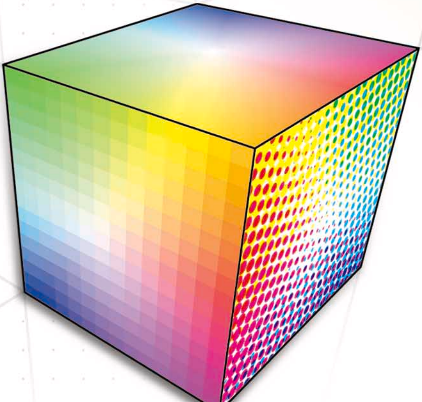
Color 101

the challenge of color printing



Color 101

the challenge of color printing

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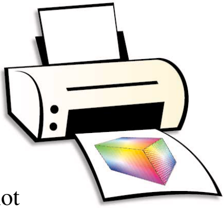
Introduction

In a perfect world, choosing a color and printing it would be as simple as it sounds. In reality, successful color printing requires knowledge of color science, experience in the printing process, and the right hardware and software.



Whether you want to produce a flyer, T-shirt, poster, or brochure, the process for printing in color contains challenges for getting the color right. It is not just a matter of choosing the color you want, but of choosing colors your output device can print. The challenge is in staying true to the desired colors throughout the document creation and printing process.

The purpose of this guide is to help you understand the challenges of color printing. It takes you through a simple, high level view of the art, science, and technology of printing color documents. Although the guide does not ignore other types of color output, it focuses on page printing.

Feel free to share this book with your colleagues, customers, and friends. If you cannot solve all of the problems that occur when trying to print in color, you will at least know why!

A Color Opportunity

Jean Merlin is a silkscreen artist. She created a beautiful print of a heron in flight that was selected by the local Historical Society to become the cover image for a history of the BayWater region brochure.

Last year, Jean's friend, Sam, painted a portrait of a local fisherman which was featured on another Historical Society booklet. She remembered very clearly Sam's reaction when he brought her samples of the booklet. The skin tones for the fisherman were orange. The fine black-edged swirls that were Sam's signature paint stroke came out as thick black outlines. The shadows were too dark. In short, the fisherman looked sickly.

Sam was shocked and disappointed. How could the print shop chosen by the Historical Society do such a bad job at matching his colors? He wondered why the text seemed so indistinct on the textured paper. Worst of all, when he saw his original oil painting hung in the Historical Society visitor's center, it too looked sickly under the yellow track lights. What Sam had hoped for was good exposure for his work. Instead, he got a color fiasco!

Jean's Turn

Although Jean is very familiar with the silk-screening process, she had never worked with other media. It was very important to her that the colors appearing in the final brochure were as matched to the original as they could be.

Like Sam, she wanted the brochures to accurately represent her art form. Determined not to be unpleasantly surprised, Jean offered to manage the entire printing process. The Historical Society gratefully accepted. Now, all she needed to do was to learn what goes into making the right decisions for successful color printing.

Jean chose a local commercial printer and met with Sandra, the owner. Jean explained what had happened to Sam and asked what Sandra could do to avoid the same problems. Sandra was delighted to have a customer who wanted to understand the printing process. She gave Jean several booklets and asked her to become familiar with them before she came back to the print shop to see her job in progress. She told Jean that if she could answer these four basic questions, she would be well on her way to understanding the challenges inherent in color printing:

1. What is color?

2. How does the information about color move from stage to stage in the printing process?

3. What factors influence how output color appears to us?

4. What can we do to make color more predictable?

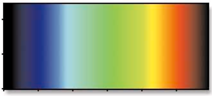
The Color Challenge

Sandra challenged Jean to identify the parts of the printing process in which data that affects color and image quality is created or converted. Jean accepted and called it "The Color Challenge." As you read this book, look for the Color Challenge symbol to see which elements of the printing process Jean identified as major factors in determining color.

What is Color

Jean first turned her attention to color perception. She learned that color is our brain's interpretation of different wavelengths of light. But, what is light? Light comes from the sun. The sun emits streams of energy in the form of billions (and billions) of electromagnetic radiation waves of different sizes. In the middle of the range of wavelengths is a small band that we can see with our eyes - **visible light**.

Visible Color Spectrum, Ultra-Violet to Infra-Red



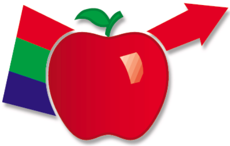
Most of the time, this band of electromagnetic energy appears to us as **white light**. White light is a continuum of wavelengths discernable to our eyes as seven distinct colors: red, orange, yellow, green, blue, indigo, and violet. Sir Isaac Newton discovered that a **prism** can be used to split white light into these discernable colors.

How Our Eyes See Color

As an artist, Jean had always been adept at choosing and mixing colors, but she never thought about how her eyes and brain worked together to accomplish these tasks. She learned that the perception of color occurs when different wavelengths of visible light enter the eye and stimulate millions of cells on the lining of the retina. The retina contains two types of light sensitive cells called **rods** and **cones**.

Rods can perceive only light and dark, and work best in dim light. Cones are sensitive to only three wavelengths of light: **red**, **green**, and **blue** (RGB). When stimulated by light, cone cells send electrical signals to the brain. The brain processes these **RGB** signals and interprets them as colors.

All objects either **emit**, **reflect**, or **absorb** wavelengths of light. The color that we perceive an object to be depends on the physical characteristics of the object and which wavelengths of light it emits, reflects, or absorbs.



An apple appears to you as red because the surface of the apple absorbs blue and green light and reflects red. The red that is reflected from the surface of the apple reaches your retina, but not the blue and green light.

