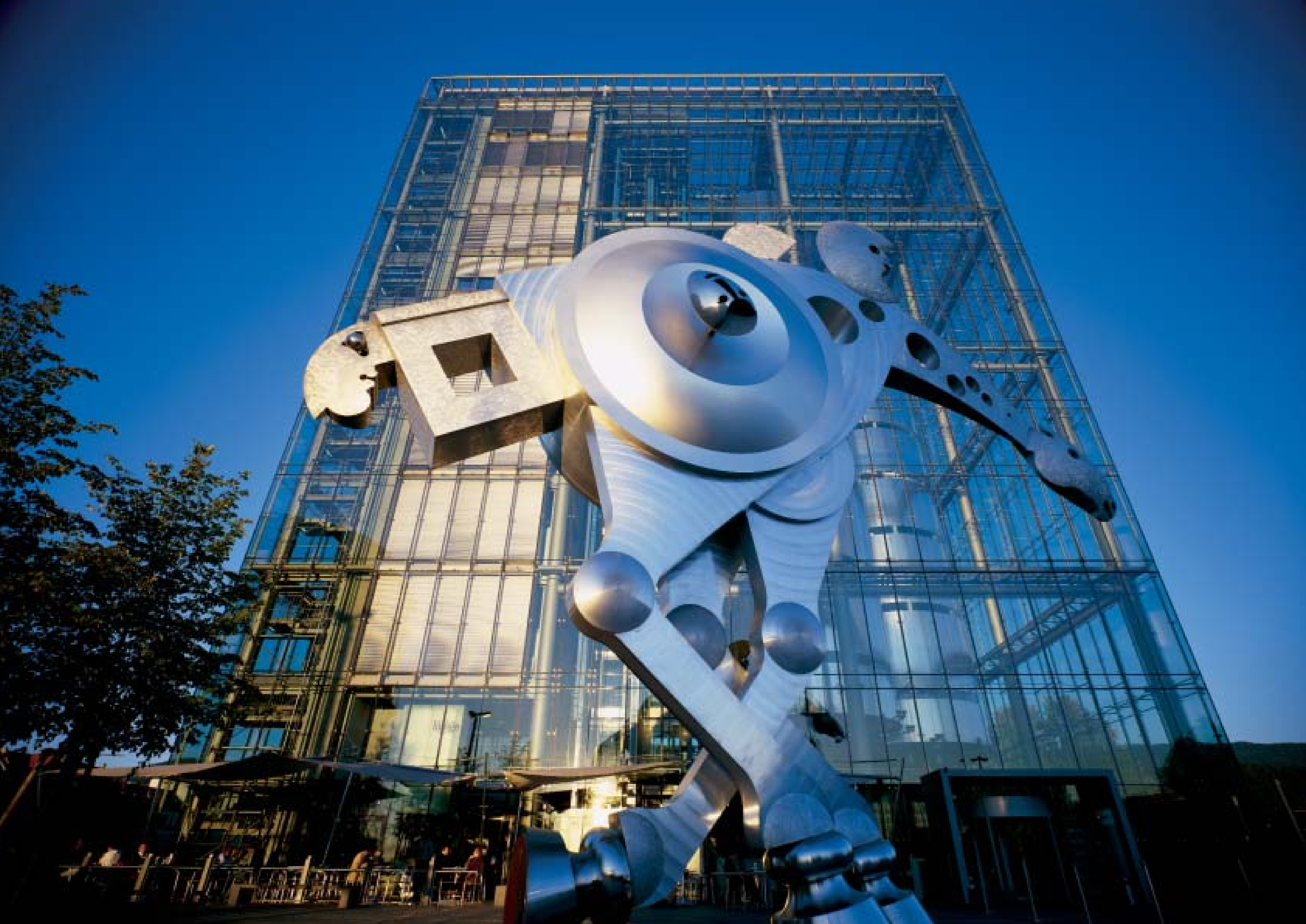
Expert Guide

08 • 2003 Heidelberger Druckmaschinen AG

Color Management

HEIDELBERG



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Color Management • Introduction to color in printing

Since the early days of printing, dealing with colors has continuously presented us with new challenges. It is essential that current expertise is constantly managed, that is collected, organized and evaluated in order to be able to implement it in changing working processes.

Each new technology helps us to develop and expand the range of possibilities. The large number of developments also increases the options available for color representation. Time and time again, the need for standardization has been recognized, initiatives have been taken and processes standardized. In the field of color management, Heidelberg® Druckmaschinen AG is regarded all over the world as a pioneer when it comes to the development of efficient solutions for the printing industry.

This edition of the Heidelberg Expert Guide should provide you with an intro-duction to the topic of color management. It will also give you interesting insights into the world of colors, no matter whether you are an expert or a layman who is encountering this topic for the first time. With the motto “You only see what you know”, this easy to understand guide will familiarize you with the current state-of-the-art of the scientific disciplines involved and the resultant possibilities for our industry.

Challenges in everyday printing

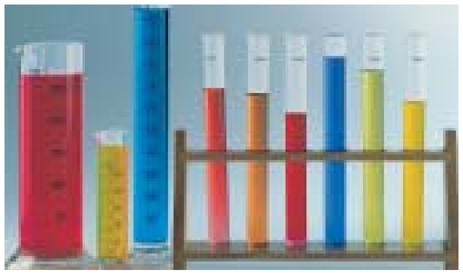
The short list of questions below underlines the frequency with which we are confronted by colors and the difficulties involved in day-to-day work:

- Do you always scan all the originals you use yourself with the same scanner?
- Do all images look exactly the same on the monitor as in print?
- Do your proofs always achieve the desired print result?
- Do you always work with the same imagesetter when creating print originals?
- Is offset printing the only output process you use?
- Do you always work together with the same printshop?

If your answer to all these questions is an emphatic yes, you are one of the few people for whom color management is only of theoretical interest. To everyone else, we would like to say “Welcome to the world of color management!”. Compare the three illustrations below. Here, you see two color representations of an original without color management. The differences are obvious. It is also quickly apparent that working with colors at this level will only seldom lead to satisfactory results. The following chapters will provide you with information on the causes of these differences, how you can master them and how you can improve your own color management in the future.

Original

Monitor image without color management



Print result without color management


Stradi Vari
Meier, Müller, Schulz
No. 11297

Color Creation • How we see what we see

The best introduction to the topic of color management is to highlight the principles of how colors are created and how we perceive them. To do this, have a quick look at Figure 1 below. Here you will immediately see a green square. But why can you see this square? And why is it green? Biology and physics can help us to find the answer to these questions.

To perceive the color of an object, we require the following:

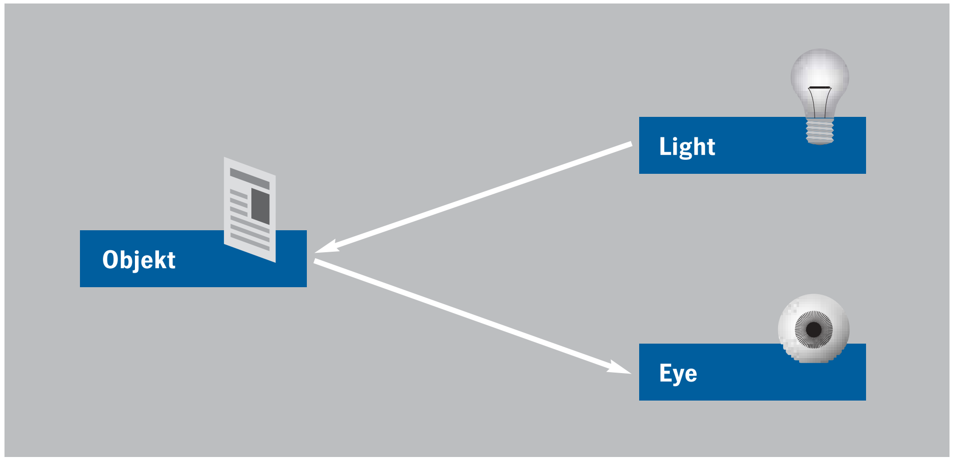
- the object or a shape,
- light that hits this object and is reflected,
- our eyes.

How our eyes see color

The light hits the square and is reflected by it. The reflected light subsequently hits our eyes and stimulates the visual cells of our retina. These visual cells consist of rods and cones. We use these rods to distinguish between light and dark. It is thanks to the activity of the rods that we can see at low levels of light (twilight) and distinguish between gray tones. In good light conditions, such as normal daylight, we only see with the help of the cones. They are also responsible for our ability to differentiate between colors. Scientific findings underpin the theory that there are three types of color receivers in the eye which are concentrated in the center of the eye (its 'yellow spot'). The light sensitivity of the cones is a result of a chemical reaction of the visual pigment. Three types of visual pigments have been found in the eye, namely red, green and blue. Color perception is brought about by various forms of excitation of the three types of cone. It is mainly the green-sensitive cones that respond to the square in Figure 1 and the light reflected by it. When they pass on a pulse to our brain, we see a green square.

Fig. 1: Here you will immediately see a green square. However, a variety of conditions need to be met for you to be able to see shape and color at all.

Fig. 2: Our eye receives light waves reflected by objects.



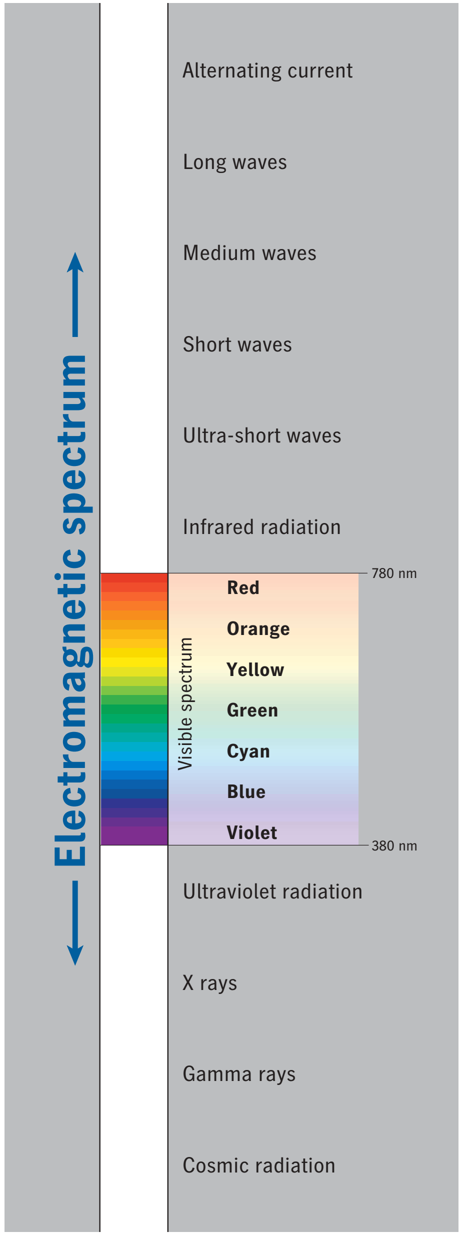


Fig. 3: Only a small part of the overall electromagnetic spectrum is visible to us and is shown here in an expanded form.

The wavelengths of colors

Physics helps us to answer the following questions:

- How are light signals transmitted?
- What stimulates the cones?
- And why only those for green?

Colored light is transmitted in the form of electromagnetic waves. Each spectrally pure color has its own wavelength. Real colors are usually mixtures of a large number of wavelengths. The different cones react precisely to these different wavelengths. The limited spectrum of perception supported by the individual types of cone allows us to differentiate between colors but means that there are a variety of waves which we cannot see. Figure 3 shows the associated wavelengths and radiation lengths.

The spectrum is formed when you divide white light by dispersing it in a prism. The primary colors of the light appear on a surface behind the prism. The main red, green and blue ranges correspond to the color-sensitivity of our eyes. When the rays of a neutral, i.e. white light source hit print products some of the light colors are reflected and some are absorbed depending on the body color. In our example, red and blue are absorbed while green is reflected and interpreted by our eye.

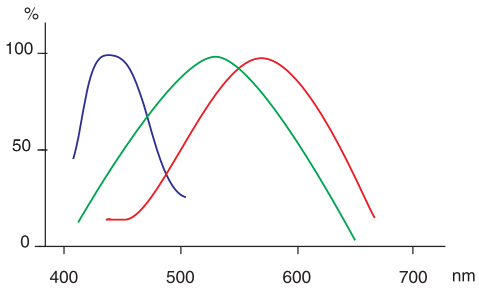


Fig. 4: The spectrum of perception of our cones can be easily illustrated by plotting wavelength against intensity.

Color perception:

- Reflected light stimulates our visual cells
- Cones enable us to differentiate between colors
- Colored light is transmitted by electromagnetic waves
- Wavelength determines the type of color perception

Our subjective perception of color

Color is not the same as color perception. We can expect people to perceive colors which are absolutely identical in physical terms in completely different ways. There are several explanations for the causes of this. Probably the most important is the variation in spectral sensitivity between different people's eyes. This may only vary slightly from person to person but can lead to significant confusion in borderline cases. For example, turquoise can be perceived in a completely different manner by different people. Some think it is more like a green while others are convinced that it is a kind of blue.

A further influencing factor is our psyche. Mood can have a significant effect on our color perception. If you are tired, a room with gray wallpaper can appear a lot darker and grayer than it would if you were in a more balanced or even positive mood. External factors also have an effect on our color perception. The type of light source plays an important role here. The difference is obvious between looking at a piece of white paper in daylight, in the light of a lamp or by candlelight. While the white paper appears dazzling in daylight, it looks a lot more yellow by candlelight. However, this is an impression that changes after a short period of time because our eyes quickly adjust to changed light conditions. After only a few seconds, the sheet of paper appears just as white as by daylight. This capacity for adjustment, known as adaption, is a great advantage when we have to enter dark rooms and find our bearings quickly. However, this capacity which has proved itself useful in our evolution is more of a burden when it comes to judging colors because our visual organs develop a manipulated image and we have to accept optical limitations as a result. In addition to light conditions, the format can also have a significant effect on our color perception. On this page, you will see that a larger square with the same green appears to be brighter and more powerful than a smaller square.

Factors influencing subjective perception:

- Spectral color sensitivity
- Frame of mind
- Light source
- Color surroundings
- Spatial surroundings

Fig. 5: The surroundings of the color have a significant effect on our perception. Depending on the surroundings, the green can seem brighter or duller.

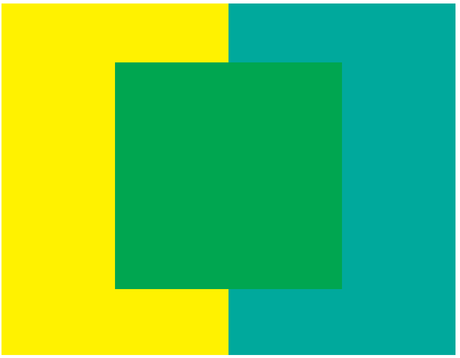


Fig. 6: The size of the color area can also change our perception significantly. Compare these for yourself. In the large square, the green appears to be brighter and more powerful than in the small square.

