Module 1–
Color Printing Fundamentals

Overview

This module describes the basics of color printing and imaging technology. By the end of this module, you should be able to identify and define basic color printing terms. You should also be able to identify the functions of ColorSync 2.0 and Apple Contone Compression Technology, the new color imaging technologies that support Apple color laser printing.

The Skills Checklist (next page) lists the skills you should be able to demonstrate by the end of this module.

Equipment Needed

- Recommended: Color monitor set to 256 colors (for best on-screen viewing of illustrations in this module)
- Paper and pencil (for exercises)

Skills Checklist

The Skills Checklist (below) lists the skills you should be able to demonstrate by the end of this module; if you think you can already demonstrate the skills, try the Exercises. If you pass the Exercises, you should be able to pass the portion of the course test that covers these skills. (The course test is found on this CD.)

Skill	Where Practiced
Identify or define the following basic color imaging terms: –RGB –CMYK –four-color printing process, –color separation	Exercise 1
Identify or define the following color matching terms: –color matching –color management system –CIEXYZ –color gamut –device profile –embedded profile –channel –interchange space	Exercise 2
Identify the following Apple technologies, their features, and their functions: –ColorSync 2.0 –Apple Contone Compression	Exercise 2

Representing Colors on Screens and Pages: Basic Color Terms

The explanation of color imaging in the following pages is a simplified summary of some very complex ideas from the field of color science. You will not become a color scientist by reading this module, but you will get a basic understanding of color imaging technologies, which will help you understand color printing problems and answer users' questions about them.

RGB and CMYK

In modern computer systems, there are basically three types of device that represent colors:

- Input devices (such as scanners and digital cameras)
- Display devices (such as monitors and flat-panel screens)
- Output devices (such as printers and film recorders)

All these devices have different ways of representing colors. Monitors use Red, Green, and Blue light (RGB) to create all the colors they can represent; they are limited to combinations of the red, green and blue phosphor dots on their screens. Scanners also use the RGB method to define colors: They read the amounts of red, green, and blue light reflected from an image and then convert those amounts into digital values.

Printers use the CMYK method—a combination of Cyan (light blue), Magenta, Yellow, and blacK pigments (which could be ink or toner or wax or any other substance)—to create the colors they print. ("K" is used for black, because "B" could be confusing: It could mean "blue" or "black.") Theoretically, cyan, magenta, and yellow could be combined to produce black, but in practice they usually produce a muddy brown, so black is added for better output.

Optical Illusions

Monitors, scanners, and printers cannot produce all the colors of the natural world. Natural colors are produced by many different frequencies of light, whereas colors produced by monitors or printers are combinations of three or four pure colors (RGB or CMYK)—that is, three or four pigments or frequencies of light. Any color except those three or four pure colors can only be simulated—in other words, it's an optical illusion.

For instance, the color orange is produced on a monitor by placing tiny dots of red and green light next to each other. To produce the same (or a similar) orange, a printer places magenta and yellow toner dots next to each other (see Figure 1-1.) The actual work of combining the dots of red and green—or magenta and yellow—into an impression of orange is done by the viewer's eye and brain. (A similar mental process allows us to combine the patterns of dots in halftone photographs, like those in newspapers, into the impression of a continuous image.)

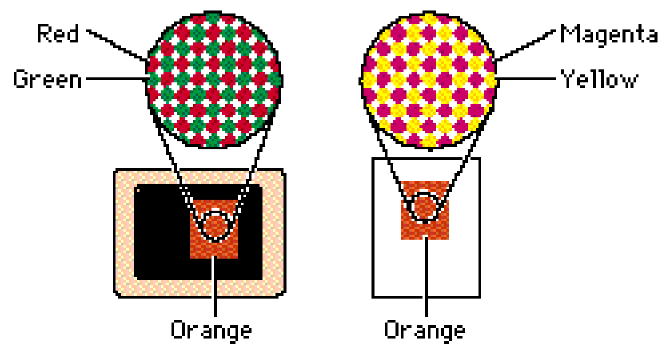

Figure 1-1: Orange on a Monitor and on a Printed Page

Color Separations

In any four-color printing process (whether on a laser printer or a printing press), each color is printed separately. In color press printing, separate printing plates are used for each color of ink. In the Apple color laser printer, each toner color is applied to the paper in a separate printing operation.