How can we see purple, yellow, or shocking pink if the cones only respond to red, green and blue light? The answer is that the brain interprets simultaneous RGB wavelengths as other colors. You perceive purple because the brain has translated a particular intensity of red and blue light together as purple.

To some degree, the perception of color is **subjective**. If you ask any two people what color something is, they are likely to have different opinions. Mood, age, capability of the eye, cultural, and psychological factors all affect how we see or interpret colors.

Color Primaries

Jean was very familiar with primary colors – those colors from which all other colors can be made. She also knew that secondary colors are made from combining primary colors. What she didn't know, is that the primary colors that she used for oil painting were not the same as primary colors used for working in other media. In her reading, she identified three sets of primary colors:

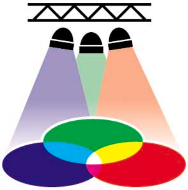
1. Painter's primaries: red, blue, yellow

2. Light primaries: red, green, blue

3. Printer's primaries: cyan, magenta, yellow

Since she already knew about painter's primaries, Jean set out to learn more about light primaries and printing primaries.

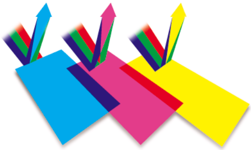
Light Primaries



Devices that emit light such as monitors, televisions, and projection systems use only three colors - red, blue, and green (**RGB**) - to create all other colors. These primaries are called **additive primaries** or **display primaries**. Secondary colors: cyan, magenta, and yellow (CMY), are created by adding two primary colors. Thus, cyan is created from blue and green, magenta from red and blue, and yellow from red and green.

The secondary colors are all lighter than the primaries because when one light is added to another light the result is a "brighter" light. When all three display primaries are added together the result is white light. Thus, white light contains all colors within it. Black is the absence of light, and therefore, color.

Printer's Primaries

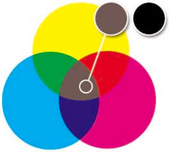


Devices such as printers create images from chemical pigments such as inks, dyes, or toners. These devices use **subtractive primaries**: cyan, magenta, and yellow (**CMY**). The subtractive primaries are also called **process primaries**. The secondary colors are red, green, and blue (RGB). Red is created from magenta and yellow, green is created from cyan and yellow, and blue is created from cyan and magenta. Notice that the additive primary colors are the subtractive secondary colors and visa versa.

	Additive (light)	**Subtractive** (pigments)
Primary	Red Green Blue	Cyan Magenta Yellow
Secondary	Cyan = Green + Blue Magenta = Red + Blue Yellow = Red + Green	Red = Magenta + Yellow Green = Cyan + Yellow Blue = Cyan + Magenta

Recall that in the case of emitted light, color was created when lights were added together. Subtractive color works in a different way. Process colors are created from light **reflected** from a surface. Pigments absorb (**subtract**) some colors and reflect others. Seeing a color in a pigment, such as red, means that red light has been reflected and the other RGB colors of light (blue and green) have been absorbed or subtracted by the surface.

Secondary process colors are all darker than the process primaries, because when you add inks, dyes, or toners to one another, the result is a darker pigment. When all of the subtractive primaries are added together the result is **black** pigment. Thus, black pigment contains all colors within it (all light is absorbed, none is reflected). White is the absence of pigment (no light absorbed, all light reflected).



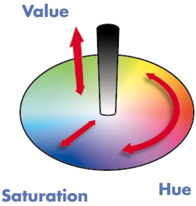
In reality, the imperfections in inks, dyes, and toners make the combination of CMY result in a color more like muddy brown. To compensate, **black** is added to the three subtractive primaries to yield **CMYK**, where "K" stands for black. CMYK are the colors of the four color process.

During the printing process, color pigment is laid down on the surface in patterns of tiny dots. Colors other than the primaries are created by varying the size and the position of dots of primary colors.

Given the different type of equipment used during the printing process – light emitting devices like monitors, and pigment producing devices like printers, Jean saw a challenge for matching colors between different kinds of devices.

Characteristics of Color

Jean was on familiar ground again when she reviewed the characteristics of color. Here are the terms used to describe colors.



The name we give to a color, such as green, orange, or purple, is that color's **hue**. Any given hue can be made lighter or darker and that is called a hue's **value** or **brightness**. Sea green and pale green are both values of the hue green. When you add white to a hue it is called a **tint**. When you add black to a hue it is called a **shade**.

A hue can range from its most colorful, or most intense, to grey. This range is the color's **saturation**. Highly saturated colors are at their most colorful. **Desaturated** colors are closer to grey.

Not all colors have hue. White, black, and all shades of grey are called **neutral** colors. The color space model shown above depicts three dimensions: hue, value, and saturation.

1.	Our cone cells allow the brain to receive signals corresponding to which of the following colors?	a. Red b. Blue c. Green d. Yellow e. Magenta
2.	True or False? An apple appears to us as red because red is reflected to our eyes and blue and green are absorbed by the surface of the apple.	a. True b. False
3.	Devices that emit light use which kind of primaries?	a. Additive b. Subtractive c. Painters d. Secondary
4.	The secondary additive colors are the same as the subtractive primaries. They are:	a. Red b. Magenta c. Green d. Yellow e. Cyan
5.	The brightness or darkness of a color is called its ______________.	a. Hue b. Saturation c. Value d. Tint e. Shade

Review One answers: 1: a, b, c; 2: a; 3: a; 4: b, d, e; 5: c

Design and Layout

After reading the booklets that Sandra gave her, Jean visited the print shop and got a chance to see her own job in progress. She asked Sandra what type of printing device would be used to print the final brochure. She wanted to understand the type of pigment used and the color primaries that would be involved. Sandra suggested Jean describe the requirements of the brochure, and she would explain her rationale for choosing a particular type of printer.