Color Measurement • Measuring colors digitally

With the constantly rising number of input and output devices and the widespread use of graphics and DTP systems, the basic conditions for editing and processing colors have seen a fundamental change. A variety of processes can now be performed much more easily and quickly than was the case ten years ago. Nowadays, almost anyone can create color graphics or edit images on their computer. However, a price often has to be paid for the range of technologies and systems in terms of transparency and conformity. Many laypersons are surprised by the large differences in color even between monitors and color printers.

The potential for even greater differences between the draft and the final product becomes obvious if you take a closer look at the steps that a document goes through. A few years ago, drafting and print preparation were usually carried out by the same person but the situation is very different today. A graphic designer develops a concept and generally sets about locating the appropriate originals for this purpose. He can scan them himself, have them scanned by a third party or use digital images downloaded from a photo database on the Internet, for example. He embeds data from a wide variety of sources in his concept while concentrating mainly on how they are displayed and appear on the monitor. Using a standard color printer, an initial print is then generated.

If the result is satisfactory, the drafts are shown to the customer and released for production following successful presentation. The data is then sent on for further production. The recipient, such as a repro studio or the prepress of a printshop, processes the data and, in turn, sends it on for printing plate production. Printing takes place in the final stage of the process chain described here. In the worst and most likely case scenario, the devices involved are not coordinated with each other and there is no information available as to what the final color representation should look like.

The digital color data has a long way to go before actual reproduction.

Opening up the previously closed systems has led to an almost incalculable number of hardware and software components. To ensure that open systems function effectively, all the input devices must be able to communicate with all the output devices. This may sound obvious but this represents an increasing challenge for service providers and users when it comes to reliable color reproductions. This is

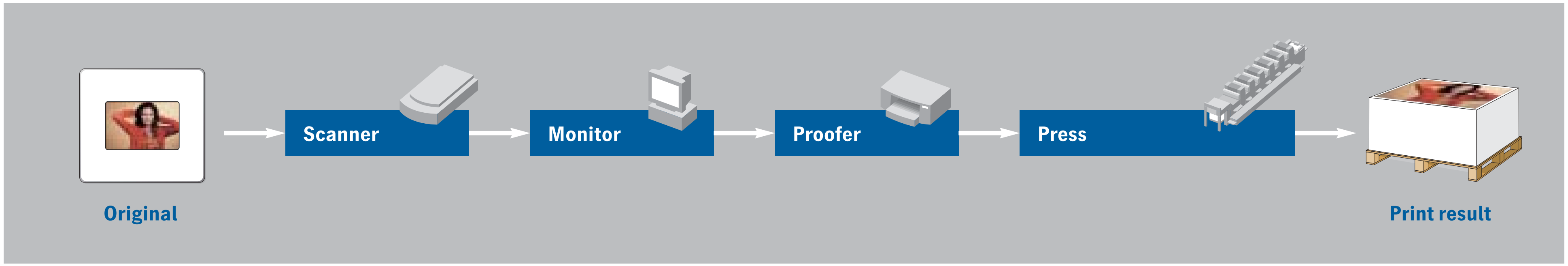
Light value measurement forms an important element in professional photography because the light values have an effect on color reproduction and color effect.

because current workflows with their almost limitless variety of input and output devices and the associated software solutions open up a whole range of potential sources of errors.

Working in open systems leads to a large variety of data and thus to a large variety of sources of errors. The following are potential sources of errors and weak points:

- Large variety of devices
- Wide range of software
- Lack of communication

Fig. 7: A simplified illustration of the workflow for digital color reproduction.



Spectrophotometers are used for objective color measurement.

Measuring colors

As already described in the previous chapter, our individual color perception can be very different and it can also be affected by external conditions. So how can one describe colors with such precision that no errors can occur? For example, the description “bright red” would be disastrous if you were designing a logo or wanted to achieve a specific hue when printing. Practical applications require greater precision and this is relatively easy to achieve.

One way to enable colors to be compared objectively is to standardize basic conditions. This can be achieved, for example, using a light box or a light table. This ensures that your originals are viewed and evaluated under standardized conditions. Printshops generally use a light source to DIN ISO standard 13655 with light type D50, which corresponds to a color temperature of 5000 K (Kelvin). Photographers often prefer a light source with a color temperature of 6500 K, which corresponds to normal daylight. The advantage of light tables and light boxes is that, once the viewing conditions have been set down, they can be kept constant. This means that you have conditions which are truly independent of external influences and you can carry out an objective color comparison.

Colors can also be measured. You could, for example, determine whether the white of this page is precisely the same as that of the opposite page. However, to carry out this measurement, you require a special device known as a spectrophotometer. When working with a spectrophotometer, the object is illuminated with a constant light source. Therefore, as in the case of light tables, the measuring conditions are standardized. This device takes account of even the smallest color differences which the human eye does not pick up.

The following example from everyday practice shows how important absolutely identical color reproduction can be: You normally use a touch-up pencil to repair minor damage to the paintwork of a vehicle. From experience, we know that almost all manufacturers have developed their own hue for their vehicles. If you want to touch up the paintwork, it is best to do it with a touch-up pencil from the manufacturer. Even the smallest differences in color that become apparent after the work is complete can be particularly annoying. Because no manufacturer can afford to have angry customers, the automotive industry is a pioneer when it comes to developing and optimizing precision color measurement methods.

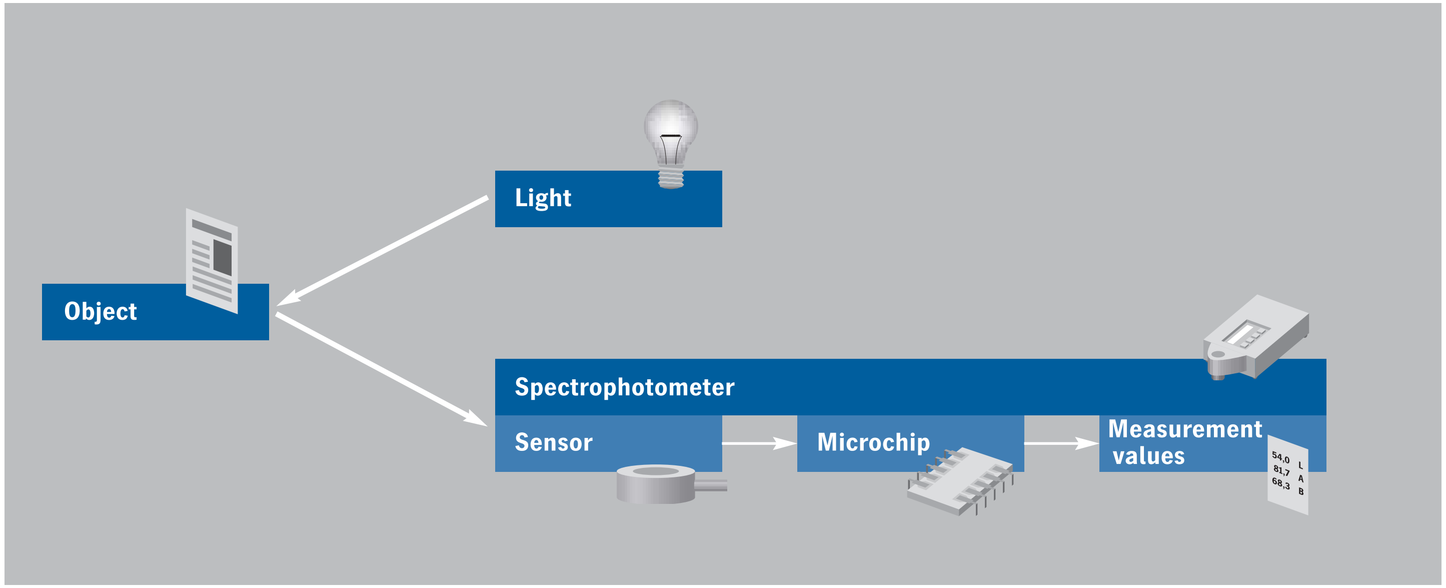
From estimation to measurability

The scanning surface of the measuring device is placed on the color area to be measured. The light reflected by the object which hits the scanning surface is guided from there via a prism and split into its spectral components. These are scanned by a special sensor. With high-quality devices, the spectral distances between the individual scans are very small. This is important because, for example, the waveband of the red signal is narrow in the case of monitors. If the distances between the individual scans were too large, the red signal could only be measured very imprecisely due to its spectral composition. After scanning, the measurement values are converted into the actual color values. Some devices show these values on a display while others transmit individual values or whole series of measurements directly to the connected computers. The individual color values can then be arranged in clear color systems. The CIE (International Commission on Illumination) plays a pioneering role in the creation of color systems. In 1931, it developed the XYZ color system, also known as the standard color system.

The XYZ color system

This system is often depicted as a two-dimensional diagram which resembles the shape of a sail or the sole of a shoe. The red components of a color are represented on the x-axis of the coordinate system and the green components on the y-axis. This means that each color can be assigned to a specific point within the coordinate system. Here you see how the colors towards the center of the sole tend towards gray, that is, their spectral purity reduces towards the center. However, this diagram does not take brightness into account. If this were to be included, you would get a solid shape approximately corresponding to a mountain with a tip above the white spot. One problem of this system is the fact that the measurable distances between the individual colors do not correspond to the color differences perceived. For example, if you look at the illustration in Figure 9, you will see that a difference only becomes visible between green and yellow-green after some distance, while there is only a small distance between blue and red. You will find further details on deriving color spaces in the annex in the chapter ‘Color space definition’.

Fig. 8: The sequence for color measurement using a spectrophotometer.



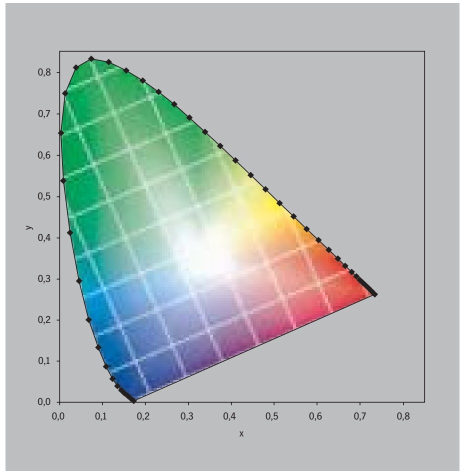


Fig. 9: Due to the fact that the standard color system does not take brightness into account, a difference between green and yellow-green only becomes visible after some distance, while there is only a small distance between blue and red.

The Lab color model

The problem of our perception of color being depicted with insufficient realism was solved by the CIE in 1976 with the development of the Lab color model. This is a three-dimensional color space in which color differences perceived to be equally large also have equal distan-ces between them which can be mea-sured. This means that each color can be exactly designated using its specific a and b values and its brightness L. The really significant factor about this color space, however, as with the standard color system, is its device-independence and its resultant objectivity. As a result, the same combination of a, b and L always describes exactly the same color, what-ever the weather, your mood or the make of your digital camera or proofer. The same naturally also applies to the press.

Objective color judgement

Technical aids:

- Light box/light table
- Spectrophotometer

Color space models/CIE color systems:

- XYZ standard color system
- Lab color space

Fig. 10: The a-axis extends from green (-a) to red (+a), the b-axis from blue (-b) to yellow (+b). The brightness (L) increases from the bottom to the top in this three-dimensional body.

