined important notions and vocabulary, such as calibration/gauging and characterization. We saw that these two steps are part of calibration in a general way.

In this second part, I will now try to show you why you should calibrate

your monitor with a colorimeter and not to the naked eye from a random print for instance, and then explain the settings and ideal values to use to calibrate your screen according to your use of it.



## Use a colorimeter or not?

Let's get rid of this problem immediatly! It is impossible without a calibration colorimeter, because the human eye has two major drawbacks.

- It is unable to determine the level of brightness of a monitor, but we know it should be around 80/140 cd/m<sup>2</sup> depending on its main use,
- And it is unable to "read" an L\*a\*b\* color without having any comparison support.

**Considering these two reasons, it is impossible to perform a good calibration to the naked eye.** You could possibly approach something not too bad, especially on a very good screen but not more. And to close this old debate forever: defects are never linear. Your monitor is never too magenta on the whole spectrum but only between one brightness value and another. So no chance to correct a grayscale with such a local area of color predominance.

The very affordable price of calibration colorimeters, even the best ones, doesn't give any decisive argument to their detractors anymore! Let's thus happily step to calibration with a colorimeter...



## Calibrate your monitor with a colorimeter



**Gone are the days when good calibration equipment was expensive. Nowadays, several generations of colorimeters succeeded the products are technically accomplished, except perhaps in their so-called economic versions (I did not say amateur). Two major brands have released monitor calibration kits, which qualities are no longer questioned: X-Rite and Datacolor. The differences between colorimeters and programs stand in their ability to set precisely:**



- Brightness - 80/140 Cd/M<sup>2</sup> -,
- Black point,
- Gamma,
- White point color temperature,
- Ambient light,
- Possibility to match several screens in order to align them in a colorimetric way,
- Possibility to calibrate laptops well,
- Possibility to calibrate Apple's iPad, - New !
- Possibility to calibrate Surface Pro et SurfaceBook,
- Possibility to calibrate a video projector.

**Each equipment will be distinguished by its number of settings, its number of calibration modes - basic and advanced - and by its reports at the end of calibration, rather than by the quality of its colorimeter - difficult to assess at home, by the way.**



If you consider that we are using the fourth generation of screen calibration colorimeters of very good value for money nowadays, you can certainly assume that the overall quality of colorimeters - 4 recent models today - is completely satisfying, except for two models: the Spyder4Express and [Colormunki Smile](#) that I would not recommend to photographers. However, depending on the price, we still see large differences in adjustment possibilities.



### **Glass or gelatin filters?**

**Colorimeters with gelatin filters don't age well. After two or three years, if you're not satisfied with your calibration anymore, consider the possibility that the problem is coming from the colorimeter. It must be renewed, even if it has not been used extensively! It is not the number of calibrations performed that is at stake, but the fact that time passes by and gelatin passes away... And think that X-Rite is releasing its Eye One Display II again, disguised into Colormunki Smile, while precisely, it has gelatin filters???**

**Datacolor colorimeters have organic filters (though their quality improved since 4th version) and X-Rite Colormunki Display and i1Display Pro have organic glass filters.**

## **1- Install the software then the colorimeter**

After installing the profile creation software and the colorimeter on your computer, quite simply as you'll see, you will thus have to calibrate your screen using the said colorimeter, also used for gauging. Your monitor should be turned on for at least 15 minutes before performing any calibration. If not functioning at the right temperature, colors may change slightly even when it seems imperceptible to the eye. The colorimeter, as for itself, will see the difference!

## **2 - Monitor brightness and contrast adjustment**

The first important point is to set the black and white points of your

monitor. Your colorimeter will then be used as a **calibration** tool. If the monitor is set too dark, the details in the shadows will be lost and if the monitor is too bright the colors will look washed out and it won't be possible to correct them properly. In addition, there will be no correspondence between the image displayed and the one printed.

It is thus important that you can distinguish a difference between a pixel at 0 and a pixel at 2 or 3 on your calibrated monitor, and this is also true for high values. Why?



Reminder! Don't look for a setting that would show a difference between a pixel at 254 level and one at 255, because it would mean that you're able to see a difference of  $1/255$  which is impossible because the most sensitive eyes see a difference of  $1/200$ . If it is technically possible for the monitor to display such a difference, it means that other values are not properly set.