Requirements for the Brochure

Jean explained that the Historical Society wanted to print small quantities of the brochure. They planned to update the brochures quarterly with new programs and schedules. They reasoned that if they printed only two or three hundred at a time, they would not create a large and costly inventory of old brochures.

Sandra determined that the best printer for the job was one of the print shop's color xerographic production printers (laser). She explained to Jean that laser printers require no costly film or platemaking inherent in the offset printing process. With a laser printer, the job is sent directly to the printer from the PC. Offset printers are better suited to color jobs requiring 10,000 impressions or more.

Producing the brochure on a laser xerographic printer involves these steps: Planning, Design, Layouts, Proofing, Printing, Finishing, and Distribution. Jean did not study all of the phases in detail; only those that dealt directly with color reproduction.

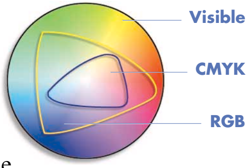
In her initial reading on all of the printing phases, Jean uncovered at least six places in the printing process in which color information would be converted, manipulated, or approved. They were:

1. Scanning to a digital image
2. Viewing the digital image on a monitor
3. Making color adjustments
4. Creating a print-ready file
5. Proofing the job
6. Printing the brochure

Sandra reviewed the list and said that it covered the basics. She encouraged Jean to begin her research by looking at the limitations that apply to all devices in the printing process.

The Outer Limits of Color Devices

Everything in the physical world that can either perceive or produce color has limitations in its ability to encompass the entire range of possible colors. Each device used in a print process has its own range of colors that it can produce, called a color gamut. The larger the gamut for a device, the more colors it can produce.



The graphic at the right represents the gamut of all visible color and the gamuts of other devices in the printing process. Notice that the gamut of all visible color is much larger than the gamut for any of the color models. The RGB color gamut used by monitors is much larger than the CMYK color gamut used by printers.

Jean quickly deduced the practical implications of this. It is possible to view colors on the monitor that you cannot print on your printer. Conversely, a color created with custom ink may be outside the gamut of colors for a monitor. The gamut for one printer will be different than the gamut for another printer. Therefore, the colors in a document printed on two different printers may not match. This is a significant piece of information in Jean's challenge.

Scanning to Digital Image

Jean wanted to know how her own image of the heron would be converted to a digital file. Sandra explained that they would use a large flatbed scanner. Sandra introduced her to the lead graphic designer, John. John explained that once converted to digital data, the heron could be viewed on a monitor or output to a printer. Jean recalled from her pre-visit reading how scanners work.

The Scanner

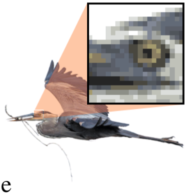
Scanners convert minute sections of a hard copy image into electrical (**analog**) voltages and then into **digital** data. This is accomplished by shining a light on the hard copy original, then using a mirror to reflect the light through a series of red, green, and blue filters.

Light filters allow only the color of light that is the same color as the filter to pass through. After passing through the filters, the varying intensities of red, blue, or green light are recorded as varying intensities of electrical (analog) energy. Converter hardware then changes the analog data to digital data. This analog to digital conversion is known as **sampling**. When the conversion is complete, the result is a digital image file.

There are several types of scanners, each using different types of analog/digital converter hardware. The popular and inexpensive **flatbed scanner** uses Charge Coupled Devices (**CCDs**). The more expensive and higher resolution **drum scanner** uses a technology called Photomultiplier Tubes (**PMTs**).

Jean guessed as soon as she learned about the RGB filters that scanners use an RGB or additive color model. Jean wanted to know how the color was recorded in the digital image file.

The Digital Image



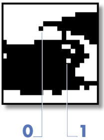
When an image is captured in digital form, the result is a pattern of squares that touch each other. These are called picture elements, or **pixels**. All the pixels together are called a **bitmap**. A digital image file also contains information about the **resolution** at which it has been scanned and its **bit depth**.

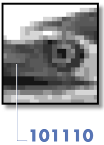
A pixel can be either black, white, a shade of grey, or a color. The color of a pixel is stored numerically in **bits**, which are binary data (either 1s or 0s).

Jean learned that the total number of possible colors or shades a pixel can be is determined by its bit depth. Bit depth is determined at the time of scanning by the operator. Every scanner has a bit depth range within which it can operate.

A black and white image can be expressed using only one bit per pixel, bit depth = 1. Each bit is either 1 or 0 (black or white.) To express more colors on a monitor, more bits are needed. Four bits per pixel defines up to sixteen colors. Eight bits define up to 256 colors, and so on until we get to 36 bits, which can define billions of colors.

Sandra said that it was a good practice to use the least number of bits that would provide good results throughout the printing process. Jean wondered why she would not always go for the most bits? Sandra explained. More bits isn't necessarily better. It can be wasteful. The more bits you need to define colors, the bigger the size of the file. The bigger the file, the more memory and resources used. Bigger files slow each device in the process.





Another important factor in choosing bit depth at the time of scanning, is whether the viewing and output devices are capable of handling the larger bit depths. If not, the data for higher bit depths will simply be reduced to lower bit depths for viewing and printing.

Scanner and Image Resolution

When an image is scanned the data is recorded or **sampled** in some number of increments per inch. This is the image's **scanning resolution** and generally recorded as **pixels per** (linear) **inch** (ppi) of output. The higher the scanning resolution, the more pixels there are per inch. The more pixels per inch, the clearer the image.

A scanner's resolution can be adjusted by the operator up to the limits of the device. Scanning ppi ranges from 72 ppi to 3600 ppi. Like higher bit depth, higher resolution increases the size of the file and may be wasteful if subsequent devices have to convert the higher resolutions into lower ones for output.