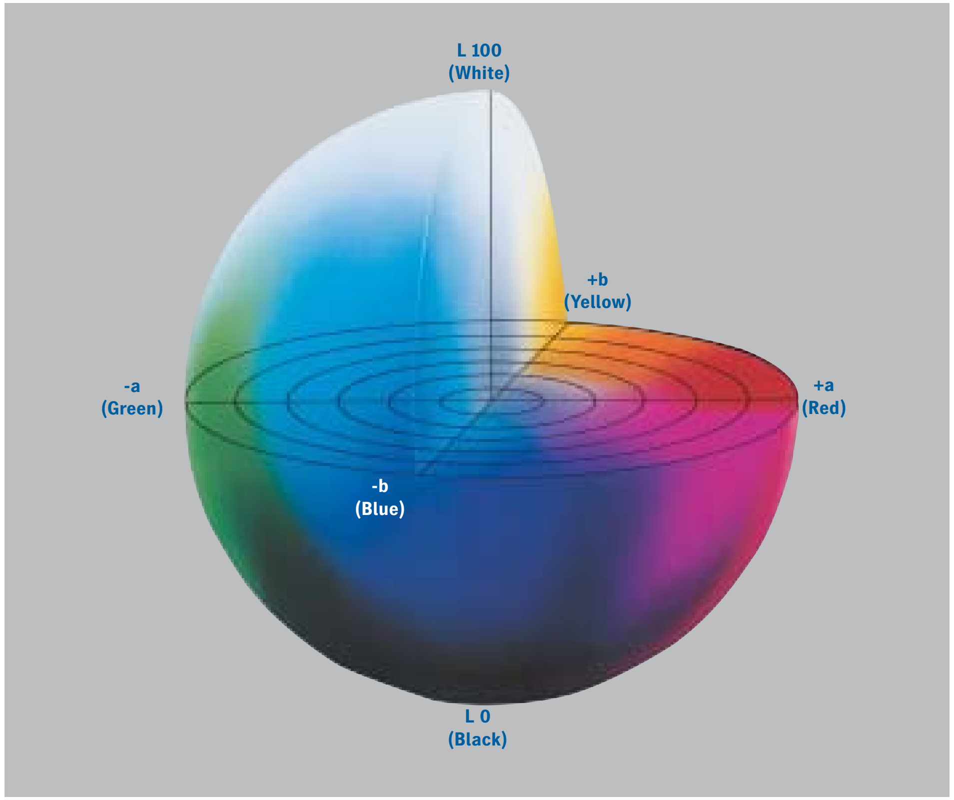
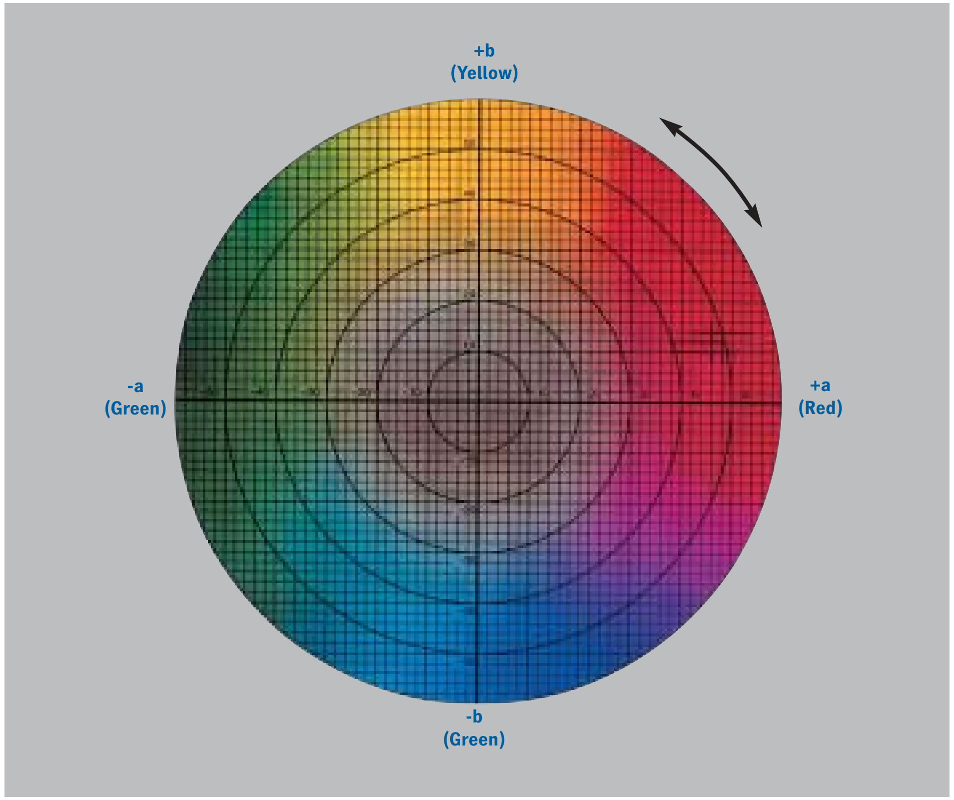
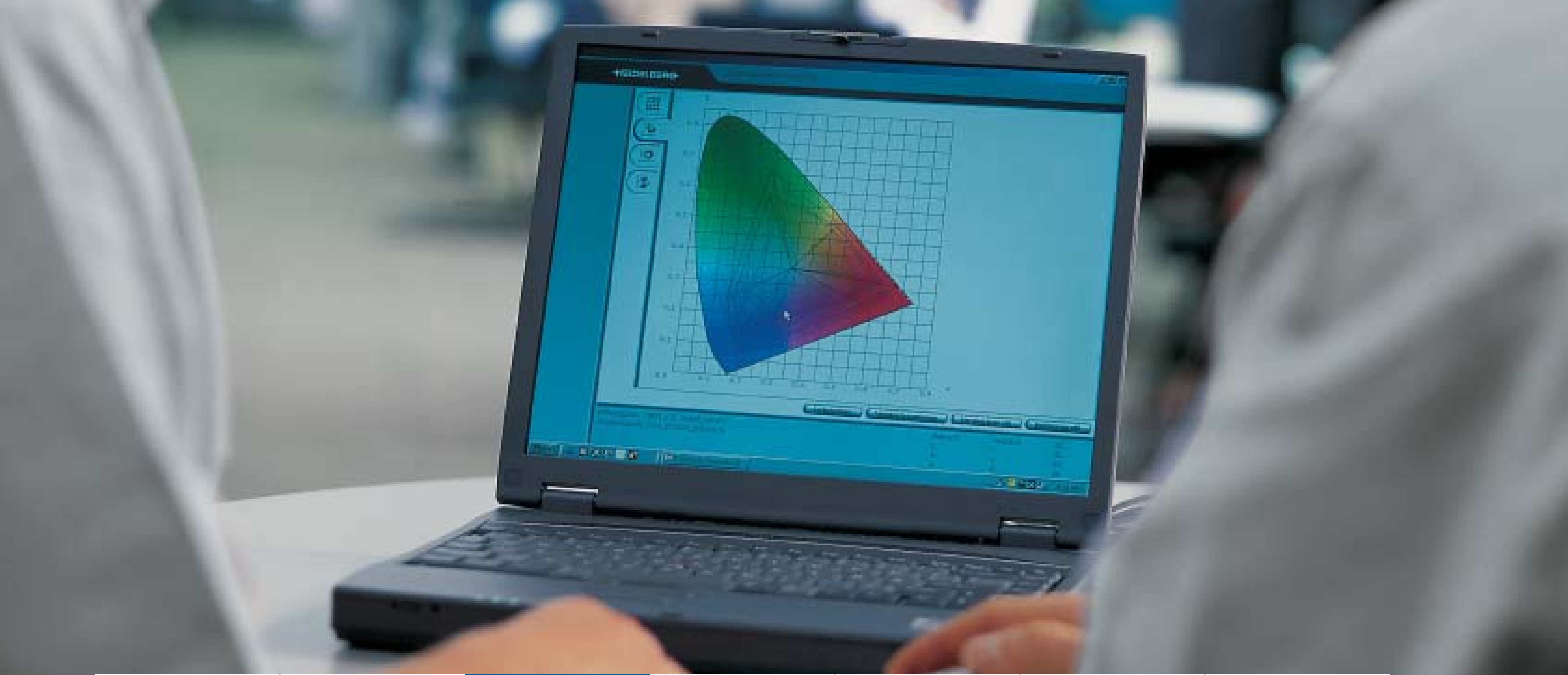


Fig. 11: If you take a horizontal cross-section through the body, you get a plane which contains all the values with the same brightness.





Color Spaces • Working with different color spaces

Working in open systems gives us enormous advantages in terms of flexible process design. However, the more flexible our approach is, the greater the challenges in working with colors and color spaces. A quick assessment of a normal working situation underlines this. Scanners, monitors and digital cameras represent all colors with RGB. They construct these colors from red, green and blue. Four-color printing and many color printers use CMYK. Color printers used to produce proofs now operate almost exclusively using the 6-color system CMYK + light magenta and light cyan. Despite the use of these additional auxiliary colors, this is also referred to as a 4-color process. The process of splitting up cyan and magenta into light and dark is the exclusive responsibility of printer control.

There is a long way to go to the final print product. The process involves many intermediate steps such as the proof shown here. Throughout all the steps leading from one color space to the next, professional color management ensures optimum color reproduction on the respective output devices.

The RGB and CMYK color spaces alone do not present us with any great problems. But when one considers the fact that there is no uniform standard for the RGB color space or for CMYK, it becomes evident that we are dealing with a large number of color spaces that have to be coordinated with each other. The lack of standardization also explains why the scan results of two different scanners can vary widely just as the reproduction on two monitors of different design can turn out to be totally dissimilar. This is despite the fact that the hardware elements are displaying colors with the same basis for color space calculation.

This becomes even more apparent when we have to convert our data from one color space to another as is the case in printing. A printed image can easily appear darker and less chromatic than in the scan or on the monitor. As if we were not already faced with enough problems in working with open systems, there is also another aspect to consider. Significant differences can occur even within the same printing process.

You might say that when it comes to color each device seems to speak its own language. However, all the systems have to be able to work together on common tasks. Therefore, an interpreter has to be found to ensure that these systems cooperate with each other and this interpreter is called color management.

Interpreters and simulators

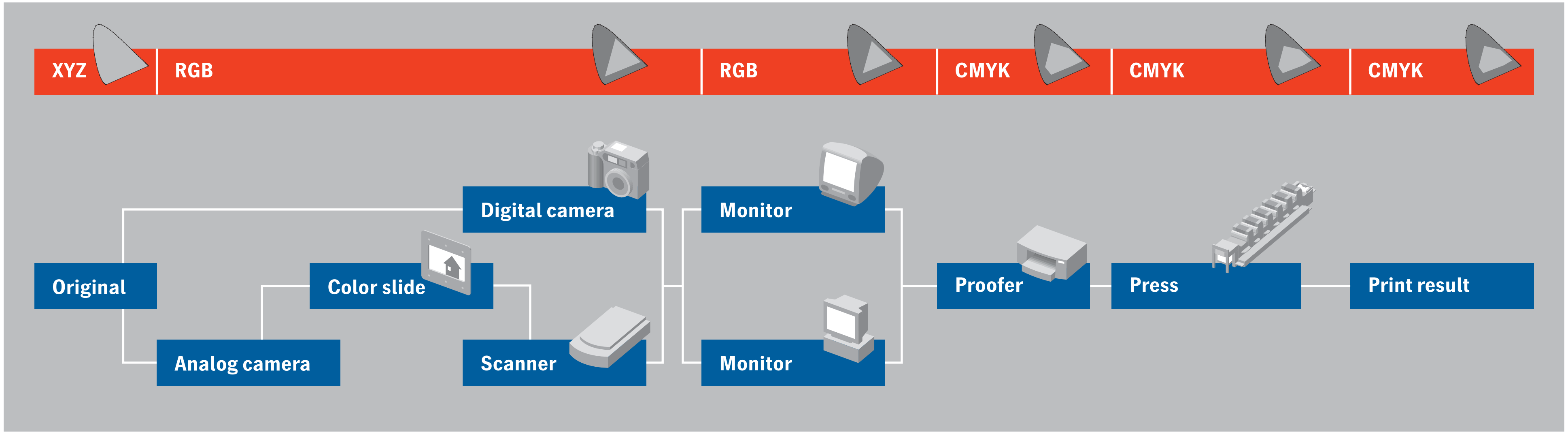
The primary task of color management is to precisely coordinate the color spaces of all the devices involved. Thanks to error-free communication, it should be possible to guarantee color reproductions which can be repeated time after time and which, most important of all, are predictable. Colors should thus enjoy the same reliability that is now expected of fonts. The font Helvetica looks the same all over the world whether you have it printed in Italy, in the USA or in China.

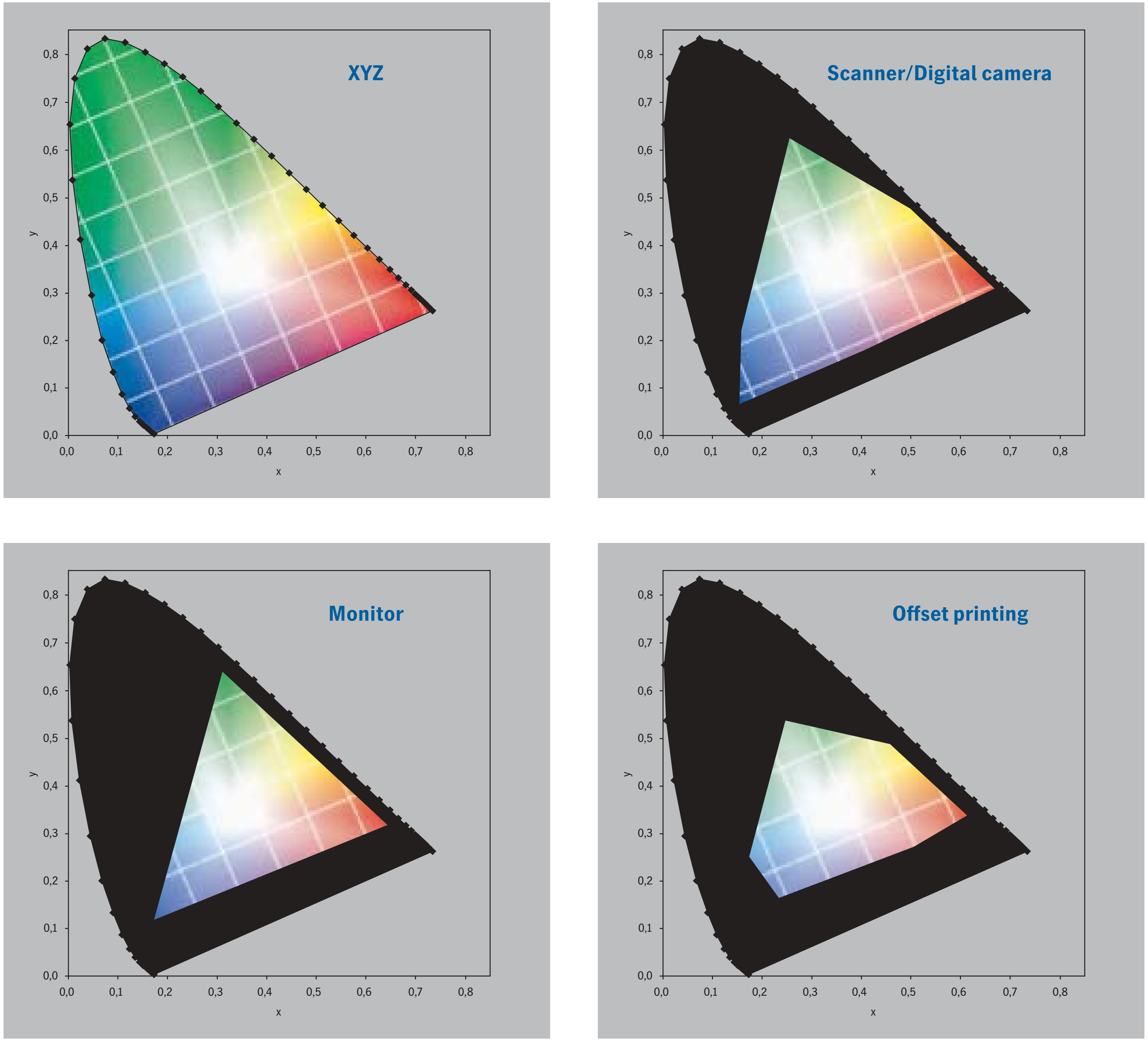
The second important task of a color management system is to simulate an output process on another output device. This ability enables us to create an image on the monitor within the context of a 'soft proof' which reproduces the color impression of the image that will subsequently be seen in the print as exactly as possible. It is also desirable to print out a proof on a color printer which provides a largely accurate image of what the subsequent print will actually look like. As a result of color management, the color printer is also able to simulate a press.

To ensure this is the case, standards that cover the entire production process have to be defined no matter how many devices are involved in this production process and what these devices are. By way of example, the illustration shows the process chain for offset printing which has to be standardized in this case.

If this standardization is in place, you have the peace of mind that the print of a photograph will look exactly the same as the monitor image. This would also apply to the printout on the color printer. Moreover, you would no longer have to worry about whether the image in the subsequent offset print would look identical to your color print. You could also be sure of reliable color reproduction if your image were to go through this process chain a few weeks later with completely different devices. The aim is thus to achieve the same harmony of color reproduction for current popular open systems as has long existed for closed systems.

Fig. 12: Each technology has its own device-specific color space. In a typical process chain, the data has to be converted into different color spaces before reproduction in CMYK is possible.





From color space to color space

Every device in a process chain operates within its own color space. If you scan an image, you are operating within the color space of the scanner, usually RGB. If you look at the image on the monitor, you are still seeing RGB data but it is different from the scanner data. If you then output the image on the color printer, you are operating in the latter's CMYK color space. The central question of color management is, therefore, how do you get from RGB scanner data via monitor RGB data to printer CMYK data without losing the color impression of the original.

Fig. 13: If you compare the individual color spaces, it becomes evident why differences repeatedly appear when an attempt is made to reproduce colors without color matching.

From transformation via conversion to color matching

When color space transformation is performed, the data from the input device (scanner, digital camera) is first converted into a neutral color space, known as the communication color space. In our case, this is usually the Lab color space. This conversion is carried out by assigning every hue a precise position with the relevant dimensions. The next step is conversion from the neutral color space to the color space of the output device (color printer, monitor, print process). For example, a specific red is measured from an original and subsequently assigned to a corresponding red from the L*a*b* space.

