1 Color Printing Overview

Introduction

This chapter provides an overview of color printing with Hewlett-Packard printers. A primary goal for HP color printers has always been WYSIWYG (What You See Is What You Get) color, where the color displayed on the screen while creating a document is the same as the color in the printed document. However, this goal has been very difficult to realize due to a number of factors such as:

- Some colors that can be shown on a computer display cannot be reproduced by a printer.
- The Cyan, Magenta, and Yellow colors used to create the colors specified in a document can differ in hue and quality from printer to printer, even printers from the same manufacturer. Furthermore, the colors produced by a given printer can change over time, due to internal changes as well as temperature and humidity.

Until recently, these and other problems have led HP to approach color matching by presenting a PCL 5 color command set giving users the ability to make both major and minor color print quality adjustments.

However, the emergence of sRGB (standard Red Green Blue) as an international color data standard and the growing sophistication of Hewlett-Packard printers has allowed HP to provide high quality WYSIWYG color documents with a much simpler PCL color command set. Therefore, this manual has two main parts: Chapters 1 through 7 present the latest, simplified PCL 5 color command set, and the appendices describe the command set described in Chapters 1 through 4 as they are supported by the Color LaserJet, Color LaserJet 5, DeskJet 1200C, and DeskJet 1600C printers. Chapters 5 – 7 pertain to both sets of printers.

Working with color documents

A document can be thought of as a series of text characters, vector graphics objects and images. The parts of a document either have color specifications in them, as do color images, or have color specifications applied to them, as do color vectors or text. For color images, the PCL 5 command set provides a way to specify the color format so that the image data can be interpreted correctly. For vector graphics and text, the PCL 5 color commands support the application of a color from a palette of colors.

Each color printed is synthesized from a combination of three colors: Cyan, Magenta, and Yellow. The way the three colors are combined to produce the desired color is called a half-tone, and the PCL 5 color command, Render Algorithm, specifies which half-tone to use for a color. Advances in Hewlett-Packard printers have allowed HP to reduce the number of render algorithms to Best, High, and Low. While the actual implementation of each of these algorithms may vary from printer to printer, HP has determined that the three algorithms are sufficient to produce high quality color documents containing text and graphics.

The colors that appear on a page also have one of two color treatments applied to them:

1 Screen Match (sRGB), which provides the best WYSIWYG color. This is the default color treatment.

2 The Vivid color treatment, which provides access to the entire device gamut (range of colors the printer can produce). However, these colors are less correlated to those shown on a monitor than colors that have had the Screen Match treatment applied.

The following factors form the heart of the PCL color graphics state:

- The palette of colors to be used in a document
- The render algorithm to print the colors
- The color treatment to be applied to each color

Palettes of colors can be referenced by an ID, and so can PCL color graphic states. At any given time there is an active palette to apply colors from, along with a render algorithm and color treatment to be applied to the colors. Palettes and their associated render algorithm and color treatment can be stored and retrieved using a palette ID. When a palette is retrieved and made the active palette, the render algorithm and color treatment stored with the palette are set as the current render algorithm and color treatment.

The PCL language also allows users to use patterns in combination with colors. These patterns and colors can be combined with text, vector graphics, and images to create new, complex graphics objects. The PCL Print Model determines the logical operations (known as ROPs, Raster Operations) used to combine each part of the graphic object.

PCL 5 Color Concepts

This section describes some of the concepts and terminology of color science related to the PCL 5 color commands.

Color

Color is a combination of human physiological and psychological responses to a relatively narrow band of frequencies in the electromagnetic spectrum. The frequencies visible to the human eye are called the visible spectrum. It's useful to understand that color comes both from direct light and indirect light that has reflected from a surface. Reflected light absorbs all but the reflected frequency. The colors seen on a color monitor are combinations of different-colored lights traveling directly to the eye. They are called additive colors since the different colors combine to form the resulting color. The colors seen on a printed material such as paper are reflected from the paper surface, which absorbs some of the light. Colors seen under these conditions depend on the viewing conditions, the amount and color of ambient light, as well as the amount and color of the reflected light.

Color Specifications and Color Spaces

A given color can be described as particular amounts of three light frequencies (red, green, and blue light). For example, equal amounts of red, green, and blue light are perceived as white light. The absence of all three primary light colors is black.