In the color laser printer, color image data sent from a computer is analyzed and reconstructed in printer RAM as four separate pages: One page for all the magenta pixels that will be printed, one for the cyan pixels, one for the yellow, and one for the black. These single-color pages are called color separations. Each color separation is printed in turn on the same piece of paper, resulting in the final full-color image. Here's how it looks (Figure 1-2):

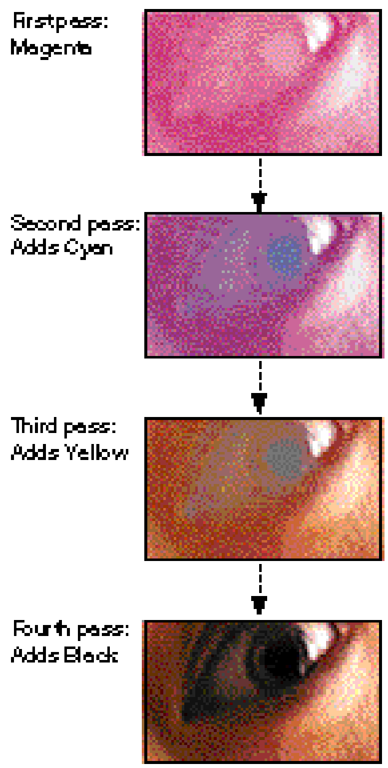

Figure 1-2: Color Separations

Exercise 1: Basic Color Terms

If you are reading these exercises on screen, get a piece of paper and a pencil. Try to answer the following questions from memory. The answers are given at the end of the exercise. (Don't worry—the material gets more challenging after this.)

1. Match the following terms with their definitions.

Terms	Definitions
1. RGB	A. A single-color page printed as one of the layers in a multicolor printing process
2. CMYK	B. A printing process that uses four colors of ink or toner
3. Color Separation	C. The primary colors used in four-color printing
4. Four-color printing process	D. The primary colors used in monitors

2. A single-color page printed as one of the layers in a multi-color printing process is a

   A. Color gamut
   B. Color separation
   C. Halftone page
   D. Page profile

3. A scanner is a

   A. Color input device
   B. Color output device
   C. Display device

Answers to Exercise 1

1. Match the following terms with their definitions.

Terms	Definitions
1. RGB	D. The primary colors used in monitors
2. CMYK	C. The primary colors used in four-color printing
3. Color Separation	A. A single-color page printed as one of the layers in a multi-color printing process
4. Four-color printing process	B. A printing process that uses four colors of ink or toner

2. A single-color page printed as one of the layers in a multi-color printing process is a

   B. Color separation

3. A scanner is a

   A. Color input device

Apple Color Matching and Compression Technologies

Color Matching

The basic problem of color imaging technology is color matching— ensuring that colors produced on one device will be reproduced accurately on another. For instance, how can you ensure that a color image will look the same when viewed on two different monitors? Or that a scanned-in image will appear on the monitor with the same colors that were in the original document? Or—most important for us—that the output of a color printer will match what was shown on the user's monitor?

It might seem easy to accurately reproduce a scanned image on a monitor, since both devices use RGB data, but it's not: Differences in the ranges ("gamuts") and calibrations of each device's colors can lead to visible differences in actual color, even though both devices use the RGB color system. Translating colors from an RGB device to a CMYK device is even more challenging.