Viewing the Image on a Monitor

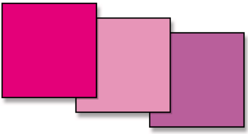
After Jean's image had been scanned into a file at a resolution and bit depth appropriate to the output device, it appeared on the monitor. Jean asked if the monitor gave an accurate representation of the image. John responded to this in detail.

Devices that emit light such as monitors and televisions use an **RGB** or **additive model** of color to produce images, just like the scanner. Monitors produce color by sending electrical signals to rows and rows of small red, green, and blue phosphors just behind the surface of the glass. RGB phosphors are grouped together in **phosphor triads** or dots. The spectrum of colors that you see are created from varying the proportions (intensity) of red, green, and blue phosphors. Recall that your eyes see only red, green, and blue, but your brain mixes these into other colors.

Upon hearing this, Jean noted that the technology used to capture her image in the scanner was different than the technology used to view the image. She identified this as an opportunity for colors to shift.

Jean learned that one problem with using RGB models to describe a color is that color is often inconsistent between RGB devices such as monitors, scanners, televisions, etc. Let us look at why this is true and what it means for predicting color.

All monitor manufacturers use the RGB model for producing colors. RGB is **device dependent**, meaning that manufacturers define their own colors for their devices. One manufacturer's red is different than another's. We can see this when we go into a television showroom and notice that the color on the screens are very different. We may even see differences among sets made by the same manufacturer. Monitors can have slightly different color gamuts.

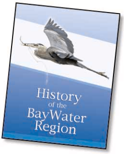


What does this mean for the user? Suppose you have chosen magenta for your company logo as seen on your office monitor. When viewed on the graphic designer's monitor this proportion of colors appears to be hot pink. When you look at the logo on your home monitor it appears more purplish. It makes it hard to predict which color will appear on the final output.

Making Color Adjustments

Jean viewed the heron image on the monitor and was surprised at how large it appeared on the screen. She compared the monitor image to the original and was pleasantly surprised to see that the colors were fairly closely matched. Jean asked John if he could make the grey of the body less blue and sharpen the eye of the heron. She was amazed at how he could alter the image pixel by pixel.

John resized the image and pasted it into the brochure. He then changed the monitor's screen resolution so that Jean could see the whole brochure at once.



Monitor Resolution

A **monitor** has around 72 phosphor triad dots per inch expressed as 72 **dpi**. A **digital image** is created with a certain number of pixels per inch (ppi). The **screen area** of John's monitor is also expressed in **ppi**, but that is not fixed. It is currently set to show 640 x 480 pixels, but he can reset it to show 800 x 600, 1024 x 768, or even 1280 x 1024 pixels.

640x480

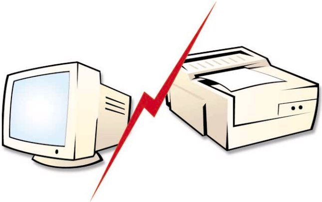
1024x768

The heron was scanned in at a high resolution because John anticipated making a number of color corrections to it and he wanted more pixels per inch to work with. The image looked large to Jean because higher resolution images naturally take up more pixels to show the same image.

John added that monitors also have **bit depth**, which can be adjusted. If your monitor is not capable of showing you a 16-bit image, then you will not see the richness of color that is actually recorded in the image file you are viewing. The file itself is not altered by the capabilities or characteristics of the monitor.

Proof the Job on the Monitor

Jean wanted to know why understanding monitor resolution information was important. John brought it into perspective for her as he began to discuss the proofing phase of the process. Jean knew all about proofing as the opportunity for making corrections before a job's final run. This was also a critical part of the printing process for a silkscreen printing.



John explained that before printing, the first level of proofing in the digital process is done at the monitor. This is called a **soft proof**. Based on what Jean learned earlier about different models of monitor and printers, she knew that the soft proof may not actually simulate the output colors of a printing device. A soft proof can be used to see the placement of text and images and look at overall contrasts.

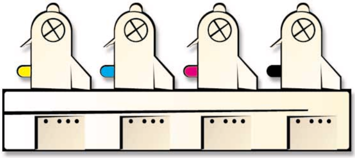
John explained that monitor resolution, at 72 dpi, cannot be used to judge the appearance of an image which will be printed at 300 dpi, 600 dpi, or higher. An image scanned in at a low resolution, such as 72 dpi, would appear sharp and clear on the monitor. But when printed at a higher resolution, such as 600 dpi, the same image may look coarse and blurry.

After Jean approved the soft proof, John was ready to create a **hard proof** for Jean to examine.

PRINTING THE JOB

Create Print-Ready File

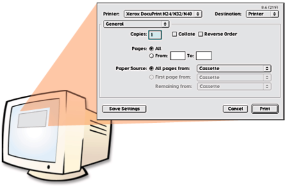
Hard proofs are printed documents created using either the final output device, such as a laser printer, or another device that serves as an interim proofing output device. For example, a color laser or inkjet printer might serve as a proof printer for a job that is ultimately to be printed on an offset press. An actual proof from an offset press, called a **press proof**, would be a very expensive and impractical early proofing device. It is only used at the actual time of printing.



John confirmed that a hard proof from a laser printer would not precisely represent what an offset print job would look like. Jean could see the advantage of running the job on a digital production printer or press where it is possible to get a proof on the same device as would be used for the final print run.

When using a software package such as QuarkXPress™ to create a document, the resulting file is in the unique language of that creation software. However, a printing device cannot read the unique codes of the various software manufacturers. Instead, a print utility, called a **print driver**, converts the proprietary code of the text, color images, and color information on a page to a file containing instructions the printer can understand. This file is called a **print-ready file**.