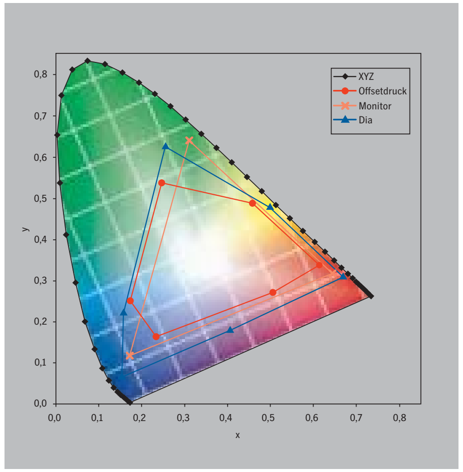


Fig. 14: The color spaces have different dimensions.

Finally, the L*a*b* red is converted into the relevant red of the output device. No problems will be encountered in the context of the transformation if you are transferring the color space of the input device to the communication color space because the communication color space is all-embracing. It is in any case larger than that of the input medium. However, difficulties can occur when converting the communication color space into the color space of the output device. Monitors, for example, cannot depict all the colors that the human eye can see. They can also represent colors which a color printer cannot produce. What do you do with the colors which can be scanned in using a scanner but cannot be printed by a color printer? Simply making all these colors black would be highly unlikely to help to reproduce the color impression of the original. Instead, the colors must be matched as accurately as possible. This process is called gamut mapping. This involves the coordination of color spaces from input via intermediate steps to the final output so that the colors which cannot be represented are replaced with an appropriate color that can be represented.

The larger input color space is contracted until it covers the smaller output color space. Therefore, if the red in the example above cannot be printed by your printer, gamut mapping selects the red most similar to the original from the tones of red which the printer can reproduce. The important thing here is that the overall impression of the original, i.e. the relationship between colors, is always retained. This shows that the sentence “color management means an exact color reproduction of the original” cannot be true, since the color space of an original is usually larger than its reproduction in four-color offset printing (see Figure 13).

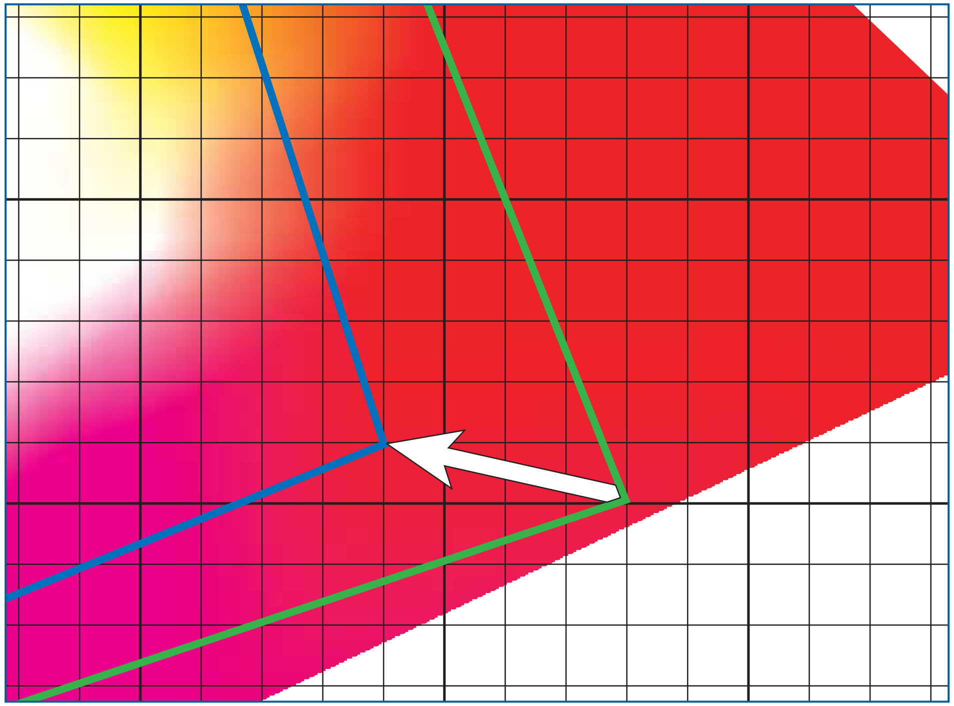


Fig. 15: ‘Color gamut’ is the term used to describe the range of a color space. The process known as gamut mapping involves matching the color spaces.

* = Reference to values in DIN ISO 12647-1: Black base, D50 light type, 2° standard observers, 0/45 or 45/0 geometry

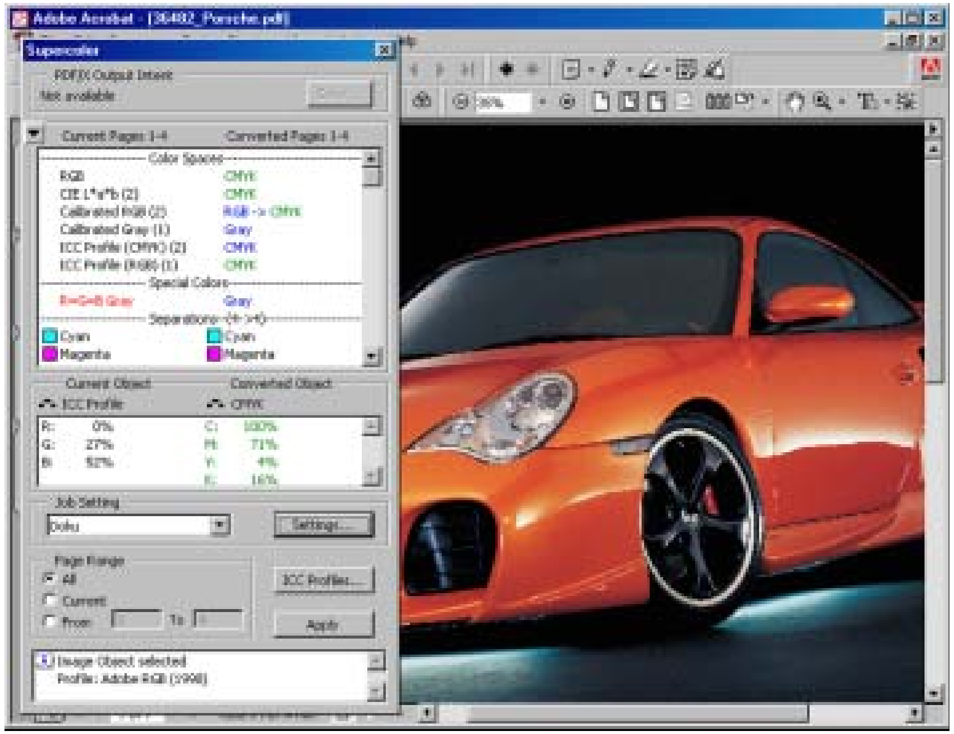


Fig. 16: Heidelberg's Supercolor is a development which supports professional color management and is particularly useful in the prepress sector in preventing errors.

Color management in operating systems

The most efficient approach is to integrate the color management system into the computer operating system. Here, every color can be processed neutrally in the computer irrespective of the input or output medium. All the hardware and software components involved in the system can access color management because they all collaborate with the computer operating system.

In April 1993 at the initiative of FOGRA (Forschungsgesellschaft Druck e.V.), several manufacturers of devices and software in the color graphics sector decided to form a committee with the aim of defining and standardizing various cross-platform device profiles for gamut mapping. The name of this committee is the ICC (International Color Consortium). The ColorSync® 2.0 system add-on by Apple®, launched onto the market in spring 1995, was the first example of a color management system based on Linotype-Hell®/ Heidelberg technology being implemented in an operating system. The same technology was used at a later date for Microsoft Windows operating systems. You will find what is known as the Color Matching Module under the term ICM in the operating system under Windows 98, SE, 2000 and XP.

Requirements of a color management system:

- Easy to use without a high level of previous knowledge
- Processes large amounts of data quickly
- Compatibility with a variety of different programs
- Can be used flexibly in a wide range of computer environments


Viewopen Assistent
HEIDELBERG
Viewmaker

Profiling • Device coordination in the workflow

Even before the first scan, the operator should know what the requirements are in the subsequent editing process and the type of color reproduction for which the data is intended.

The most important requirements for a color management system to function properly are that the color spaces of every system component are known and are precisely coordinated. The normal sequence for this is as follows:

1. Calibration: Creating a defined basic status.
2. Characterization: Recording the color properties of a device using a suitable original (e.g. ISO original, see p. 23).
3. Profiling: Creating a device profile from the characterization data for the calibrated status of the device.

A modern digital workflow system could be compared with an expensive stereo. There is little point in simply buying the most expensive individual components in the hope of getting the best sound quality. Instead, you must ensure that all the components are perfectly coordinated with each other. The same applies to the relationship between scanners, monitors and printers. The color characterization of a device is essential for this coordination. This characterization provides us with what is known as a device profile.

The device profile is often supplied by the manufacturer. However, it should be noted that these are usually average values and the color properties of a device can change over time. For example, older color copiers tend to change in terms of color representation over the course of only a day. Over longer periods of time, this also applies to scanners or color printers. Offset printing also involves different printing materials and inks. It is in any case important that users are able to calibrate and characterize their devices themselves using a tool in order to subsequently create a new device profile.

Example: Scanners

For the purpose of profile generation, individual color loci are defined across the whole of the scanner's color space. These should be dimensioned so that the distance between neighboring loci is not too large and is visually equidistant. If this is the case, intermediate values can easily be calculated, if required. You do not need to search for

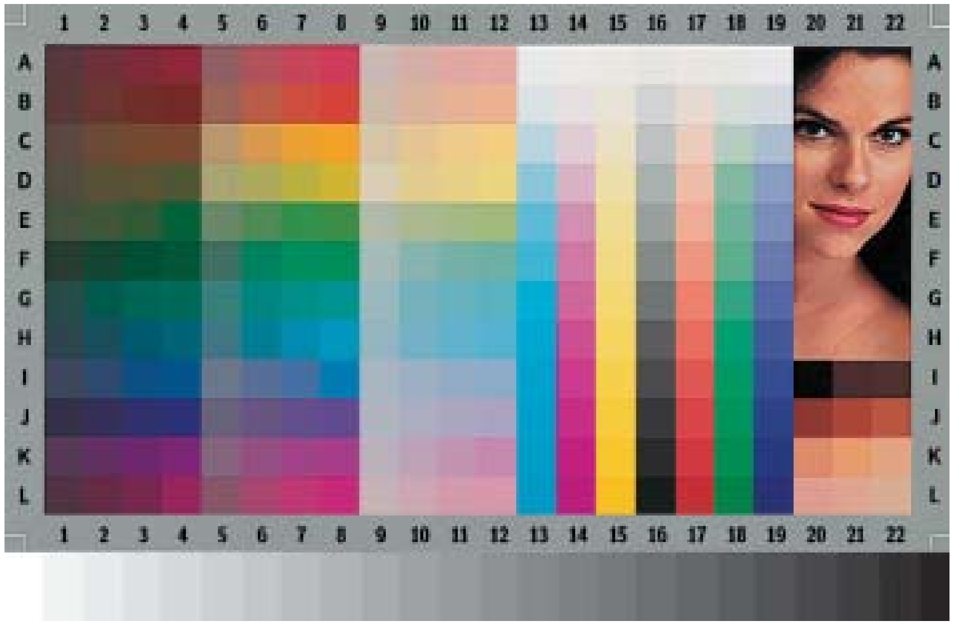


Fig. 17: The standardized ISO chart is used to calibrate scanners as an aid to coordination. The color values of the individual patches are fixed. Portrait photos are generally not taken into account in the calibration but are useful for checking skin tones, which are difficult to represent.

color loci yourself. Instead they are set out on a test chart. These test charts are normally included with the scanner profiling program (see Figure 17). The number of color loci determines the accuracy of the subsequent profile. A simple profile can be created with only a 3x3 matrix. That means that only nine reference points are used to determine the entire color space. Understandably, this results in relatively inaccurate values and a lot of room for interpretation. This is not necessarily a bad thing though. If you are operating in a system with simple components, it can be perfectly adequate to create a profile in this manner. Other profiles are created using a 32x32x32 matrix and are, of course, a lot more precise as a result of the 32,768 reference points available.

Standardized charts are available for color characterization. These charts were defined by an ISO committee. ISO stands for the International Organization for Standardization and is an international standards organization which Germany also contributes to. The sub-committee which is important to us in this context is called TC130 (Technical Committee 130) and deals with defining standards in relation to color graphics applications. There are two charts for scanner calibration which are defined in ISO standard 12641. The charts are also known by their old names IT8.7/1 (transparency) and IT8.7/2 (reflective).

If the ISO chart is scanned, you get the device-specific color values of the individual patches (actual values). At the same time, the original color values are present as device-independent values (for example, as $L^*a^*b^*$ values) on a data carrier (target values). The actual values supplied by the scanner are then compared with the target values present in digital form. The difference between the target and actual values provides us with precisely the information we require about the color space and character of the scanner. In the course of the device characterization, a conversion table (color look-up table) is compiled from the comparison of the target and actual values. This table for the color patches of the chart is in itself, however, not sufficient.

It should be safe to assume that a scanner can represent a larger number of colors than the number of color patches on the test chart. Interpolation thus takes place in the second part of the characterization process. This involves the use of mathematical algorithms which are responsible for calculating intermediate tones not shown on the chart. Gamut mapping from color space A to color space B is carried out for all processes relating to colors using the conversion table and the arithmetical algorithms. This also underlines the fact that the quality of a color management system is largely dependent on the quality of the algorithms. They have to work quickly and reliably.

The device profile that is created can be stored directly on the computer or submitted as a digital file so that you can always access it from the scan program. The profile can also be saved in a TIFF file (i.e. directly with the image data). The technical term for this is an 'embedded profile'. The advantage of this method is that corresponding programs such as Adobe Photoshop can transform the image back into the original color space using the embedded profile. If you were to work with a large number of individual profiles, this could often result in lots of individual gamut mappings. In the case of the soft proof on the monitor, for example, the input data must first be converted into CMYK data for the final output device and then into monitor RGB data. It is only then that the monitor is able to depict the image as it would appear in print.

Calibrating alternative data suppliers

A few years ago, the scanner was still the only device which produced digital image data and could be integrated into a color management process but the range of devices is now significantly larger. Alongside the scanner, cameras and video cameras have become increasingly established as suppliers of digital image data. Flatbed scanners and digital cameras operate on the same principle. Light reflected by an object is projected onto a CCD chip using an optical system and there split into the primary colors red, green and blue. The camera or scanner forms a digital image from this and makes it available to a processing program or first stores it on an integrated storage medium (memory card). The advantage of the scanner is that it always works with a constant light source. Only photographic material, prints or drawings are scanned. This means that the scanning color space can be defined with great precision.

After intensive use, visible changes can occur in color reproduction.
The scanner must be recalibrated when this occurs if not before.