Color/Grayscale

Color printers for computer systems often contain some built-in method for translating RGB data from the host computer into CMYK data for the printer engine. Apple has carefully engineered the built-in color transformation capabilities of the Color LaserWriter 12/600 PS to give excellent color matching for most situations. Users without special expertise use this built-in system without knowing it, because it is the default setting of the Color LaserWriter printer driver (LaserWriter 8, version 8.3 and later). In the Print Options dialog box, this option is called Color/Grayscale.

ColorSync 2.0

Good as it is, Color/Grayscale is a device-specific solution: It is limited to the specific printers and color displays for which it was designed. A more general solution would be a color management system, a system that would ensure faithful communication of colors between any devices that conform to its standards. In fact, Apple has just built this kind of color management system into the Mac OS: It is called ColorSync 2.0.

ColorSync 2.0 software is installed in the Mac OS System folder when you install the LaserWriter 8.3 printer driver. As a color management system, ColorSync 2.0 ensures that colors are communicated accurately between any devices that support the International Color Consortium (ICC) standards on which ColorSync 2.0 is based, and as long as compatible application software is used.

Module 3, Color Printing Utilities, will give you practice setting ColorSync 2.0 options on your own Macintosh system. This section introduces you to the basic terms and concepts behind those options.

Device-Independent Color Standards: CIEXYZ

A basic requirement for a color management system is a device-independent color standard—a way of defining colors that represents human color perception in a reliable, reproducible way, so that the colors represented by each device (monitor, printer, scanner, etc.) can be referenced to the same objective standard.

One such standard, now widely accepted, was created in the 1930's by an international organization of color scientists, the Commission Internationale de l'Eclairage (International Lighting Commission), or CIE. The CIE standard, CIEXYZ, maps all the colors perceivable by human beings as points in a three-dimensional color space, with the coordinates X, Y, and Z standing for three imaginary constituents of light that can be combined at different levels to produce all the colors the human eye can see. Theoretically, anyone wanting to define a color in a way that can be reproduced exactly by color scientists anywhere can do so by specifying its X, Y, and Z values in the CIEXYZ system.

Note: There are other CIE color standards, including CIELAB, but all of them are transformations of CIEXYZ. For the purposes of this discussion, we will use CIEXYZ as representing CIE color standards. ColorSync 2.0 supports both CIEXYZ and CIELAB; device profiles (discussed later) specify the CIE standard that ColorSync should use to perform color transformations for specific devices.

Color Spaces and Channels

RGB, CMYK, and CIEXYZ are examples of color spaces. A color space is a way of representing color in terms of the values of a specified number of parameters, called color components or channels. In RGB color space, the channels are red, green, and blue; in CMYK color space, the channels are cyan, magenta, yellow, and black. You can think of channels as the axes of a graph that depicts the color space.

(The parameters, or channels, of a color space are not always what we think of as colors. For instance, in CIEXYZ color space, the values of channels X, Y, and Z are defined by mathematical functions that combine color, illumination, and other conditions.)

ColorSync 2.0 provides for up to eight channels (color components) of input and output color data, twice as many output channels as the Color LaserWriter printer can use. This eight-channel capability is used to support Hi-Fi printing, a high quality printing process done at specialized print shops, which requires from five to eight color separations. (Even with eight colors, any color except the eight colors of toner or ink is an optical illusion. But it's a better illusion.)

Note: A greater number of channels does not necessarily mean that a greater range of colors can be represented: CIEXYZ has three channels and can represent all the colors the human eye can see, while the CMYK space of any particular printer has four channels but can only represent the limited color range provided by that printer's pigments.

Color Gamuts and ICC Device Profiles

No matter how good your equipment is, there is no way to represent the full range of natural colors—produced by the many wavelengths of natural light—by the limited combinations of three or four colors that monitors and printers can produce.

For this reason, color management systems recognize the limitations of each color imaging device. The range of colors a device can produce is called its color gamut.

For each device, ColorSync requires a set of device-specific color information and attributes to match the device's color gamut to the CIE color space. That set of color information and attributes is called a device profile.