Two examples of print-ready file languages are Adobe PostScript (PS) and Hewlett Packard Page Control Language (PCL). These files contain all of the information about the page layout, the colors selected, and the color model used.



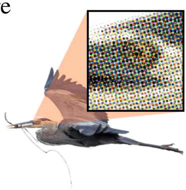
John selected the printer from a list. He chose a nearby desktop inkjet printer to create a color proof using a print driver that was developed by the manufacturer of his printer. To create the print-ready file, John simply selected “print.” The print driver converts QuarkXPress™ code into a print-ready file of PostScript code and submits it to the printer. John noted that using a different print driver might produce slightly different results, even on the same printer.

John printed a proof and handed it to Jean. Knowing that she had done some reading in advance, he asked her if the proof copy was adequate to make decisions about the color of the final output. Jean paused before answering to consider what she knew about how printers worked.

How Printers Create Color

Devices that produce color from pigments, dyes, or toners use a **subtractive model** of color to produce images. These devices lay down varying amounts of subtractive primaries (CMY) on the surface in the form of dots.

Subtractive models for creating color are also **device dependent** because the various manufacturers of printing devices and their associated toners, dyes, or inks, use their own specifications for defining color.



Printing devices can have very different color gamuts. And, as Jean already discovered, printer gamuts can be very different from monitor gamuts. Thus, a shade of green seen on your monitor may show up as a bluish green on your inkjet printer and a turquoise on your color laser printer.

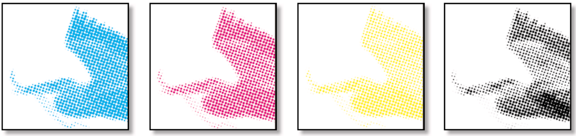
Creating the Raster Image

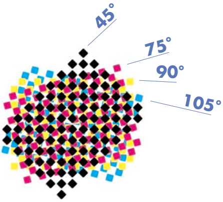
Jean asked John to explain what happens when the print-ready file gets to the printer.

A color printer includes software that reads the print-ready file. The software creates four separate maps or patterns of dots called **raster images** for each page of output. The process of creating raster images is referred to as **raster image processing** or **RIP**.

The raster images are created for each CMYK color. These are called **color separations**. Color separations include all of the color data for the entire page, including text, borders, images, etc.

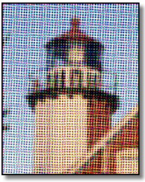
The heron and the photographs to be included in the brochure are all continuous tones images, called **contones**. During the RIP, contones are converted to **halftone** dots for printing which then become part of the color separations.





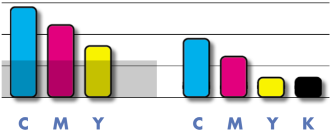
The halftone dots for each CMYK color are laid down at different angles. The result is a blending of dots into a **rosette** pattern, which the eye perceives as continuous. As the paper moves through the printer, each color is laid down in a pattern of dots specified by its respective color separation. When the angles are off, the rosettes do not form. Instead, undesirable dot patterns called **moiré** form on the page.

During the RIP, the printer uses a **color rendering dictionary** (CRD) to convert the RGB values into CMYK data.



Color Adjustments

Adding black pigment to the process not only gives a true black when needed, it also sharpens the appearance of the other colors. It is also used to reduce the amount of CMY pigments needed to create a particular color in a process called **Under Color Removal** (UCR). When a hue requires all three CMY colors for creation, the printer's RIP may use UCR to remove a proportion of the three colors from the formula and replace it with true black.

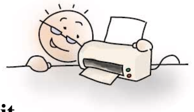


Another related process, **Grey Component Replacement** (GCR), uses black to replace greys that would otherwise be created by using all three CMY colors together.

The RIP calculates the correct amount of black to add, and CMY pigments to subtract for both UCR and GCR. Different RIPs may handle this differently creating yet another opportunity for variation in the printed color.

John asked Jean if she could guess at what bit depth the inkjet printer operated. Jean looked at the beautiful color output and ventured that it must be at least 16-bit.

Printer Bit Depth



John laughed at the thought of his desktop color inkjet as a 16-bit printer. He explained. A printer operates at a **bit depth** level that determines the possible colors that it can print. But, in determining color possibilities for printers, we have to take bit depth into consideration for **each** of the CMYK process colors.

A black and white laser printer is a **1 bit printer**. One bit is adequate for a printer that produces only black dots on paper because, in binary terms, it either produces a dot (1), or it doesn't (0).

John said that his inkjet printer, as well as many laser printers, can create color output at only one bit. "How is that possible?" asked Jean. "I thought you could only create black and white with one bit?" "A monitor requires at least 4 bits to show color." John explained. "But for a printer, color can be created with one bit."

He explained further. For a given image, four halftone separations are created – one for each CMYK color. For each color, the printer either produces a halftone C, M, Y, K dot, or it doesn't. Some laser printers can vary the value of each dot using advanced electronics. This is the printer's bit depth. Only when the dots for all four colors are laid down on the paper do we have the maximum color possibilities for that printer. Therefore, an **8-bit color printer**, such as those produced by Xerox, can produce far richer and more varied colors than a 1-bit color printer.

Jean surmised that bit depth defines the total number of colors mathematically possible for each pixel. This does not mean that each of the colors defined is within the gamut of the device. A pixel may mathematically represent a deep forest green, but that color may be outside the gamut of the monitor or the printer.

Printer Resolution

The quality of an image is strongly influenced by the resolution of the printer. Printer resolution is determined by the maximum number of **dots per inch** (dpi) it is able to print. The more dots per inch, the higher the resolution, and the higher the image quality. Laser printers use a fixed grid (raster) upon which the dots of an image are printed or recorded. Many desktop printers print at 300 dpi or 600 dpi. Production printers print at 400, 600, 800, 1200 dpi, and higher. Finer gradations in tones can be produced by higher resolution printers because their dots are smaller.