Color can be described in ways other than amounts of red, green, and blue light. Generally, these color specification systems are known as color spaces. For example, The Cyan, Magenta, Yellow (CMY) color space is used to describe colors that are printed by depositing varying amounts of these three ink pigments (Cyan, Magenta, Yellow). The absence of pigment is considered to be white, and the presence of all three is black. The CMYK color space is similar to the CMY color space, but black pigment is used in place of 100% C, M, Y since imperfections in the hues of the C, M, Y pigments yield a dark brown rather than black.

A color specification, then, depends on the color space as well as the values used to describe a given color. Black in the RGB color space is described using the three numbers (0, 0, 0), but in the CMY color space it is described as (100, 100, 100), where the values are percentages of each color.

Color Management and the Standard Red, Green, Blue Color Space

For color to be reproduced in a predictable manner across different devices and materials, it has to be described in a way that is independent of the specific mechanisms and materials used to produce it. For instance, color displays and color printers use very different mechanisms for producing color. Traditionally, operating systems have supported color by declaring support for a particular color space (RGB in most cases). However, since the interpretation of RGB values varies between devices, color was not reliably reproduced across different devices.

The needs of the very high-end publishing sector could not be met by the traditional means of color support, so the various computer operating systems added support for using International Color Consortium (ICC) profiles to characterize device-dependent colors in a device-independent way. They used the profiles of the input device that created an image, and the output device that displayed or printed the image, to create a transform that moved the image from the color space of the input device to that of the output device. This resulted in very accurate color and access to the entire color gamut of both devices. However, it also involved the overhead of transporting the profile of the input device with the image and running the image through the transform.

Note HP’s ICC profiles are available through normal HP software distribution channels. For those who want the additional control available through building their own ICC profiles, there are several vendors of profiling tools available. To provide access to the printer's pure primaries and entire available printer gamut, the Vivid mode may be used when profiling the printer, and subsequently when using the ICC workflow.

However, there are a broad range of users that do not require this level of flexibility and control in an embedded color profile mechanism. Instead it is possible to define a single, standard default color space for exchange and interpretation of color data. Additionally, most existing file formats do not support color profile embedding, and may never do so. There is also a broad range of uses that actually discourages people from appending any extra data to their files. The sRGB color space addresses these issues.

The sRGB color space maintains the advantage of a clear relationship with ICC color management systems while minimizing software processes and support requirements. Since the image is in a known color space and the profile for that color space is included within the operating system and display application, this enables end-users to enjoy the benefits of color management without the overhead of larger files. Application developers and users who do not want the overhead of embedding profiles in documents or images should convert them to sRGB. While it may be that profiles buy slightly higher color accuracy, the benefits of using a standard color space far outweigh the drawbacks for a wide range of users. The migration of devices to support the standard color space (sRGB) natively will further enhance the speed and quality of the user experience.

The international standard color space sRGB (IEC 61966-2-1) is designed to complement current color management strategies by enabling a simple, robust method of handling color in the operating systems, device drivers and the Internet. This solution provides good quality and backward compatibility with minimum transmission and system overhead. Based on a calibrated colorimetric RGB color space well suited to cathode ray tube (CRT) displays, flat panel displays, television, scanners, digital cameras, and printing systems, the sRGB color space can be supported with minimum cost to software and hardware vendors. The four major technical components of the sRGB color space are the standard CRT primaries (HDTV P22 phosphors); the simple gamma value of 2.2, a D65 white point, and its well-defined viewing conditions.

Palettes and Color Selection

The PCL 5 language allows the user to define a palette of colors. Each color is specified by three quantities or values which are interpreted depending on the color space. For example, the color white in an RGB palette is (1, 1, 1) while this set of values in a CMY palette defines the color black. Each color in the palette is accessed using an index number, starting with 0 as the first color in the palette. The largest palette holds 256 colors, which is approximately the largest set of distinct colors the human eye can distinguish under normal viewing conditions.

A color from a palette can be applied to either text or vector graphics using the Foreground Color command. Once the command is invoked the selected color will be applied to all text and vector graphics page marking primitives, and to a certain extent to raster images.

Palettes can be identified with a Palette ID and then stored and recalled as needed. A palette stack mechanism is also supported for the convenience of applications that work well with a graphics stack.

PCL 5 Color Graphics Context

The Palette acts as the focal point of the PCL 5 color graphics context. The color space, render algorithm, color treatment, and pixel encoding mode are stored along with the palette. Therefore, selecting or restoring a palette also restores these values.