The International Color Consortium (ICC), of which Apple is a founding member, has published a cross-platform specification for color device profiles, the ICC profile specification. All devices with ICC-compatible profiles will be compatible with ColorSync (version 2.0 and later), no matter what company manufactures them and no matter what platform (Mac OS, Windows 95, UNIX, etc.) they were produced for.

Where Do Device Profiles Come From?

Manufacturers of ColorSync-compatible devices provide profiles for their products, just as they provide the software that comes with the product. For instance, the Color LaserWriter 12/600 PS printer profile is part of the LaserWriter printer software (version 8.3 and later), and is installed automatically by the Installer disks.

Apple also expects that profiles, like fonts, will be created and marketed by multiple vendors. Several competing or complementary profiles could be created for the same device, optimizing color for different purposes. Profiles simply need to be installed in the ColorSync Profiles folder (inside System/Preferences) to be used by the system. You will learn more about this in Module 3.

Profiles can also be created and recalibrated by special profile-building tools, combinations of hardware and software that allow device colors to be measured and profiles created from the measurements. For example, a sample page can be scanned by a color scanner; software can compare the resulting data with the known sample file to produce a profile for the scanner.

Embedded Profiles

In order to ensure that the color management system knows what device originally created the colors in a given file, the ICC standard requires that all files contain the profile of the device that created them, embedded in the file itself. When a file with an embedded profile—for instance, a file created by a scanner— is displayed on a monitor, ColorSync uses the embedded profile of the originating device (the scanner, in this example) to figure out the colors of the original document. Then it uses the device profile of the monitor to choose the colors available on the monitor that will best match the original colors.

How ColorSync Uses Profiles

ColorSync uses device profiles to translate color data from device to device, choosing the best matches at each step of the process. The profiles allow ColorSync to translate device-specific color data from an input device into the device-independent CIE color space, and then back to the device-specific space of the next display or output device. The CIE space is used as an interchange space: a common ground between devices.

For example, suppose you create an image on a monitor and then send it to a color printer. Figure 1-3 shows what ColorSync does.

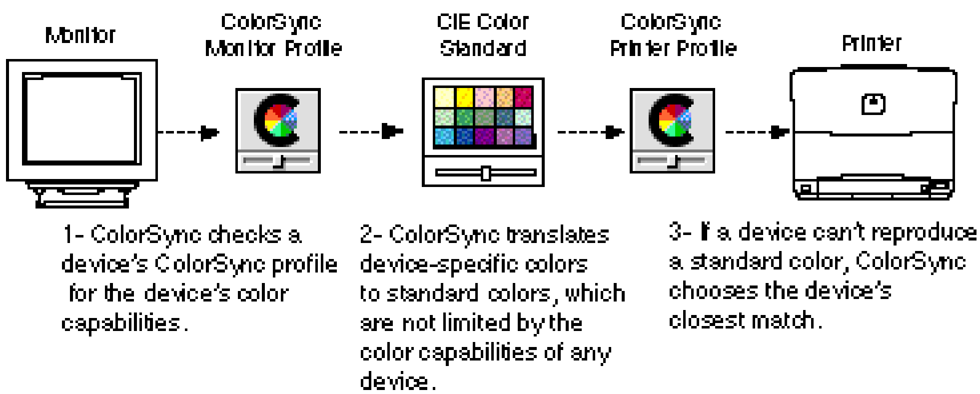

Figure 1-3: How ColorSync Uses Profiles

Gamut Mapping

When an image is received by a particular device, the device can only display those colors that are within its gamut. Devices that use different pigments have different gamuts and cannot reproduce each others' colors exactly. So one of the jobs that the ColorSync color management system performs is to choose the best substitutes within each device's gamut for colors that it cannot produce. This is called gamut mapping.