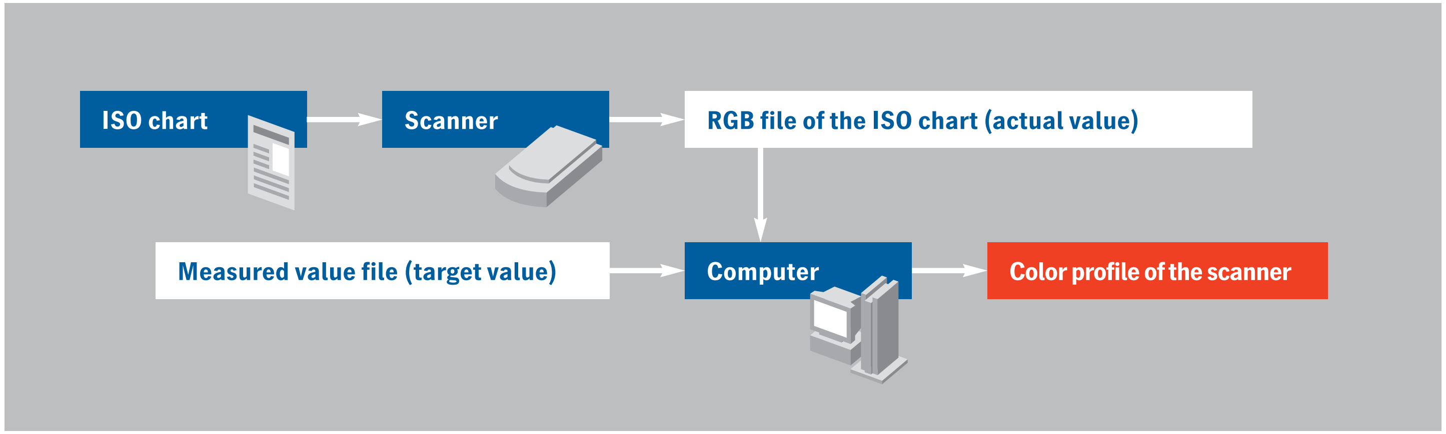


Fig. 18: The values of the standardized ISO chart generated by the scanner produce the actual value which is compared with the device-independent target value. The resultant differences are recorded in the scanner profile.

In the case of digital photography, this is even more difficult. Unlike with scanning, calibration is virtually impossible here. The variety of light conditions under which the digital photographs are generated is too great. The reflection characteristics of the different objects to be photographed also vary too widely to allow reliable calibration to be carried out. It is only under studio conditions and in the case of serial pictures of similar objects that an ICC profile can be created. To do this, a standardized color chart is photographed under the same conditions used for the actual objects to be photographed later. For practical reasons, this hardly ever happens. Instead, photographers prefer special test charts, which are generally easier to use and can be employed to judge the quality of a digital photograph. Many digital camera manufacturers even supply ICC profiles along with their software. This is particularly true for professional devices.

A third method of producing digital color data is offered by the large range of graphics programs. These programs can generate almost anything from simple logos with text to complicated 3D graphics which often look so genuine that you can hardly distinguish them from a photograph. In the past, use of color management was restricted to scanning photographs and slides but it is now normal for all colored objects of a print original to be depicted, proofed and printed in true-color. To do this, it is important that all the programs in which colors are created and evaluated have a color management capability. This particularly applies to scanning and image manipulation programs. They must have the ability to open supplied data with the associated ICC profile and to represent it in the desired output color space. In most cases, a profile of the offset printing process is selected for the output color space.

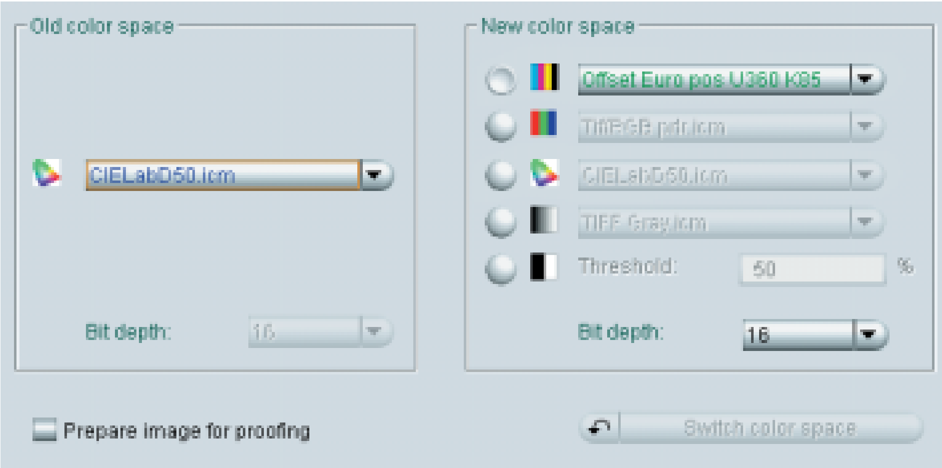


Fig. 19: Color management tools not only support transformation from color space to color space, they can also take into account all the device profiles available to them.

is

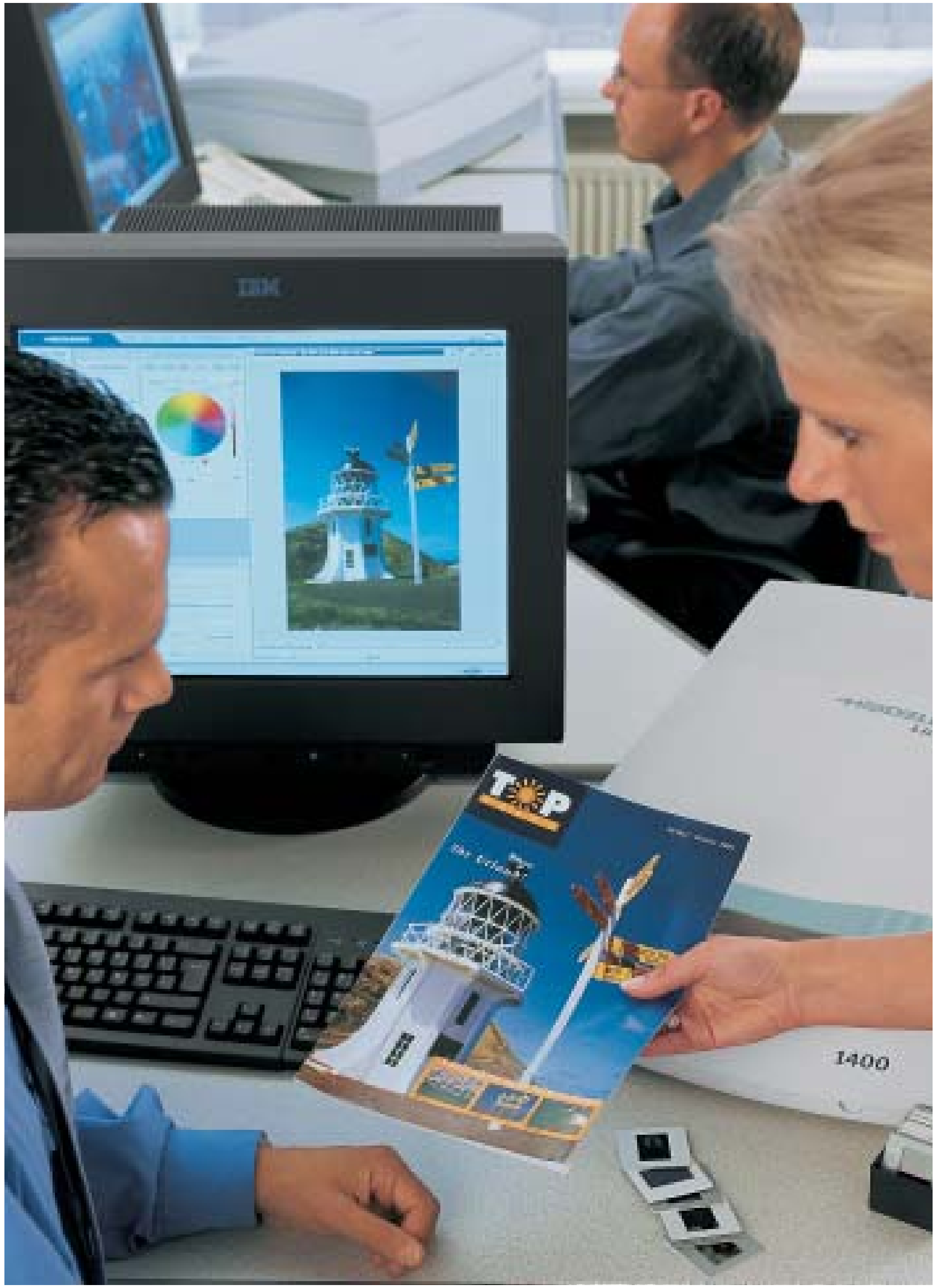
Working with difficult source data

As a result of the decentralized creation of digital print data, it is unfortunately only seldom possible for printshops to determine the origin of the color data. An ideal situation would be if all data was supplied with the relevant profiles. However, this is likely to remain a dream for printers for a long time to come. In the meantime, the number of color spaces used is constantly rising. Documents often contain RGB images from digital cameras, graphics created in CMYK, special colors which may need to be printed as special colors or broken up into the process colors CMYK, and finally images with profiles that do not fit into the image at all. The only thing that all the data has in common that it does not fit into the color space of the offset printing process. While CMYK data that has already been matched to an offset print can be matched relatively easily to the new print process, there is no chance of doing this with RGB and Lab data. In most cases, the print result will be very different from the color impression of the original, with the result generally turning out to be worse.

The easiest thing for the printshop to do would be to return the data to the person who produced it to prepare it for printing but this cannot usually be done for two simple reasons. Firstly, there is usually no time for this nowadays due to tight deadlines and, secondly, the person who produced the data will probably not understand what the printer wants them to do. After all, the blue on their monitor was just what they wanted. The printer is left with no option but to first convert all the data into a device-independent color space such as Lab. If he does not have the correct profiles available, he can only work according to the “best guess” method. He tries out different profiles and uses the one that looks best for the gamut mapping. He then converts the data into the final print color space using his press profile. The proof is then produced. If the client is not satisfied, the necessary reworking must be done in prepress. These are all processes which make the print job unnecessarily expensive and could have been avoided if only better data had been provided.

How can you avoid this scenario? Close cooperation between the printshop and client helps to achieve this. It is important that the client explains to the printer the methods they used to create the digital data and whether they used color management in doing so. The printer can then provide the client with the printer’s own ICC profiles, which the client can use for checking and any proofing. Conversely, the client can send profiles used to create their data to the printer who can then use it for conversion back into the original color space.

This is why color management always starts with the desired result and works towards data preparation. You might say it works back to front. A scanner profile alone is no use when looking at the monitor. A monitor profile by itself is equally useless. What do you want to see when you are carrying out color retouching and design on the monitor? Presumably, what you will eventually see in the actual print? This can only be achieved using the press profile.



Calibrating monitors

In the image manipulation process, all the changes and corrections are usually made using the monitor image. A print-out is only produced when the monitor image is deemed to be acceptable. This underlines the importance of the monitor displaying a reliable test image. It would be unfortunate if you were to assume from the monitor image that there was a strong red cast in the original, you were to correct it on the monitor image, output the data and then find out that the image was actually quite good apart from the presence of a green cast that had come about because you corrected a red cast that was not actually there. To prevent this, the monitor must be calibrated, as this is the only way to obtain truly reliable images.

The calibration procedure is the same in principle as for scanners or printers. If the manufacturer has not supplied monitor profiles or if you suspect that your monitor has changed over time, start this calibration process again with profile generation. To do this, you will need a special device which is very similar to a spectrophotometer but does not have an integrated light source. There is no need for a light source because the light is produced by the monitor itself.

Created on the monitor and no nasty surprises with the finished print product. Calibration can play an important role in achieving this.

The colorimeter for monitor calibration is able to operate without its own light source and is therefore significantly smaller than a spectrophotometer.

The device is fixed to the monitor. The calibration software produces a variety of colors one after the other on the monitor and these colors are measured. These color patches all appear at the same point so that you do not need to perform the laborious task of removing and remounting the device for each new color. Just as in the case of the scanner, the measured colors are also compared here with the existing target values. The device profile is then determined from the differences between the target and actual values. Just like all other profiles, the quality of the profile depends on the number of color loci and, of course, on the quality of the measuring device and the software used. Generating a profile of adequate quality is, however, easier with the monitor

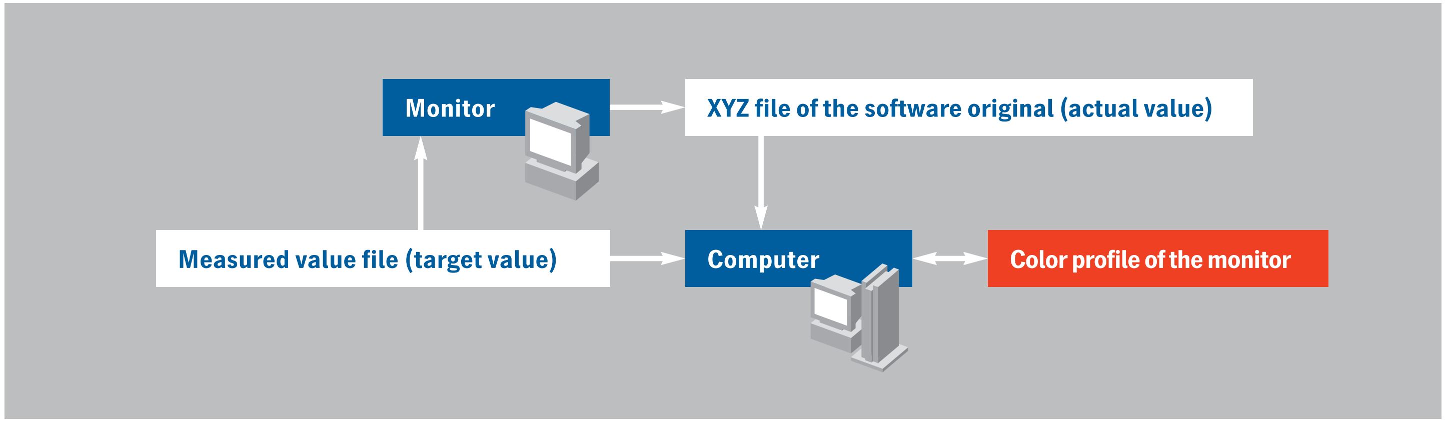


Fig. 20: As in the case of the scanner, a comparison is made between the target and actual values for the monitor in order to create the profile.