PCL 5 Color Mode

The PCL language has four modes or ways of specifying and using color:

- Black-and-White (monochrome) mode is the default mode so that backward compatibility with previous printers is maintained. When the printer is turned on it has a 2-entry palette containing the color white at index 0 and black at index 1. When the printer is reset with an $^{E}{}_{C}$E it reverts to this mode.
- Simple Color mode is entered with the Simple Color command, which creates one of three fixed color palettes:
  - A monochrome, two-entry palette with white at index 0 and black at index 1.

- An RGB, eight-entry palette with the following colors starting at index 0: black, red, green, yellow, blue, magenta, cyan, and white.
- A CMY, eight-entry palette with the following colors starting at index 0: white, cyan, magenta, blue, yellow, green, red and black.

- PCL Imaging mode is entered with the Configure Image Data command that creates a programmable palette of a programmed size. This palette can be programmed using the color component and set index commands.
- HP-GL/2 Imaging mode is entered when HP GL/2 mode is entered and the initialize command IN creates a programmable palette that is shared between PCL and HP-GL/2.

Any and all of the modes can be used on a page. For example, you could enter the Simple Color mode to print a headline and bar chart, PCL imaging mode to print a photographic image, and Black-and-White mode for the text on the page. Each mode is described in more detail in Chapter 2. “Using Color Modes.”

PCL 5 Raster Images

Monochrome PCL 5 raster images are made up of a series of zeros and ones. A one indicates that a black dot should be deposited, a zero indicates no dot, letting the white background show through. A one-inch wide image with a resolution of 600 dots per inch (DPI) has 600 consecutive zeros and/or ones, which represent a horizontal slice through the image starting at the left edge of the image. This slice is known as a raster row. For an image one inch high and one inch wide, at 600 dpi there are 600 hundred rows of 600 zeros and/or ones. Color raster images follow the same conventions with this major exception: the representation of a dot is changed from a single zero or one to a color specification (a pixel).

Pixels and Pixel Encoding

Raster images can be thought of as being composed of a series of pixels (picture elements). In the case of monochrome raster images, a pixel is a single bit which takes on a value of zero or one. In color images a pixel is essentially a color specification. However, there are several ways of specifying a color, and how the color is specified is called the Pixel Encoding Mode (PEM).

The PCL 5 color command set supports several Pixel Encoding Modes. The PEMs are categorized first by whether the pixel is an index into a palette, or a color specification. The other PEM categorization is whether the pixel data is divided into planes and transferred one plane at a time or is transferred in sequential order. There are four supported Pixel Encoding modes:

1 Indexed by Plane

2 Indexed by Pixel

3 Direct by Plane

4 Direct by Pixel (also known as 24-bit direct).

For example, the format known as direct by plane, uses a 3-bit pixel where the first bit indicates the presence or absence of a red dot, the second a green dot and the third a blue dot. The data is still arranged in rows, but all the red data is sent, then the green and finally all the blue. The example below represents the commands to transfer an image with the direct by plane PEM. The underlined bits, while transferred separately, are logically from the same pixel.

Ec*b#V	row 1	plane 1 (red)	b1	b1	b1	**b1**	b1	b1...
Ec*b#V		plane 2 (green)	b2	b2	b2	**b2**	b2	b2...
Ec*b#W		plane 3 (blue)	b3	b3	b3	**b3**	b3	b3...
Ec*b#V	row 2	plane 1 (red)	b1	b1	b1	b1	b1	b1...

The direct by pixel PEM uses only the row transfer command. Each pixel is composed of three bytes, one byte per component of the color specification. All the bytes of a given pixel are transferred before the next one is transferred.

Ec*b#W	row *x*	b1	b2	b3	**b1**	**b2**	**b3**	b1...

The *indexed by pixel* PEM is similar to the direct pixel PEM but the pixel occupies at most one byte and is an index into the current palette.

The *indexed by plane* PEM is similar to the direct by plane PEM except the pixel's value is an index into the current palette. The use of this mode is discouraged due to the extra processing required to combine the bits from each plane into a single number, which is then used as an index into the current palette.

Well-Behaved Raster

PCL raster images are processed most efficiently when the height and width of the image are specified before the Raster Start command begins an image data transfer. Furthermore, the entire image should be transferred before using the End Raster command to end the image. If the image is broken into pieces, certain print artifacts such as lines or squares can appear in the image. These can occur when “nearest neighbor operations” are applied to pixels that appear to be at the edge of an image, but are really inside an image that has been artificially broken up into smaller images.