The ideal brightness for a monitor lies between 80 and 140 Cd/m<sup>2</sup>, depending on the luminosity of your work environment or on the destination of your photos: rather 80/100 Cd/m<sup>2</sup> if you print and 120/140 cd/m<sup>2</sup> if you only display them on the web. To properly set black point AND white point at the same time, you must adjust your monitor's **brightness AND contrast. Brightness setting is used to adjust white point and joint setting of contrast is used to adjust black point.**



Tip! On [laptop monitors](#) - see this page for recommendations more specific to their calibration -, you can not perform manual contrast adjustment. So it has to be performed automatically. Hopefully the new generation of calibration colorimeters [Spyder5Pro](#), [Spyder5Elite](#), [Colormunki Display](#) and [i1Display Pro](#) all have this functionality. If you have an older colorimeter, it will be a huge improvement for you to replace it.



### **My recommendation!**

**I thus recommend you to set brightness value between 80 and 140 Cd/m<sup>2</sup> by sections of 10 Cd/m<sup>2</sup> then control this adjustment by comparing it to one of your prints. However, if you never print and to the contrary, only share your work on the Internet, you'd better choose a value between 120 and 140 Cd/m<sup>2</sup>. Concerning contrast, the best is to let the software decide when it is possible. Doing it manually will not bring any improvement or precision.**

### 3 - Gamma setting

Depending on the colorimeter you will use, it is possible to choose the targeted **gamma**. Theoretically, you should target 2.2 nowadays BUT depending on the monitor you will calibrate, it may be wise to stick to 1.8 if your monitor, often a Graphic Art, is set to 1.8 by default (often for pre-press world). In that case, trying to target 2.2 will not work and after trying it, I do not recommend it. Then choose the native gamma of the monitor.



Note! The war between Mac (1.8 gamma) and PC (2.2 gamma) is now over and Apple is now using the most "natural" gamma for the eye: 2.2.



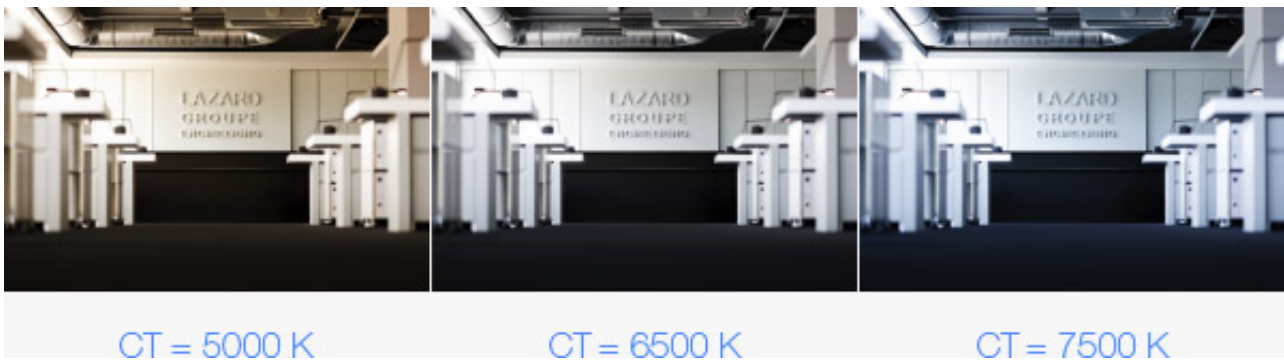
### **My recommendation!**

**In the end, if you calibrate with high-end colorimeter and software, you will have the possibility to choose a gamma value between 1.6 and 2.4 (by sections of 0.1). I suggest you try two or three values around 2.2 and see with which one your monitor's gray gradient is most beautiful. There is a big difference between theory and practice and I was pretty surprised after calibrating around 1.8 or even 2, monitors that were normally made for 2.2.**

**Strange, so let's not be dogmatic! With Graphic Art monitors, choose the native gamma. It is where it will work at its best.**

## 4 - Color temperature adjustment

The last important point is the color temperature of the monitor, or more precisely of its white point. When you display a white in Photoshop (255, 255, 255) does it really look white or is it displayed as a warm white that is to say a little yellow or is it displayed as a cold white that is to say slightly blue? At 9,300 K, default factory setting for most monitors that are not graphic art ones, the monitor is too bright and cold (too blue). For many monitors around 500€/1,000€, the factory setting is around 6,500 K.