150 dpi

300 dpi

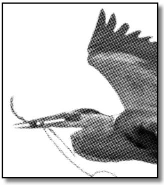
600 dpi

Choosing a Printer: Resolution vs Bit Depth

Jean asked if they were going to use the highest resolution color printer they had to print the brochure. John explained that they actually had slightly higher resolution color printers than the one Sandra selected, but they were only 1-bit printers. In her selection, Sandra considered both resolution and bit depth, especially since Jean was very concerned about color fidelity. The final printer Sandra had chosen combined adequate resolution with 8-bit color capability.

Screen Frequency

John wanted Jean to be aware of another element in their quest for color accuracy and image quality. He explained that clarity and sharpness of an image was not a function of resolution alone. Higher resolutions provide clearer images because more pixels per inch are available to create an image. Also important is **screen frequency**. Screen frequency is the distance between each line of pixels or dots in a raster image and is expressed in **lines per inch** (lpi). Screen frequency is also called **screen ruling** or **line screen**. It ranges from 55 to 600 lpi.



50 lpi

175 lpi

Higher resolution balanced with higher lpi allows for finer gradations in tones, and thus, richer colors. For example, newsprint photos are printed at low resolution and around 85 lpi. They appear coarse. We can actually see the white spaces between rows of dots. At the high end, magazines are printed at around 2400 dpi and 200 lpi. Such images are rich and detailed.

Jean Answers the Question about Proofing

Jean returned to her answer about the adequacy of the inkjet proof. She deduced that it could adequately illustrate the layout and perhaps fonts, but was not an adequate proof of the color of the final laser printer. Here are her reasons:

- The inkjet printer and the laser production printer were made by different manufacturers and their color definitions were device-dependent
- They each use different pigments for creating color - ink vs. toner
- They had different resolutions - 300 dpi vs. 600 dpi
- They had different bit depths - inkjet: 1 vs. laser: 8
- Each printer had a different formula for UCR and GCR

John was quite pleased that Jean had spotted many of the differences between the two printers. He added two more:

- The gamuts for the two printers were different
- Different print drivers would be used to create print-ready files for each printer

Sandra joined Jean and John to review the proof of the brochure. She recalled Jean's story about Sam's project and asked John to print a page of the brochure on a sheet of yellow parchment paper. Jean examined the sheet and was amazed at how difficult the text was to read and how off-color the heron looked against the yellow background.

Sandra then took her to a section of the print shop where she could compare the two outputs under different colored light. Jean remembered from her reading about the effects of the paper's surface and color on the quality of the print.

Paper and Light

As if it were not enough to grapple with the forces of color science and modern technology, we also have to contend with other factors that can affect the color and clarity of printed output. The surface of the paper, the color of the ambient light source, and the subjectivity of our human perception all affect our perception of color.

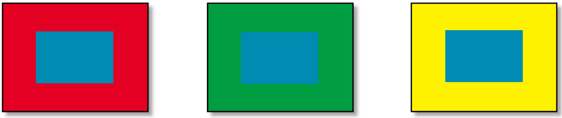
Colored Light

Colors do not look the same under different lighting conditions. The effect of colored light on perception is called metamerism. A color that looks bright and vibrant under white light may look dull and washed out under colored light. It is important to use a consistent light source when proofing colors. If the final output is to be viewed under colored light, it may drastically alter the appearance of the document and should therefore be considered in its design.

Consider these two examples of metamerism. Grocery stores make conscious use of the principle of metamerism and use fluorescent lights with a warmer color cast in the produce section to soften the appearance of the vegetables. They also use halogen lights to brighten the appearance of fruit. Restaurants know that candlelight and incandescent light enhance our skin tones.

Background

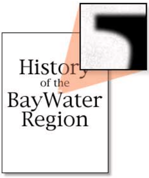
Colors are strongly influenced by their surroundings. We perceive a color differently depending on the background. This is called the **adjacency effect**. Note how different the blue center rectangles below look against different background colors.

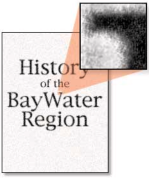


We are less able to differentiate between colors if the colored object we are viewing is small. This is what happens when we buy paint chosen from a paint chip sample card and are shocked at how different it looks when the much larger painted object is viewed against other background colors.

In the printing environment, using color inks, dyes, or toners on colored paper will yield a different result than using the same pigment on white paper. For example, some of the vibrancy of navy blue text will be altered if it is printed on goldenrod paper. Paper with an off-white or grey cast will reduce image quality.

Paper Stock



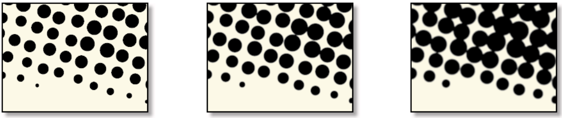


The type of paper stock used has an important effect on the appearance of the final document. Paper finish, brightness, and surface texture alter the perception of color and its sharpness. White paper with smooth surface provides the best base material for printing high quality output. Use of paper with color variations, such as parchment, will alter the image quality. Paper with a rough surface does not absorb toner well and image quality is reduced.

All paper absorbs the ink or toner in such a way that the dots spread out. This effect is called **dot gain** and can alter both the color and image quality of a document. Some paper, such as newsprint, absorbs a great deal of the ink.

This is what happened to the fine black lines that were part of Sam's signature brush stroke. Dot gain caused them to become larger and bolder – they were no longer subtle.