In Figure 1-4, you can see why gamut mapping is necessary: The largest (horseshoe-like) shape represents the CIEXYZ color space. The shapes inside it represent the color gamuts of various devices and media: a CRT display (large yellow outline), color film (large blue triangle), an offset color press (small green circle), a newsprint press (small red outline). Notice how many of the colors that are visible on the display cannot be reproduced even by a conventional offset printing press.

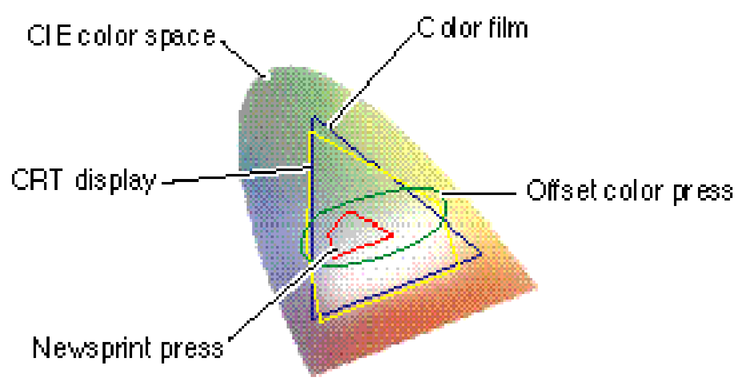

Figure 1-4: Color gamuts

Gamut Mapping and User Perceptions

As Figure 1-4 shows, some screen colors—especially intense, highly saturated colors—simply cannot be reproduced on a color printer: They are outside its gamut. Current applications (as of June ‘95) do not alert users that they are trying to print a color that is outside the printer’s gamut, although ColorSync provides support for out-of-gamut alert messages. So it may fall to you, as a service technician, to judge when a user’s complaint of a “color mismatch” between his screen and the printer is a serviceable problem, or a limitation of the technology. If you think the complaint is unjustified, don’t “swap till you drop”—instead, escalate the problem to your technical support group.

Apple Contone Compression Technology

Apple Contone Compression Technology is Apple's proprietary data compression technology for printing. Together with Color PhotoGrade, another Apple technology, Apple Contone Compression Technology provides near-photographic quality for color images while at the same time reducing the RAM requirements on Apple's printer I/O boards, thus reducing printer cost. Without Apple Contone Compression Technology, the Color LaserWriter 12/600 PS would require 122 MB of RAM for a high-quality letter-size image; with it, only 12 MB is required.

Based on research into what the human eye can distinguish and what it ignores, Apple Contone Compression Technology analyzes page data into interiors and edges, and then compresses interiors differently from edges. Interiors are optimized for tone and color, edges for position, smoothness, and resolution.

Images are treated as interiors, text and lines as edges. This results in sharp text and lines along with excellent color and image quality. (However, text contained within an image is treated as an image; as a result, it may be less sharp than normal text. You will learn more about this issue in Module 4, Print Quality Issues.)

Apple Contone compression takes place in the I/O board of the Color LaserWriter printer. For more details about Apple Contone Compression Technology, see "A Look Inside the Color LaserWriter" on this CD.

Note: Contone ("continuous tone") is the ability to provide 16.7 million different colors per pixel. A 24-bit monitor is a true contone device. Some printing technologies, including the Color LaserWriter, provide "near-contone quality," but are not true contone devices according to the strict definition.

Dropout

In the Color LaserWriter 12/600 PS, Apple Contone Compression Technology is tuned to print a standard letter-size or A4 page using only 12 MB of RAM on the printer's I/O board. If a user attempts to print a legal-size page with 12 MB of printer RAM, some areas of light colors will appear white, and some data may disappear altogether. The name for this effect is "dropout."

The cause of dropout is this: To fit a legal-size image into the same amount of RAM as a letter-size image with only 12 MB of RAM available, Apple Contone Compression Technology uses a higher compression technique and only the C, M, and Y color planes. This causes data loss (dropout).

The solution to dropout is to add more RAM to the printer's I/O board. Adding 4 MB RAM (for a total of 16 MB) will allow legal-size pages to print without dropout. With the additional RAM, dropout does not occur.