The ideal target value is therefore between 5,000 K and 6,500 K, 6,500 K being the traditional color temperature of the light on a sunny day.



**Important! 5,000 K is the default setting for the pre-press world as quality print controls are made at 5,000 K. This value has to be chosen with graphic art monitors most of the time, and even a bit more if you have multiple monitors and they are not all of the same quality, as you will never reach 5,000 K with these more conventional monitors. As a compromise, I chose 5,500/5,800 K.**

However, if your screen is not calibrated on 5,000 K by default, you will never reach this value - without getting weird defects - with a monitor made to work at 6,500 K or 9,300 K. At 5,000 K, your monitor would look suspiciously yellow and strange! So with all other monitors, I recommend

targeting 5,500 to 6,500 K with a preference for 6,000 K. I think it is also more natural when you look at your prints under a natural light or spotlights. No exhibition is lit with 5,000K cabins!

It is important to know that ultimately, the choice is of no real importance as long as color temperature is selected priorily to the characterization of the monitor. 5,000 K indeed corresponds to the D50 illuminant for pre-press, but D65 (6,500 K) is more natural since it corresponds to the daylight we are used to for the 4,000 years. The final choice is yours, depending on your work habits and tastes. Note that the monitor will still get worn out a little bit slower when used at 6,500 K because the gap with the factory default settings is less important. **Personally, I like adjusting my color temperature between 5,500 K and 6,000 K.**



### **My recommendation!**

**Except for Graphic Art monitors which white point temperature is set at 5,000 K, try to set color temperature between 5,500 and 6,000 K. At 5,500 K, low or even medium range monitor are often too yellow (as their default setting is around 9,300 K!). I like 5,800/6,000 K but not all colorimeters enable to choose this value. Now choose wisely!**

## **5 - Ambient light control**

Some models of calibration colorimeters enable to measure the ambient light in order to perfect brightness level adjustment. Why not, if this one does not change too much and remains in a stable lightened environment, otherwise why bother? You will find really few color management specialists to tell you that it is essential, at least with old colorimeters, since new generation ones as Colormunki Display make this measurement process mandatory. Also note that it is possible, in those circumstances, to ask the software to measure ambient light regularly and automatically. Real progress or gadget, we will see... Personally, I do not like it because in

some cases the solution is worse than the initial problem, especially if your room is lit with fluocompact lamps at night.



My recommendation!

Don't activate this function of ambient light measurement.

## **6 - Characterization**

The next calibration step, called characterization, will happen without your intervention. The colorimeter is required again. Depending on the calibration software you use, a parameter that does not depend on you but on the colorimeter's manufacturer, you will see on your monitor many colored patches, more or less numerous, that the colorimeter will now measure in order to reveal the gamut of your monitor and its color characteristics - else said, its defects! -. This phase highly depends on the quality of your calibration and the quality of the filters inside the colorimeter. Spyder3Express and Pro or Elite version don't have the same, although they're all made by Datacolor. In addition to that, with the colorimeter control program, they determine the quality of the process.

Finally, you just have to check visually if everything seems to have gone well and above all, give a name to the ICC profile of your monitor that day.

**Your monitor is now calibrated!**



## **Check your calibration with three tests**

**I invite you to perform the following tests in order to check the quality of your calibration:**

- Black point
- White point
- Grey gradient.



## Check black and white points...

There is a simple way to check that your screen is not too dark or too bright with Photoshop. Here is the procedure:

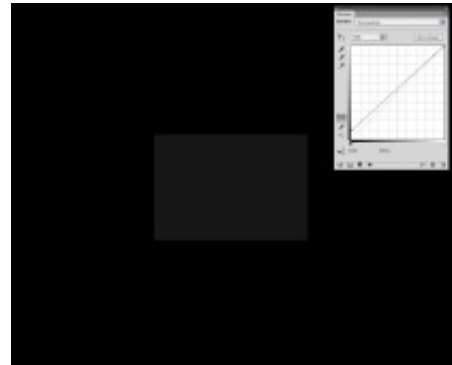
1 - Create a new document of the size of your monitor definition. CMD+N (CTRL+N) and fill it, using the paint bucket (shortcut G), with black (0, 0, 0) or white (255, 255, 255) ...