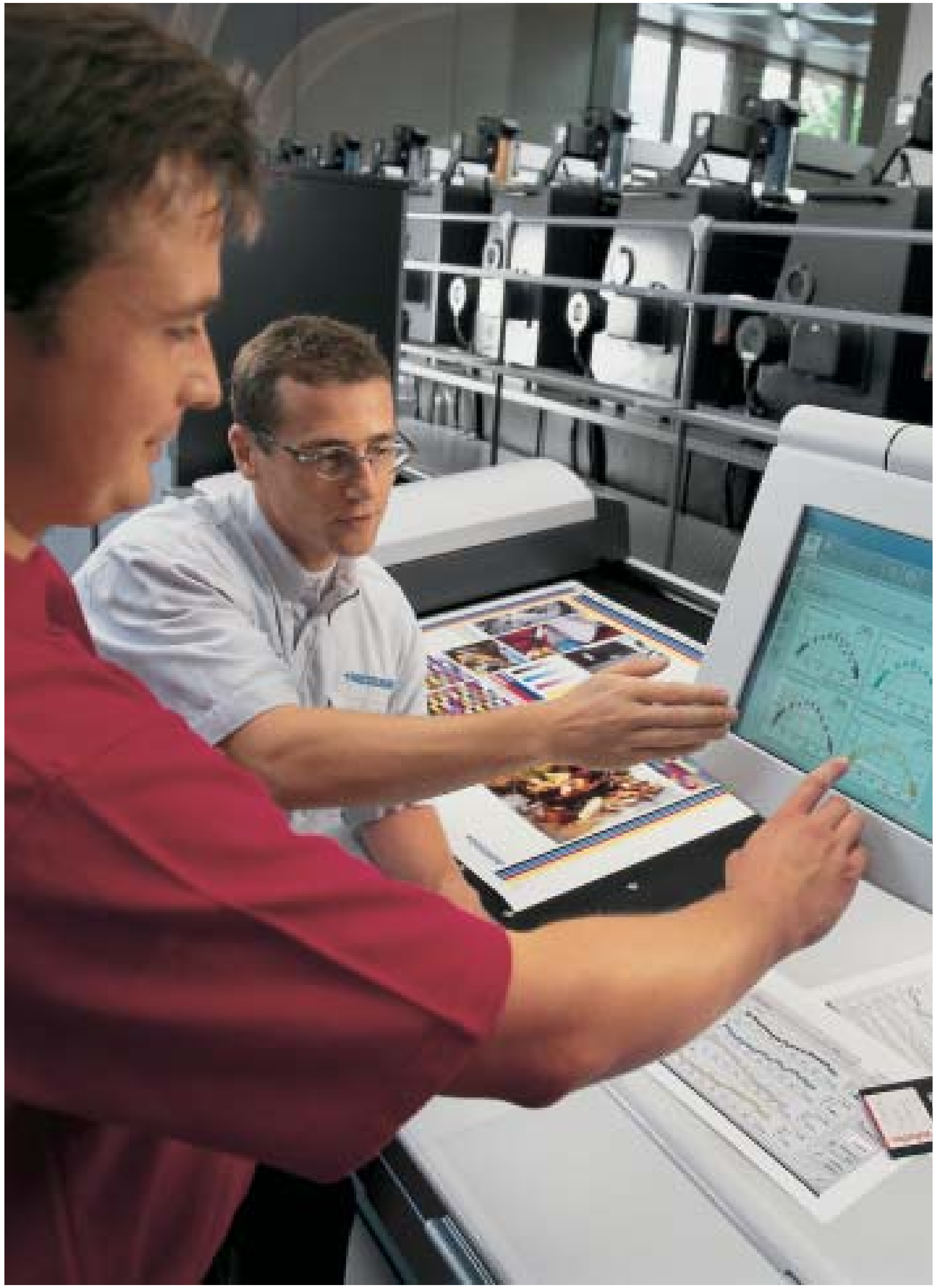
than with a scanner, as much fewer color loci are needed here. For a simple monitor profile, often only the three primary colors red, green and blue and a gray scale are scanned. This amounts to between only six and eight color loci. Of course, this leaves some leeway but is sufficient for semi-professional use. High-quality profiles are also generated for the monitor using only comparatively few reference points. The profile created can then be used again in a color management application where the profile is taken into consideration in the gamut mapping, for example, from Lab to monitor RGB.

ICC profiles can be created for all devices. In order for them to describe the current device status, the devices must be calibrated on a regular basis.

Difficult color ranges for monitor displays

The color space of the monitor is larger than that of a printer or offset printing. Therefore, it can generally display a larger range of colors. However, there are color ranges in which even a relatively simple color printer is superior to the monitor. The ranges involved are cyan and yellow. These color ranges represent primary colors for all printers because they use CMYK. However, in the case of a monitor using RGB, these are secondary colors. The monitor must first compile these from red, green and blue. Printers therefore have an obvious home advantage in these color ranges. As a result, it can be difficult to display a light cyan precisely on the monitor.

This issue must be taken into consideration in the soft proof which is supposed to simulate the color impression of a printed image on the monitor. In this case, the quality of the gamut mapping and thus the reliability of the soft proof on the monitor depend on the quality of the monitor and the quality of the color management application.



Profiling output devices

There are various methods of producing color prints. Inkjet, color laser and thermal sublimation methods are only a few examples. If one compares the technologies, output quality and costs of purchasing and operating the various devices, clear differences become apparent. We would like to take this opportunity to focus mainly on inkjet printers and, in particular, the bubble jet method because this is the most commonly used process. Inkjet printers use either CMY or CMYK. In the case of CMY devices, black is produced by 100 % overprinting of the three other process colors. The only problem is that this black is usually not black but is more of a greenish-brownish color. It is thus worth investing in a printer which uses CMYK, i.e. one that prints black as a separate color.

How does an inkjet printer work? There is a print head for each of the basic colors (see p. 16). These print heads are mounted one after the other on a carriage. During printing, this carriage moves backwards and forwards perpendicular to the feed direction of the paper so that the ink can be applied. The colors are applied using liquid inks in the print heads. The ink in the inkjet nozzle is heated for printing. This heating causes the formation of a small bubble which creates high pressure in the nozzle. When this pressure becomes too great, the ink tries to escape via the specified exit and is expelled from the nozzle in the form of a droplet. The speed of the ink can be up to 700 km/h. Several thousand droplets can be released every second using this method and applied to the paper as print dots. The single print dot represents the smallest unit of printing. It is our pixel. Once a whole line has been printed, the paper is moved on and the process starts all over again.

The following problems are the most common ones encountered when evaluating colors using a printout from an inkjet printer:

- The colors run because there is too much ink on the paper.
- The image is too chromatic because the whole color space of the device is used if color management is not employed.
- Streaks form due to poor adjustment of the print heads.

The quality of the print is closely dependent on the quality of the gamut mapping, i.e. how well the transformation of the input color space into the output color space works. An important requirement for optimum transformation is the profiling of the color printer. Special tools are available for this purpose. The first of these is a test chart which is supplied as a digital data set rather than an image. They also include profiling software which brings together the target and actual values. The test chart supplied as a data set is sent to the printer as a print file and printed out. The individual color patches of this printout are subsequently measured with a spectrophotometer.

Influencing factors outside of color management

The example of inkjet printers highlights the fact that not all color differences are the result of color management or can be resolved with color management. Alongside climatic conditions, the inks and paper used can also have a large influence on the print result.

The individual inks are liquid. In technical terms, color printers approach this problem by trying not to print all the colors at the same time but waiting until a layer has dried. However, this is not always totally successful and the slight running together of colors cannot be avoided. This is most evident at the sharp edges of the image. This is why running can often be seen where two areas with completely different colors border each other. The type of paper used plays a large role in determining how pronounced these effects are. Before you start to create a profile, you should ensure that the printer is correctly set up and calibrated for the type of paper that will be used. Manufacturer specifications are usually stored in the device or can be selected in the print driver. High-quality printers also have an automatic calibration function. This should always be carried out prior to profiling. This ensures that the results are repeatable.

Standard recycled paper is highly absorbent. It absorbs the inks applied like a piece of blotting paper. This in turn makes it difficult to keep colors separate and, as a result, the colors appear paler. A large degree of the color brilliance is thus lost.

Average quality prints can be achieved even with normal, coated white copy paper. Premium quality, however, can only be achieved using special paper. Because the substrate is so important for calibration, you will need to create a printer profile for each type of paper you use. This means that you will have to carry out the process of outputting and measuring the test chart in the way described above for each type of paper individually. You will be sure to see differences in the data.

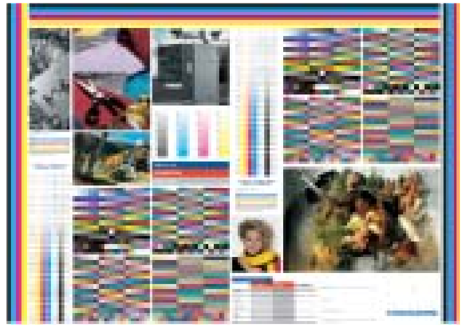
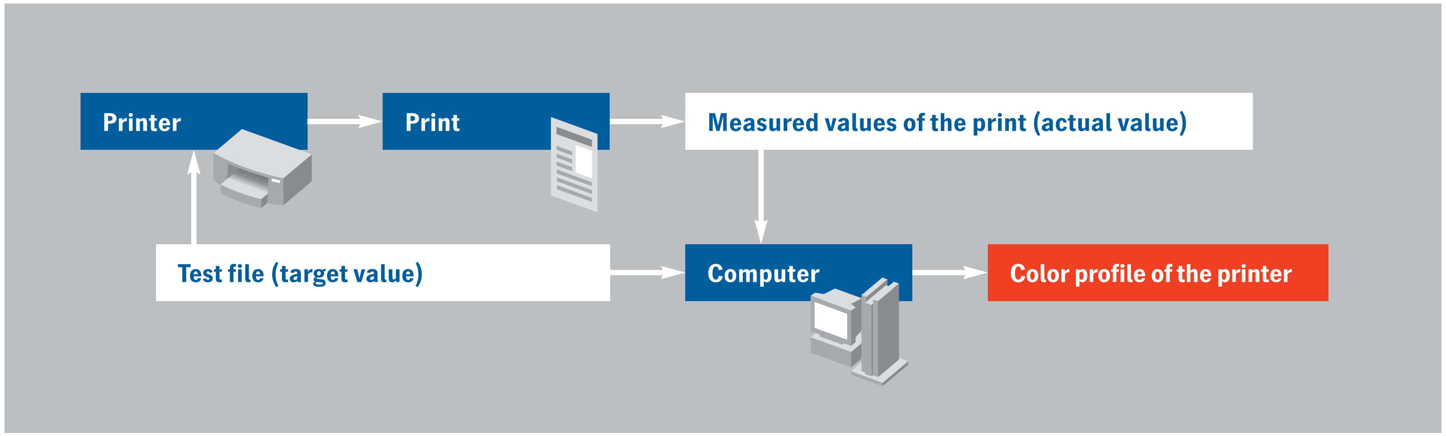


Fig. 21: Typical test print for comparing the actual values of the print with the desired target values of a test file.

Fig. 22: A device profile can be created from the differences to the test file. This device profile should be used for all further gamut mapping. Once gamut mapping has been completed, you can start production using the profiled device.



Reproduction • From proof to perfect color reproduction

A proof should reliably show the result of a subsequent printing process. This print is used as the basis for final corrections and fine tuning and to ensure that all the images are correct. What do you need to create such a proof? The first thing is a color printer which is capable of reproducing the whole color space of the printing process. Standard inkjet printers are most commonly used for this purpose. They have the advantage over special high-quality proof printers offered by well-known manufacturers that they are relatively cheap to buy and, in most cases, to maintain. However, producing true-color proofs with these devices also requires great care and precise calibration. You must be aware of the fact that, particularly in the large format sector, these devices were not originally developed and designed to produce proofs. They are mainly used by architects, display manufacturers, screen printers, stand constructors, advertising studios, etc. Turning these printers into proofers requires additional technical measures which will not be dealt with here in

Using the proof, you can easily see the subsequent print colors by comparing them with the color scale.

greater detail. It must, however, be said that suitable devices are available in all format classes. The quality of output is constantly improving. Increasingly high resolutions and fine droplet sizes of spray-applied ink ensure that the level of quality is rising consistently.

The second important component for successful proofing is the RIP (raster image processor) which is used to generate printable screen bitmaps for output devices from digital originals (pixels and vectors). This RIP must be able to work with ICC color profiles. It must also be capable of processing data created in the prepress phase for manufacturing the printing plates as precisely as the RIP in platesetters and imagesetters. Preferably, it should be one and the same RIP. A RIP must feature at least the following components if it is to be suitable for proofing:

- CMM = Color Matching Module
- Input option for a press profile
- Input option for a proofer profile

Problem colors

The reproduction of some colors will continue to present us with considerable challenges in the future. For example, the blue shown here in the left-hand square is printed as an additional special color. If you were to try to create it using normal four-color printing, you would never exactly match this hue because it lies outside the CMYK color space. The best you could do would be to get a close approximation.

Perfect color reproduction – the result of a multi-stage color management process which extends all the way from prepress to the final print.

Fig. 23: On the left, the special color Heidelberg Blue, on the right, its approximate value in CMYK with cyan 100 %, magenta 50 %, yellow 0 % and black 20 %.

How do you make a proof true-color?

If you were to output a print file in the color space shown in Figure 24, the result might well be nice to look at but would be unusable because the proof print features and can depict colors that lie outside the subsequent color space of offset printing. Figure 25 shows a typical color space for offset printing. It is immediately apparent that it is significantly smaller. In this case, a RIP equipped with color management will use the appropriate profiles and the Color Matching Module to carry out gamut mapping in which the color space of the printer is matched as precisely as possible to the offset color space. Figure 26 shows the result. The two color spaces are almost identical. Matching of this type results in very small differences in the region of 2 Delta E (ΔE represents the difference between two colors, whereby on average the eye can differentiate 1 ΔE). In practical terms, this is a very good result. If you would like to further improve the gamut mapping, the profiles would have to undergo further editing.

Fig. 24: Proofer color space

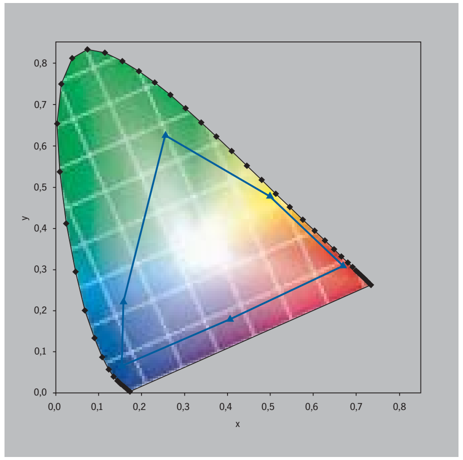


Fig. 25: Print color space

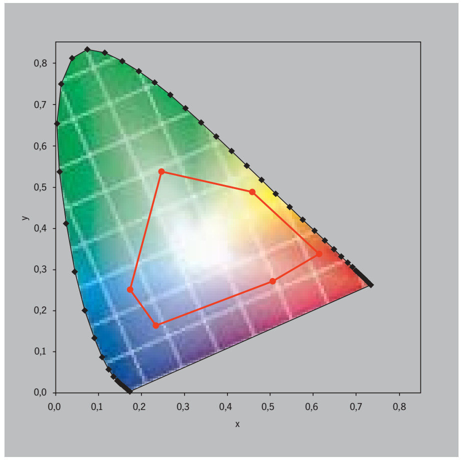
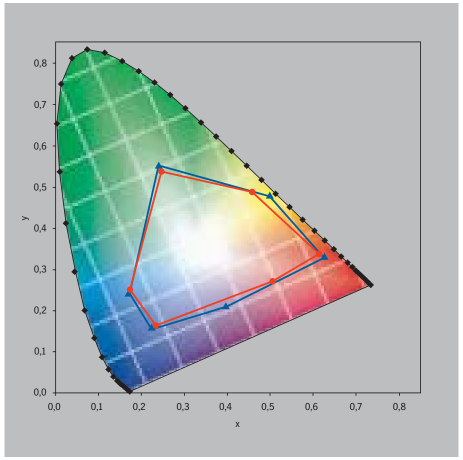


Fig. 26: Comparison of a proofer color space matched to the print process to the print process color space. The results of the proof and the offset printing are now almost identical.