Exercise 2: Apple Color Matching and Compression Technologies

If you are reading these exercises on screen, get a piece of paper and a pencil. Try to answer the following questions from memory. The answers are given at the end of the exercise.

A. Fill-in Questions

Fill in the blanks below by choosing the most appropriate term from the following list:

- color matching
- color gamut
- profile
- interchange space
- ColorSync 2.0
- Apple Contone Compression Technology
- channel

1. __________________ helps ensure that colors produced on one device can be reproduced accurately on another device.

2. ___________________ is the color management system built into the new Mac OS software.

3. The ICC standard requires that all files contain an embedded ______________ of the device that created them.

4. The range of colors a device can produce is called its _____________ .

5. _____________ allows the Color LaserWriter 12/600 PS to print a letter-size color page using only 12 MB of printer RAM.

6. A _____________ is one of the color components (parameters, axes) that defines a color space.

B. Multiple Choice Questions

Choose the item that best fits the description or missing portion of the statement.

1. This color standard, developed by the International Lighting Commission, maps all the colors human beings perceive as points in a three-dimensional color space.

   A. CIEXYZ
   B. CMYK
   C. ColorLab
   D. ColorSync

2. ColorSync 2.0 provides for up to __________ channels of input and output color data.

   A. 2
   B. 4
   C. 6
   D. 8

3. This standard requires that all files contain a profile of the device that created them, embedded in the file itself.

   A. CIE
   B. ICC
   C. ILC
   D. RGB

4. A file containing color information and attributes for a device is called a

   A. Channel
   B. Color map
   C. Gamut
   D. Profile

5. This is the name for a device-independent color space that is used as a common ground when transforming colors between input and output devices.

   A. Channel
   B. Color gamut
   C. Interchange space
   D. Profile space

6. Apple's proprietary data compression technology for printing is called

   A. Apple Color Fine Print Compression Technology
   B. Apple Color Photograde Compression Technology
   C. Apple ColorSync Compression Technology
   D. Apple Contone Compression Technology

7. A customer complains that legal size color prints are not printing correctly on his Color LaserWriter 12/600 PS—some areas of light colors are printing out as white, and some information is disappearing altogether. What’s the most likely cause of this problem?

   A. ColorSync 2.0 is not installed in the System Folder
   B. RGB data is not being converted to CIE data
   C. The printer needs more RAM
   D. The colors are outside the printer’s gamut

Answers to Exercise 2

A. Fill-in Questions

1. Color matching helps ensure that colors produced on one device can be reproduced accurately on another device.

2. ColorSync 2.0 is the color management system built into the new Mac OS software.

3. The ICC standard requires that all files contain an embedded profile of the device that created them.

4. The range of colors a device can produce is called its color gamut.

5. Apple Contone Compression Technology allows the Color LaserWriter 12/600 PS to print a letter-size color page using only 12 MB of printer RAM.

6. A channel is one of the color components (parameters, axes) that defines a color space.

B. Multiple Choice Questions

1. This color standard, developed by the International Lighting Commission, maps all the colors human beings perceive as points in a three-dimensional color space.

   A. CIEXYZ

2. ColorSync 2.0 provides for up to __________ channels of input and output color data.

   D. 8

3. This standard requires that all files contain a profile of the device that created them, embedded in the file itself.

   B. ICC

4. A file containing color information and attributes for a device is called a

   D. Profile

5. This is the name for a device-independent color space that is used as a common ground when transforming colors between input and output devices.

   C. Interchange space

6. Apple's proprietary data compression technology for printing is called

   D. Apple Contone Compression Technology

7. A customer complains that legal size color prints are not printing correctly on his Color LaserWriter 12/600 PS—some areas of light colors are printing out as white, and some information is disappearing altogether. What’s the most likely cause of this problem?

   C. The printer needs more RAM

Click here to go to Module 2,

The Four-Color Printing Process