2 - Create a rectangular selection (shortcut M) in the middle of your window, about 150 to 200 pixels wide.

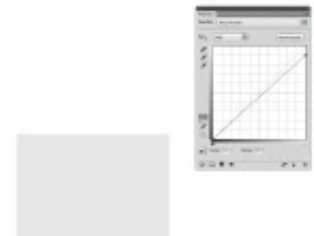
3 - Hide this selection with CMD+H (CTRL+H).

4 - Create a Curves adjustment layer.

a) For black point (on a black background): click on the bottom left part of the curve to display the input and output fields. Set 3 as output value and have a look at the zone of your selection at the center of your screen. If you can see a slight difference appearing, it is OK, otherwise, your monitor is too contrasted. You need to try to calibrate your monitor with a lower contrast value.



b) For white point control (on a white background): click on the top right part of the curve to display the input and output fields..



Put 252/253 instead of 255 as output value and do the same check on the central part of your monitor, in the selection area. You must see a slightly greyish rectangle appear. The selection rectangle is brighter by two or three luminosity levels if you check black point and very light grey, distinct from white, if you check white point.

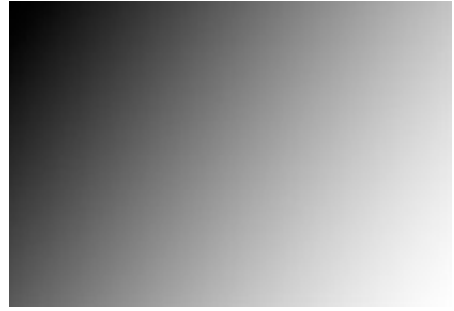
Type twice the F key and then Tab. This will display your document in fullmonitor without the tool bars and menus, therefore without any window that could mislead your observation of black or very light grey.

In your work environment, if your monitor is set properly, you should see the rectangle slightly lighter if you perform the control for blacks and slightly grey if you perform the control for whites. This checking process is valid with all the calibration procedures

and works very well.

## Choose your gamma and check its calibration...

There is a simple way to check that the monitor works with the best gamma in Photoshop and that the colorimeter chosen is the best one (in case you want to compare); here is the procedure:



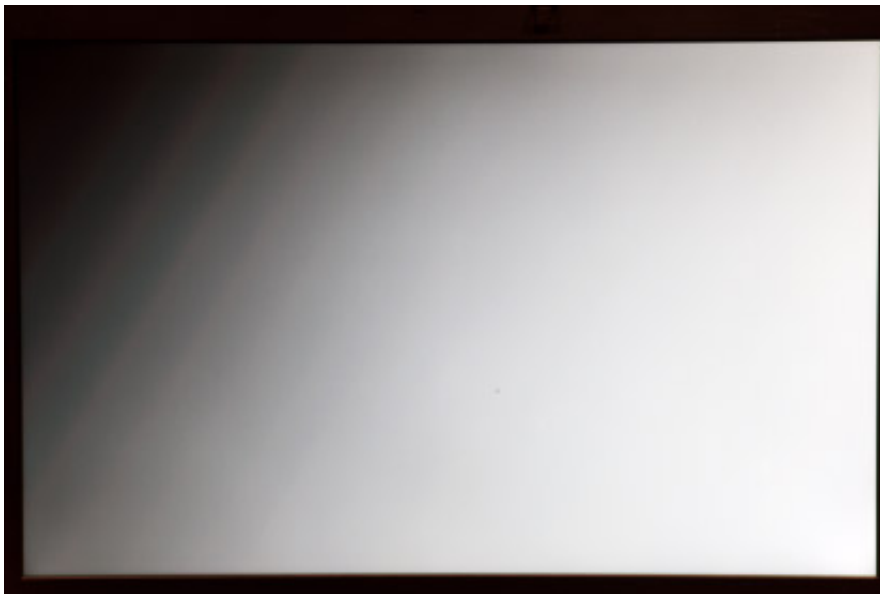
**1 - Create a new document the size of your monitor definition. CMD+N (CTRL+N) with an sRGB ICC profile...**