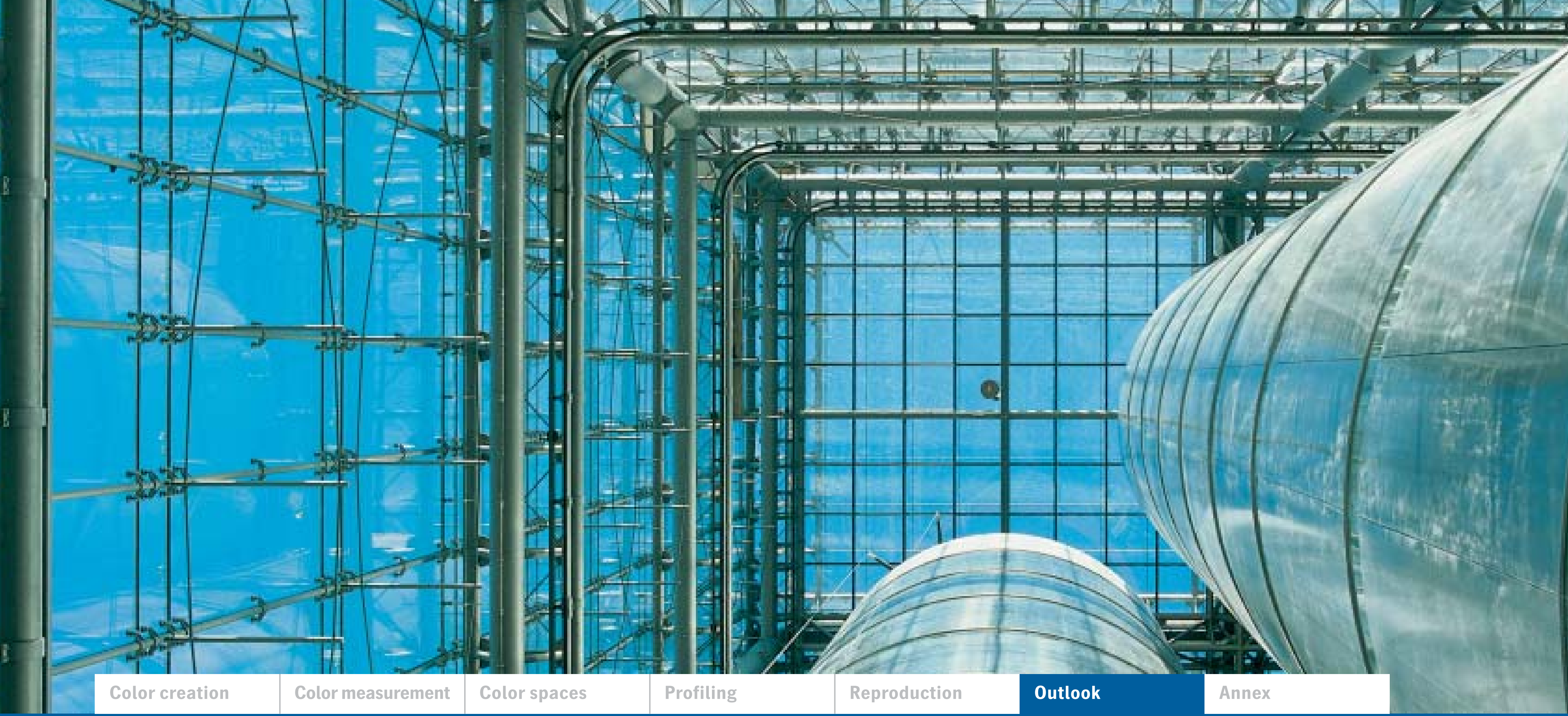
General proofing requirements

Proofing equipment

- Complete CMYK color space cover
- Consistent color reproduction
- High resolution
- Fine droplet size

RIP - Raster Image Processor:

- ICC-compatible
- CMM = Color Matching Module
- Input option for print process profile
- Input option for proofer profile



Outlook • The future of a worldwide standard

Color reproduction will continue to present printshops with considerable challenges in the foreseeable future. Digital images sent directly from digital cameras for editing on a computer will be just as difficult to reproduce as computer-generated color graphics. In both cases, colors are generally used that are very difficult or even impossible to mix using the four process colors. Many of the rich blue and green tones that you can see on the monitor pose huge problems when it comes to producing them using CMYK. Even the best color management system with gamut mapping cannot solve this problem. This means that such colors must be avoided or the cost of printing a special color must be added into the equation.

The limits of the standards

A major problem in ensuring the precise repeatability of a print result is the fact that the large range of different components which have an effect on the print result have not yet been standardized. For example, there is no standard for the CMYK color space. In Japan, Toyo-Inks defined to the JIS standard are used is most cases, in the USA the Swop standard applies, while in Europe and especially in Germany, the ISO standard is used (BVDM's process standard for offset printing). Only worldwide standardization, now in its initial stages, will bring an improvement. Even inks are not truly standardized in individual regions. If the printer changes ink supplier, this can lead to a change in results.

Critics of modern color management systems often comment that standardization will just end up leveling everything out. Of course, it is not easy to give up individual achievements with supposed advantages in terms of quality as the price for a standard. Unfortunately, however, the arguments of those opposing the standard are idealistic concepts which no longer bear any relation to real open system environments. They also like to ignore the most important aspect of our business, namely efficiency. This, in turn, is based on the savings in material, time and costs that smooth communication makes possible. This type of communication does not function according to the principle of trial and error when printing colors but instead achieves the idea of WYSIWYG, what you see is what you get, throughout the whole process chain.

In the age of globalization, another issue to be addressed is the regional independence that widespread standardization brings. Intercontinental data transmission is no longer a problem. So why not work with graphic designers in Japan and the USA who use the data to create a document in their own country and have the finished product printed in Europe?

The most important thing, however, is that good results are no longer dependent on good fortune when color management is used consistently. Image data can be reliably reproduced at any time, with any device and by any user. High reliability in production is achieved even on Mondays and between Christmas and New Year.

The future of color management

We can be confident that reliability in color reproduction will not remain a dream forever. Existing color management systems will continue to improve in terms of both the quality of gamut mapping and user-friendliness. Color management will then finally become transparent and easy to use for everyone. Of course, these changes will be accompanied by improvements in hardware. Color copiers are already available which identify changes in humidity and temperature and adjust to them so that they always achieve the best possible results. Other devices such as scanners or imagesetters will become more color-stable so that they do not need to be calibrated as often. Standards will increase in popularity. Many more applications will be available which will be capable of generating or using ICC profiles. We will undoubtedly achieve a situation where color information can be transported just as reliably and easily as fonts are today. Then, there will be no more boundaries to worldwide cooperation in the reproduction of color images.


LIFETIME PRINTERS LAYOUT
top 10
ASIEN
GLOBUS
OPEN-AIR
KNEIPEN-
RESTAURANTS
JAPAN
BÜRGERLICH
TRADITIONELL
MEDITERRAN
EXOTIC

Color space definition • Theoretical background

The CIE standard color system

Creating a common color standard covering the most important color solids and enabling an agreement on colors is of elementary importance to the development of a color reproduction system. The CIE's standard color system is such a standard. CIE color standardization is based on imaginary primary colors with the designation XYZ which cannot be achieved physically. They are purely theoretical and are thus not dependent on a device-related color solid such as RGB or CMYK. However, these virtual primary colors were selected such that all of the colors visible to the human eye lie within this color space.

The XYZ system is based on the response curves of the three color receptors in the eye. Due to the fact that these are slightly different for each individual, the CIE has defined a 'standard observer' whose eye sensitivity is about the same as the average over the whole population. This enables objective colorimetric recording of colors.

First of all, the three primary colors of CIE's XYZ reference system need to be represented in spatial terms with the coordinates (X), (Y) and (Z), as shown in

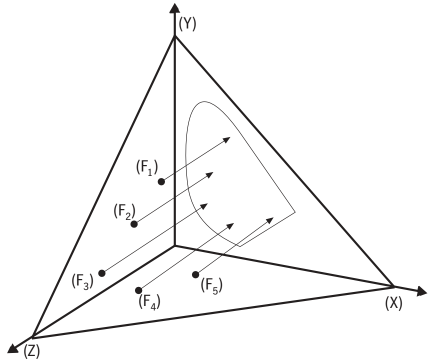


Fig. 27: From the three-dimensional to the two-dimensional depiction of the CIE reference system.

Figure 27. This enables a chromaticity triangle to be drawn. To convert this into a two-dimensional depiction, i.e. the sole, this triangle is projected into the red-green area. However, this is only useful if corresponding standardization is carried out at the same time which allows the lost value (Z) to be read off from the new two-dimensional depiction. This standardization is carried out by introducing the CIE chromaticity coordinates x, y and z.

Settings are entered for:

$$x = \frac{X}{(X + Y + Z)} \quad \text{('Red component')}$$

$$y = \frac{Y}{(X + Y + Z)} \quad \text{('Green component')}$$

$$z = \frac{Z}{(X + Y + Z)} \quad \text{('Blue component')}$$

where:

$$x + y + z = 1$$

The value z for a particular color can thus be obtained by subtracting the chromaticity coordinates x and y from 1:

$$1 - x - y = z$$

A color cannot be uniquely defined simply by specifying its chromaticity (using x and y). A 'brightness coefficient' must also be entered. The eye response curve for sensitivity to green is standardized in the XYZ system so that it also reflects the perception of brightness. It is thus identical to the V (λ) curve. A color is fully described if it contains the brightness coefficient Y alongside the values x and y. In the standard color triangle, the right-angled chromaticity triangle created by the coordinates zero, x = 1 and y = 1 marks the limits of this reference system. Chromaticities outside the triangle are not conceivable. The closed curve represents the position of the spectral colors (see Figure 28). Colors between the triangle and the spectral color curve can be defined but are virtual, i.e. they cannot be implemented in physical scenarios.

With the introduction of the standardized CIE color plane, color determination has changed from a qualitative description to a quantitative, number-based system. In addition to the measurability achieved, the CIE standard color system also has the advantage that it can easily

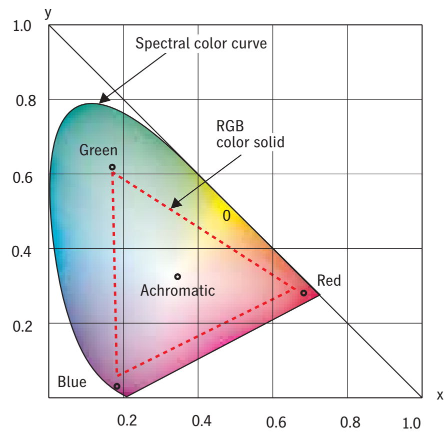


Fig. 28: The RGB primary colors of a reproduction device form a triangle within the sole. Such a triangle then represents a relatively small color solid with the achromatic point approximately in the center.

represent the results of additive color mixing. The results always lie on straight lines between the starting colors. The CIE standardization also enables any number of color transformations from one color solid to another, for example, converting a specific color from the RGB color solid of the monitor into the CMYK color solid of a printing process. There are, however, the following drawbacks to the standard color system:

- Including brightness in the representation presents difficulties
- There is a discrepancy between the perceived color differences and the color distances in the system

The CIE's Lab color space

Seeing colors does not just involve merging color values in the eye. The retina registers three color stimuli that largely relate to red, green and blue beams of light but three perceptions occur in a further processing stage:

- a red/green perception
- a yellow/blue perception
- a brightness perception

This allows us to develop a "complementary color system" which is based on three pairs of elementary color opposites, as shown in Figure 29.

We know from experience that, when examining color on a perceptual level, red can never contain green components, blue cannot contain yellow components and white cannot contain black components. When asked what the primary colors are, most people do not say the

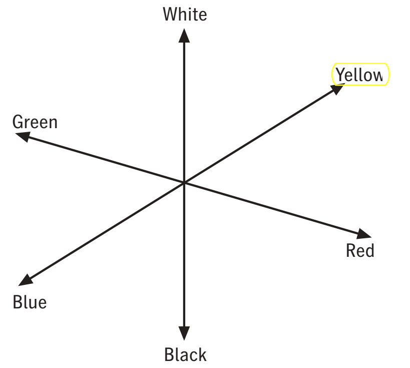


Fig. 29: Complementary color system. It is based on three pairs of elementary color opposites.

three primary colors red, green and blue but mention four, namely red, green, blue and yellow. People are unwilling to recognize colors such as black, gray and white as colors at all.

They seem to be perceived in a completely different manner. The lack of chrominance in a black and white film on a screen, for example, is fully accepted by us after a short period of adjustment. We can conclude from this that, in a correctly structured perception-based reference system, the achromatic brightness information and the color information should be clearly separated both quantitatively and qualitatively. This is what the Lab color system developed in 1976 by the CIE achieves. It is based on the XYZ primary colors but also includes the complementary color model described above. The hue and the chroma are defined by the coordinates a* and b* which can have positive or negative values. Like the chromaticity triangle, this color system displays all conceivable colors. Numerical values for the hue and chroma can be derived from a* and b*:

- Hue: $h = \arctan(b^*/a^*)$.
  This corresponds to the angle between the color vector and the a+ axis.
- Chroma: $C^* = \sqrt{(a^{*2} + b^{*2})}$
  This corresponds to the distance from the color locus to the gray of the color solid perceived to be equally bright.
- The third property, brightness (or lightness), is displayed vertically by a brightness scale with the designation L* with scale values from 0 (black) to 100 (white).

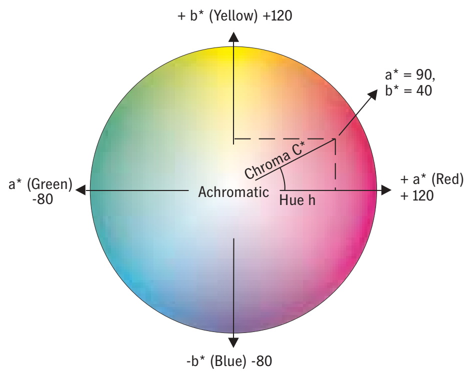


Fig. 30: Definition of hue and chroma using coordinates a* and b*.

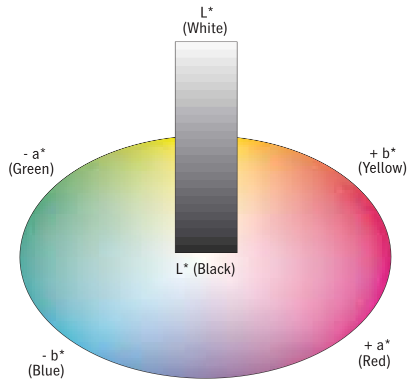


Fig. 31: Recording brightness using an additional scale value.