A few of the causes of dot gain are paper absorbency, ink or toner quality, and capabilities of the printing device. An experienced designer can work with the print shop to anticipate and compensate for dot gain.



The Secret Weapon

Sandra asked John to print a proof of the brochure on the final output production printer. She brought the proof back for them to review and compared it to the inkjet proof. Jean compared the two proofs to the colors on the monitor and to the original. After all that she had read about the factors that might cause the colors to vary, Jean was astounded that the colors were very closely matched!

Both Sandra and John laughed at Jean's amazement. "It is time to tell you about my secret weapon," said John. "I think I know what it is," replied Jean, "Color Management." "Right!" said John.

1.	The total range of colors that a device can reproduce is called its ________.	a. Saturation b. Visible light c. Prism d. Gamut
2.	A bitmap image is made up of small elements called:	a. Tints b. Primaries c. Pixels d. Resolutions e. Shades
3.	True or False? Monitors and printers use device-dependent color, meaning that the manufacturers determine how each color appears to us.	a. True b. False
4.	The total number of color possibilities that a pixel can have is determined by the ___________.	a. Bitmap b. Resolution c. Bit Depth d. Secondary colors
5.	The four-color printing process uses which colors?	a. Red b. Magenta c. Blue d. Yellow e. Black f. Cyan

Continued...

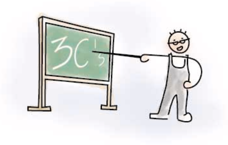
6.	The process a printer uses to interpret a print-ready file and create raster images in each of the toner colors is called the _____________.	a. Desaturation b. RIP c. Press proof d. Line screening e. UCR
7.	The four maps of the dots required for each color in the four-color process are called the _____________.	a. Color Separations b. Visible Light c. Line screen d. Color gamut
8.	When a colored light hits an object, our perception of the color of that object changes. This is called _____________.	a. Metamerism b. Adjacency effect c. Dot gain d. Saturation

Review Two answers: **1: d; 2: c; 3: a; 4: c; 5: b, d, e, f; 6: b; 7: a; 8: a**

If we consider all stages in the printing process in which color can be altered, it sounds almost impossible to get the color we want! Realistically, it is impossible to have *absolute* control over color. But there are several things that can be done to make the probability of achieving a desired color much higher.

The term we use to describe the steps taken to predict and control color in printing is called **color management**. There are three factors that we can manage to make color more predictable:

1. **Calibration**
2. **Conversion**
3. **Characterization**



John explained that sometimes these three factors are called the "three Cs." He went on to explain each of the factors of color management separately.

Calibration

One of the elements in the unpredictability in output colors is a deterioration in the performance of the input and output devices. Over time, input and output devices begin to perform outside the parameters within which they were designed. They require a tune-up much like a guitar requires tuning to produce its best music.

The age of a scanner, the software settings, and the conditions of the analog-to-digital converter technologies (CCDs and PMTs) affect how it performs. The age of a monitor, how the settings are adjusted, and the condition of the phosphors are just a few things that affect how it performs. The type of paper used in a printer, the toners, alignment, registration, and the density of the dots are just a few things that affect how a printer performs.

This deterioration can be fixed by a process known as **calibration**. Calibration means to measure and adjust the performance of a device so that it performs as the manufacturer intended. A properly calibrated machine helps us predict the output colors because we know it is performing as it should as measured against the standards the manufacturer set for that device.

Conversion

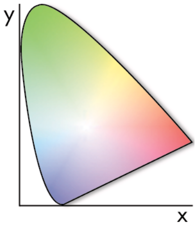
Every time an image moves from one device to another, a **conversion** is done to translate the colors of one device to the colors of another. For example, conversion is done when an image is transferred from a scanner to monitor (RGB to RGB model), and from a monitor to a printer (RGB to CMYK).

Since all device gamuts are different, the conversion process must redefine any colors that fall outside the gamut to fit within it. The colors that appear in a photo will be "compressed" into a smaller gamut that is within the gamut of your scanner. This will happen again as the scanner data is converted into data for your monitor, and again at the printer.

Conversion is done by software utilities within various devices. During the printer RIP process, for example, PostScript can use a Color Rendering Dictionary (CRD) to translate RGB values into CMYK values. Conversion from RGB to CMYK can also be done at the PC.

We know that RGB and CMYK color models are device-dependent and that such models can result in inconsistent color conversions. To overcome this, new, perceptual models of color were created.

Perceptual models are based on how the human eye sees color. The Commission Internationale de L'Eclairage (CIE) was formed to study human perception of color and to set the standards for the measurement of color. CIE standards have become accepted internationally. Two common CIE models are **CIE Yxy** and **CIE LAB**. Each defines a color mathematically. These color models are **device independent** and can be used by any manufacturer as a standard against which color can be measured.



The usefulness of device-independent color models is that they increase the predictability of color as it moves from device to device. This is done by converting, for example, RGB values to CIE color space values, and then into CMYK values.

Characterization

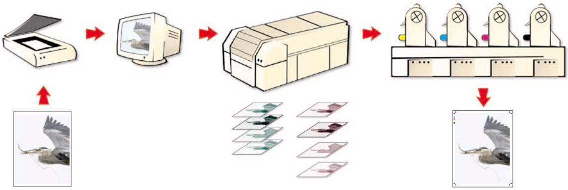
The color gamut of a device is expressed as data in a digital file, called a **device profile**. Characterization is how we describe the color gamuts for devices. For example, EFI ColorXTension for QuarkXPress™ and ColorSync 2™ are applications for the Macintosh computer that contain device profiles for a number of different manufacturers of monitors, scanners, and printers. The profile for a device must be created by the manufacturer for correctly calibrated machines.