**2 - Choose the gradient tool, from black to white (G),**

**3 - Pull the gradient from the top left to bottom right. The monitor should fill with a nice gradient... it should!**

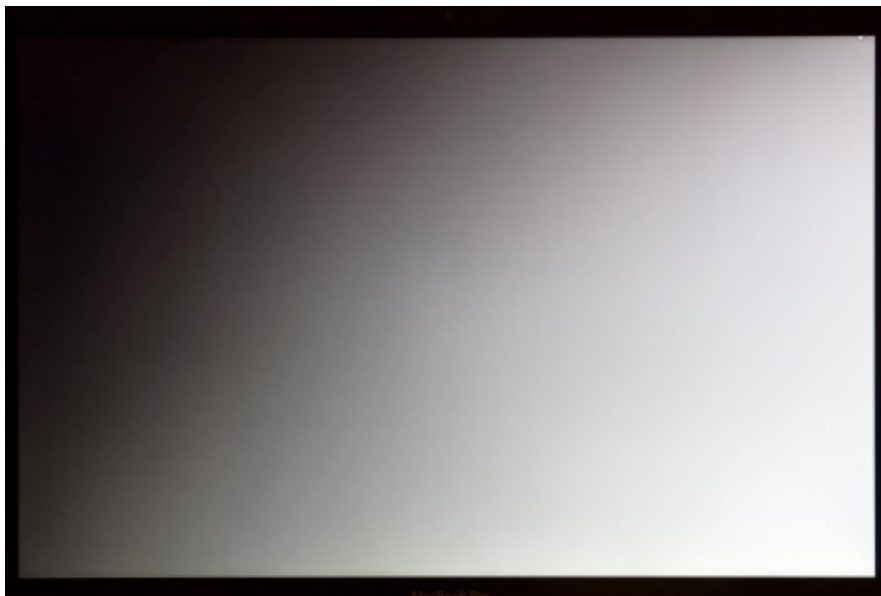
Then just observe. You will be able to see two things:

- Possible tone breakings, sometimes colored ones, indicating a bad calibration or the limits of your monitor.
- A nice progressive gradient from black to white. Often, the black or white proportion is too high, indicating you a wrong choice of brightness, contrast or gamma values.



**Tone breakings are highly visible and characterize a low-quality panel.**





**And here is how it can look like when you calibrate a good monitor using a very good colorimeter! (here a MacBook Pro 15 inches monitor calibrated with the colorimeter i1Display Pro).**

Finally, I recommend to perform calibration three or four times a year, the first three years, when the monitor is doing well and maybe a little more often then. I stopped calibrating every week long ago!

One exception: professional editors will do it every week or before each important session of edits, but they have a contractual obligation to work on the best monitors and a regular calibration is compulsory, to "make sure".

#### **To be remembered!**

- **Calibrate your monitor visually is delirious nowadays! Buy a good colorimeter from \$170 on.**
- **The eye, as a tool, is excellent for a comparison job, but terrible without a reference!**
- **Calibrate at 80-100 Cd/m<sup>2</sup> if you want to print your pictures and use a value of 120-140 Cd/m<sup>2</sup> if you just want to display your images on internet.**
- **Choose a gamma of 2.2 except if your monitor is a Graphic Art monitor which native gamma is almost always 1.8.**
- **Choose a color temperature of 5,800/6,000 K: for the most part of monitors, it represents a good compromise, slightly "warm". If you have a Graphic Art monitor, choose a value between 5,000 and 5,500 K.**

**Note! Not all calibration devices enable to choose 5,500 K or 6,500 K.**

- **Do not always check ambient light : because if your room has low consumption lamps, the light spectrum is not uniform and the automatic correction of the ICC profile will be a disaster!**

**If you're an amateur photographer, or even a professional but you're not a professional editor, you can calibrate your monitor only 3/4 times a year. However, if you're demanding hence on a top-range monitor, a very regular calibration will always be recommended (just in case!).**

**[All calibration colorimeters on the market ▶](#)**

**[My recommendations to choose and buy a photo monitor ▶](#)**