For reasons of clarity, not all the different brightnesses of the spectral color curve are shown. A horizontal cross-section forms an upper limit for the model. All the colors with the highest chroma are situated on the outer surface of this ideal color solid. We can clearly see from this that the darker the colors become the more they lose in terms of chroma. This is logical if you consider the fact that when the minimum brightness value is reached, each color becomes black and the chroma value thus equals zero.

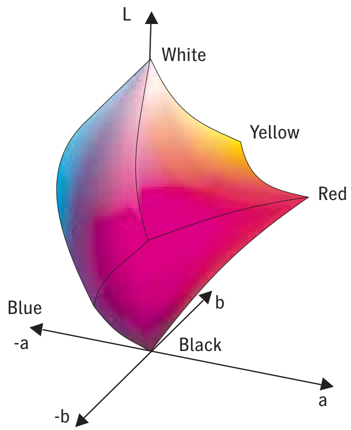


Fig. 32: A color solid which is based on real colors might have approximately the shape shown here.

Two things become apparent here:

- With both increasing and decreasing brightness, the chroma of the colors falls down to zero when white or black is reached.
- In contrast to the CIE chromaticity triangle, the lines connecting the corner colors are not straight lines. The reason for this is the visual equi-spacing of the colors in this color space. This is achieved through the non-linear transformation of the XYZ values into Lab values.

The main formulae for the transformation of XYZ to Lab are as follows (for X, Y and Z that are not too small):

$$L^* = 116\ Y^{1/3} - 16$$
$$a^* = 500\ (X^{1/3} - Y^{1/3})$$
$$b^* = 200\ (Y^{1/3} - Z^{1/3}),$$

where X, Y and Y are standardized to 1.

Gamut mapping in the Lab color space

Among the main advantages of the Lab color space are its device-independence in color representation and capacity for intuitive color adjustment when operating a repro system. Just like the XYZ color space, the Lab color space is able to represent all real color solids as subsets. Now, let's assume a repro device is based on the RGB color space. For printing purposes, the RGB color values have to be converted into CMYK color values. The two color spaces are different both in terms of their size and position. Due to the fact that the repro system has RGB as a reference system, colors from the CMYK color space which cannot be represented in RGB can also not be printed in CMYK even though the CMYK color space does not prevent this. RGB thus acts as a limit on CMYK. This applies, for example, to a dark and chromatic cyan that cannot be displayed on the RGB monitor and cannot be reproduced in these circumstances. To display this in graphic form, a cross-section, as shown in Figure 33, can be taken through a stylized color solid.

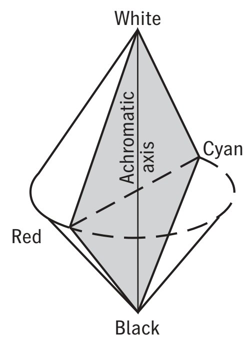


Fig. 33: Cross-section through a stylized color solid.

Here, for example, we can see the cyan-red area.

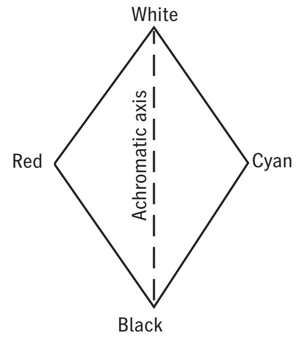


Fig. 34: Cross-section through the color solid to view the cyan-red area.

The problem is easier to represent if only one area (the cyan area in this case) is taken into consideration.

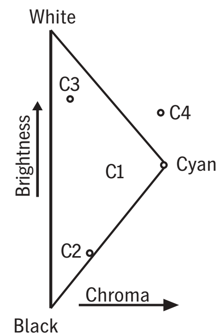


Fig. 35: Model section of the cyan area.

The plotted colors are as follows:

- C1, the cyan with maximum chromaticity
- C2, a cyan that has the highest possible chroma in relation to this brightness value.
- C3, a light, achromatic cyan.
- C4, a cyan that lies outside the color space.

In the figure, all of the colors have the same hue, namely cyan. All the colors, apart from the C4 which lies outside the color space, can also be reproduced. If the printable colors are included in this diagram, you will see that the two color spaces are not identical. The fact that the two color solids overlap means

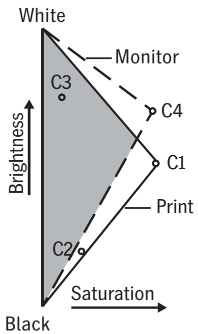


Fig. 36: Differences in the color spaces of the monitor and print in the case of cyan.

that only the colors within the common color-highlighted section are reproduced identically both on the monitor and in the printing process. In a device-based reference system such as RGB or CMYK, colors which lie outside their reference system inevitably cannot be reproduced even if they are present in the target color solid. This highlights the advantage of comprehensive reference systems such as the XYZ or Lab color space which do not have any restrictions of this type. Gamut mapping can be used here to coordinate the color solids so that the whole color gamut of the target color solid can be exploited.

Intuitive color manipulation

If a color slide containing very dark, achromatic tonal value areas alongside vibrant colors is to be reproduced, you should ensure that the dark sections of the image are brightened while retaining the vibrant colors. To illustrate what happens in such a case, let us take a look at a combination of a few highly chromatic colors and a gray scale. Figure 37 represents such an original.

The tonal values of the gray scale are so dark that it appears necessary to brighten them. The gradation function is used to do this in a conventional CMYK or RGB repro system. All the color channels are affected to the same degree (cf. Fig. 38). As a result of the corrected gradation, the tonal values of the gray scale are now easier to see but the chromatic colors are light and more achromatic. To maintain the chroma of the original colors, it would be necessary to rectify each individual color at great effort. This disadvantage can be avoided by using a Lab editor. Here, the achromatic colors are treated separately from the chromatic colors (cf. Fig. 39). There is no longer any need for subsequent rectification. A greater degree of security and reduced time required for editing are the result.

A similar advantage can be obtained in the case of overexposed originals. The colors are then usually too pale and their chroma level has to be improved. A simple change in gradation is not sufficient to do this because the overly pale colors only become darker and lose chroma as a result. Using conventional techniques, each individual color then has to be touched up. Brightness and chroma have to be matched, a process which is time-consuming and less than ideal in terms of quality.

When working in the Lab color space, the chroma of all the colors can be raised in a single editing step as a result of separating brightness and chroma. To this end, Lab editors are equipped with a chroma gradation editing function. Even this short explanation highlights the benefits of working in the Lab color space. The Lab color space has further benefits in the context of image editing. The separation of brightness and chroma also results in greatly increased quality of the sharpness filters and hugely improved color correction can be carried out, leading to a clear increase in image data quality.

Fig. 37: Original composed of gray scale and chromatic colors (colors dirty, tonal values too dark).

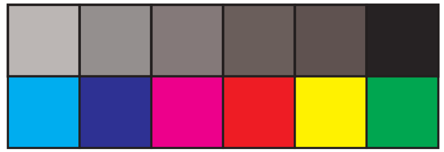


Fig. 38: Overexposed original (lack of color saturation).

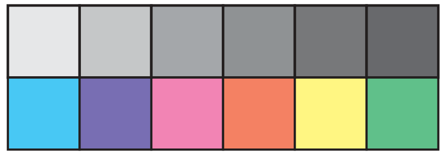
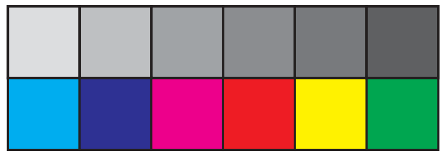


Fig. 39: Chroma profile corrected in a Lab editor.



Explanation of terms • Definitions and explanations

Additive colors

Light colors based on red, green and blue which produce white light when mixed together in equal components with maximum color values. Depending on the color component and intensity, almost all colors can be mixed from the primary colors. Devices such as scanners, digital cameras, monitors, etc. are based on this technology.

Calibration

To ensure the correct reproduction of images, all devices such as the monitor, color printer, proofer and imaging unit should be coordinated such that the fixed numerical values for CMYK can be represented correctly. In the broadest sense, this also applies to offset printing. Here, imagesetters have to be linearized and inking characteristics of the presses have to be matched to the real ink consumption.

CMM (Color Matching Module)

This is a computational module which carries out the gamut mapping and defines the position of the colors in the color space using the profiles. The CMM's structure is very important for the quality of color management. The CMM can be a component of the operating system or can be integrated into an application program. This means that all the main applications relating to color management have a CMM. The CMM can be found in the Microsoft Windows 98, ME 2000 and XP operating systems and in Apple Macintosh operating systems under the term ICM (Windows) or ColorSync (Apple). Modern proofing systems also contain a CMM to combine press profiles.

Color profiles

The profile is both a fingerprint of a color space that was previously measured and a set of instructions for the gamut mapping that is to be carried out. There are different types of profiles which can be divided into two main groups. Device-dependent profiles such as printer, scanner and monitor profiles. They each describe the color space that can represent the device. In the case of print profiles, the combination of ink and paper used is more important than the device. This is particularly apparent when one considers how many of these combinations can be printed with a press. The second group is the device-independent profiles. These are profiles which describe a freely defined color space. For example, this can be the whole Lab color space or a color space defined for different applications. Examples include the sRGB color space or the color spaces ECI-RGB, Adobe-RGB or NTSC (American/Japanese television standard).

Color separation

The separation of an image or a whole printing form into the printable primary colors of a multicolor printing system. A color separation is created for each primary color.

Color space

Description of a representable number of colors in a geometric coordinate system, i.e. for each color there is an exact description of its position in the color space. Precise illustrations of color spaces are always three-dimensional, i.e. in the form of 3D bodies. The most common are the Lab and XYZ color spaces. The CIE (International Commission on Illumination) standardized the XYZ color space in 1931 and the Lab color space in 1976. They represent all the colors that the human eye can perceive. Larger color spaces would be pointless because they would not have any advantages for us as observers. This would only make the conversion processes more difficult.

Contract proof

True-color or true-to-print test print. True-color means the simulation of the color reproduction (90 % to almost 100 %) using a color management system, in which the printing stock should be included if possible. True-to-print means the 1:1 simulation of the screen, register marks and trapping of the expected production run on the printing stock.

Delta E (ΔE)

The Greek letter Delta (Δ) stands for difference. ΔE signifies the difference between two numerical values. The letter is used for the distance between colors in the CIE color space. A ΔE is the smallest color distance that the human eye can identify. If we assume that CIE defines the value ΔE 1 as the value which is the smallest color difference which a standard observer can see, we can consequently ignore values smaller than 1. However, we know that color perception is affected by subjective impressions and influences. There will obviously be people who will be able to identify differences smaller than ΔE 1. The following figures have proved their worth as a rule of thumb for most applications:

between	
0 and 1	a difference which is normally not visible
1 and 2	a very small difference that can only be identified by a trained eye
2 and 3.5	a moderate difference that can also be identified by an untrained eye
3.5 and 5	a clear difference
more than 6	a marked difference

Gamma curve
Gamma curves are non-linear transfer functions for converting signals into values which are better suited to the reproduction properties of a device. Gamma curves are also used for dynamic matching to achieve uniform reproduction of color values.

Gamut mapping
This refers to the transfer of one color space to another. For example, this can be from RGB to CMYK, from Lab to RGB or from one CMYK color space to another CMYK color space. The latter, for example, always takes place during the proofing process, the color space of the proofer being matched to the color space of the press. When performing gamut mapping, there is the option of either directly transforming from one color space to another or selecting an intermediate step via an independent color space such as Lab. The latter option has the drawback that different color spaces also have different color space gamuts and an adjustment process usually has to be carried out.

Gradation curve
This refers to the typical profile of the gray levels (contones) in reproduced (digitized) images.

Gray levels
These describe the gradations of gray values between black and white. The number of gray levels of an 8-bit gray level image is 256 (including black and white).

ICC (International Color Consortium)
This is an independent association of manufacturers, users and advisers dealing with the topic of color management. The aim of this consortium is the worldwide standardization and distribution of color management products. The ICC, for example, defines what a color profile must or may contain so that it can used for all devices irrespective of the manufacturer. This prevents solo efforts and the user can be certain that his color management works with different products and applications.

ICM (Image Color Management)
The Windows counterpart to Apple's Color-Sync., the operating system component which is responsible for calculating the gamut mapping (with the CMM and the ICC profiles).

Moiré
Interference pattern in screened images which is generated when an image that has already been screened is scanned in again. An object moiré is generated if the original has a fine structure such as fabrics or loudspeaker boxes. These problems usually occur when using conventional screening methods. The geometrical structures of the screen dots overlap unfavorably with the geometrical shapes of the image.

Rendering intent
The manner in which you wish to transform colors from a source color space to a target color space must be determined by the CMM using a rendering intent. Depending on what is desired, a selection can be made from the following four intents:

1. Perceptual
This intent is always selected if you wish to perform gamut mapping in which the target must correspond visually as closely as possible with the source, but the target and source color spaces are different, for example, if a scanner RGB has to be transformed into a printing press CMYK. With this method, the colors that cannot be represented in the target space are placed at the edge of the target color space and the other colors are positioned relative to them in the color space. The aim is to achieve as exact a representation as possible which the human eye then perceives as being almost identical to the source color space. In some applications, perceptual is also referred to as 'photographic'.

2. Relative colorimetric
This intent brings about a 1:1 transformation from the source to the target color space. To do this, it is necessary for the target color space to have at least the same color gamut as the source color space. It is better if the target color space is larger. If a relative colorimetric transformation of printing colors is carried out, the underlying color of the printing stock (paper) is not taken into consideration. For example, if the result of a newspaper print is to be reproduced on a proofer using very white paper, the hues are reproduced

correctly but look too clean as the 'soiling' of the colors by the gray newsprint is not taken into account. Colorimetric gamut mapping is only useful for similar color spaces such as CMYK to CMYK.

3. Absolute colorimetric
This is the intent that should always be used for proofing. In principle, it works exactly like the relative colorimetric process but takes the color of the printing stock into account. Continuing with the newspaper example, the print on the proof is reproduced exactly if the absolute colorimetric process is used. The gray of the newsprint would be represented on the white proofing paper. This is why you will often find the term 'proof' or 'proof reproduction' instead of 'absolute colorimetric' in the color management section of an RIP.

4. Saturation
With this type of gamut mapping, colors with a high level of chroma are reproduced as chromatically as possible. To do this, the hues situated in the middle of the color space can be pulled towards the outside. This intent should only be used if an exact color reproduction is not required. It is thus seldom used in the graphics industry. The situation is a little different in office applications. High levels of chroma are often desired here, particularly when the source color space is made up of the CMYK of the printing colors.

Soft proof
A color simulation of another output method (e.g. a printing process) on a calibrated and profiled screen.

WYSIWYG
What you see is what you get. This means that the screen output is identical to the subsequent print product.

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