Color Management Systems

Color Management Systems (CMS) are software applications that help us do the job of color management. They keep track of the device profiles and help to manage and control the color **conversions** between devices. For a CMS to work properly, each device must be properly **calibrated** and each device must be accurately **characterized**.

Some CMSs work at the level of each application. Some work at the RIP level. The newest advancement in CMS software allows it to work at the operating system level, thereby affecting the definitions of color used by all applications.

A CMS coordinates the device profiles of many different devices so that color is reproduced on screen or in print in a consistent way. It adjusts the color of an image on a monitor to approximate the corresponding color within the gamut of the output device. To do this, a CMS depends on device-independent color models.



Revisiting Proofs with a CMS

We know that proofing a job on different devices can make the job of predicting and controlling color even more difficult for all of the reasons that Jean and John cited earlier. Having a Color Management System operating in the background adjusts color as you view it on the monitor to match output. It also adjusts the colors of your proof printer output to match final output. With a CMS, making decisions based on proofs created on different devices yields more satisfactory results.

John explained that the CMS used by the print shop was working behind the scenes to assist in the process of color matching. This is why Jean's proof print matched the final output so closely.

1.	The term we use to describe the steps taken to predict and control color in printing is called _______.	a. Raster image processing b. Color management c. Under color removal d. Four color process e. Metamerism
2.	True or False? Using color management systems that run at the operating system level of our computers allows us to control printer color with 100% certainty.	a. True b. False
3.	Match the definition with the term: 1 Calibration 2 Conversion 3 Device profile 4 Device-independent model	a. The translation of the colors of one device to the colors of another. b. A file describing the color gamut for a device. c. Measuring and adjusting the performance of a device so that it performs as the manufacturer intended. d. A way of viewing the color spectrum based on the way humans perceive colors.
4.	True or False? A Color Management System can improve color consistency for both soft proofs and hard proofs.	a. True b. False
5.	Select all that apply. Which of the following can affect a monitor's ability to create color?	a. Age b. Phosphor condition c. UCR d. Setting adjustments e. RIP

Review Three answers: 1: b; 2: b; 3: 1c, 2a, 3b, 4d; 4: a; 5: a, b, d



Jean recalled Sam's assumption that the printer had simply done a poor job of picking out the colors for his job. She is now familiar enough with the color printing process to understand the complexities of color matching and knows exactly where in the printing process color can go astray.

Here is Jean's answer to the Color Challenge. She lists here the specific stages in the printing process where color is approved, manipulated, converted, and viewed.

1. Perception of color is somewhat **subjective**. Mood, age, capability of the eye, cultural, and psychological factors all affect how we see colors.

2. Scanners, monitors, and printers use **different technology** for creating color. Scanners use CCDs or PMTs to record color data. Monitors use phosphor triads, and printers use dots of toner, dye, or ink to create color.

3. Scanners, monitors and printers use **different models** for creating color. Monitors and scanners use an additive, RGB model for light, and printers use a subtractive, CMYK model for pigment.

4. Manufacturers use their own definitions for creating color. The colors seen on monitor and printers are **device dependent**. Device dependent models are often inconsistent between devices.

5. Each device has a range of colors it can produce called a **color gamut**. This range defines the limits for that device. The vivid blue seen on your monitor may be outside the color gamut of your printer. The fabulous color of your orange T-shirt may not be a color that your monitor can create.

6. The **bit depth** of an image determines the number of colors available to be assigned to each pixel.

7. The **resolution** of your input devices will affect the clarity of the image and how many pixels there are to receive color. The resolution and bit depth of the output device likewise affect clarity and color possibilities.

8. An image may undergo **color adjustments** during the print process.

9. The **line screen** of the scanning device and the output device is a factor in creating the total color possibilities for a given image.

10. The **conversion** of an image's color, bit depth, and resolution for each succeeding device in the production print process may cause variation from the original colors. This happens when a **print driver** is used, and at the **RIP**.

11. The color of the output will be affected by the application of **Under Color Removal** and **Grey Color Removal** formulas.

12. The devices in the printing process have to be properly **calibrated** so that they consistently yield their intended color output.

13. **Printer bit depth** plays a role in color output. The greater the bit depth, the more colors available.

14. The **paper color** can affect the appearance of color images and the color of text on the page.

15. **Paper texture** affects the clarity of the text and the appearance of the colors on the paper.

16. The **light** of the surrounding area influences how the colors appear to us.

Setting Expectations

After Jean's brochure was printed and ready for distribution, Sandra asked her what she thought was the most interesting thing she learned from her experience in the print shop. Jean responded, "The many factors in color reproduction that can yield unexpected color results. And that these are no fault of the operator, manufacturer, or software."

Sandra nodded and added, "The best defense against unpredictable color is an understanding of the complexities of the color printing process and exerting influence over the points at which you do have control." Color management is the best answer we have for creating predictable color and involves:

1. **Calibrating** devices so that they work at peak performance.
2. **Converting** the data when color moves from device to device using device-independent models.
3. **Characterizing** the color gamuts of each device, precisely.

Color Management Systems are an evolving breed of software applications. For now, they give us the best control we can get. In the future, we may have true What-You-See-Is-What-You-Get (WYSIWYG) color selection and printing.

A Happy Ending

Jean met Sam the next day at the regional art gallery. Sam told Jean that the Historical Society wanted to use his painting on another brochure, but was thinking of turning them down. She then showed him a copy of her brochure. He was very pleased that her experience had been so good but was curious to know how she managed to get such good results. “I took the Color Challenge.” she told him. “I’ll send you some material to read and give you the name of a good printer.”

The following resources were used in the creation of this book.

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8. *From Design to Distribution in the Digital Age*, Agfa, 1999

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