A Look Inside the Color LaserWriter

Color Without Compromise

Contents

Apple Color LaserWriter Overview

In the past, color laser printing technology has required users to make the difficult and complex choice between quality output and affordability. With the Apple® Color LaserWriter® 12/600 PS, Apple's innovations and breakthrough technologies bring to the market what until now was unattainable:

- Great quality output
- Easy set-up and use
- Fast printing
- Affordable pricing

Until now, the gap between affordable and high-quality machines—not only in terms of price but also simplicity—has been substantial. In designing its Color LaserWriter, Apple's goals were to achieve the professional quality available on machines costing $50,000 to $70,000, make the printer much easier to use than those high-end machines, and sell it for about one-tenth the price, thereby making it both usable and affordable to standard office users. Some of Apple's competitors in this area, on the other hand, have settled for either lesser quality or the equivalent quality at a higher price.

The Apple Color LaserWriter print architecture—in addition to offering *true 600 dpi*—has advanced the state of the art in color laser printing in five areas:

1) Outstanding, near-photographic quality printing and consistent color output with *Color PhotoGrade*™
2) High print quality made affordable by Apple *Contone* Compression Technology
3) Easy setup and maintenance for non-technical users in an office setting—made possible by a print engine and controller architecture that feature:
    - *Mono-component toner* cartridges that do not require separate developer
    - Graphical LEDs
    - Single-sided access to the engine interior
    - Simple jam clearance
    - *Automatic color calibration*
    - Simple connection to an Ethernet network (concurrent TCP/IP, Novell, and EtherTalk®) or bidirectional parallel port for Macintosh®, Windows, and UNIX® users

True 600 dpi - Refers to a whole printer designed to print optimally at 600 dpi. This includes vertical and horizontal resolution, laser dot size, and toner particle size.

Color PhotoGrade - Apple's color print quality enhancement technology, which provides near-photographic quality output.

Contone (continuous tone) - The ability to provide 16.7 million different colors/pixels. A 24-bit monitor is a true continuous-tone device. Some printing technologies, including the Color LaserWriter, provide "near contone quality" but do not qualify according to the strict definition of contone.

Mono-component toner - The color laser technology that reduces the number of consumable items by combining the colored toner particles with the charge-carrying element into one.

Automatic color calibration - The process by which the Color LaserWriter automatically measures patches of toner on the drum and adjusts itself to maintain consistent and predictable printing results.

ASICs - Application Specific Integrated Circuits -Hardware chips designed to accomplish a specific task.

JPEG compression - The Joint Photographic Experts Group, or JPEG, is a lossy compression technique designed to greatly reduce the RAM space required for photographic images.

ColorSync 2.0 - Apple's rearchitected color management system. ColorSync provides superior color matching services to the Macintosh operating system and Color LaserWriter.

4) Excellent performance at high quality—for both color and black-and-white pages—allowing the printer to be shared in an office environment:

   - High-performance Apple-designed controller architecture using three proprietary system *ASICs* that support Color PhotoGrade, Apple Contone Compression Technology, and color-matching acceleration
   - *JPEG* support in the LaserWriter printer driver

5) Added value in Apple's software functionality and unified color architecture:

   - *ColorSync® 2.0*
   - JPEG driver support
   - Desktop Printer extension
   - Printer-based queue

Apple's ability to offer excellent quality, ease of use, and high performance at an aggressive price point is the result of a number of technological breakthroughs. Here are background and details on each of these innovations.

Superior Print Quality with Color PhotoGrade

Apple believes that the print quality standard for color laser printers should be substantially higher than what is currently available from its competitors. Apple's goal has been to introduce a true 600-dpi color laser printer that rivals the quality available on color laser copier/printers costing more than $50,000. The challenge has been to provide this excellent print quality without sacrificing the other requirements of ease of use, speed, and affordability.

Apple's research (conducted by a contracted research firm at Macworld in January 1995) showed that 93 percent of 260 users surveyed preferred the output of the Color LaserWriter with Color PhotoGrade to that of either the Hewlett-Packard Color LaserJet or the Xerox 4900.

Primary colors - The four colors that the Color LaserWriter can print without mixing. These colors are cyan (blueish), magenta (pinkish), yellow, and black.

Secondary colors - These are the three colors that can be created by mixing equal proportions of two of the primary colors. The three secondary colors are red (mix of yellow and magenta), blue (mix of magenta and cyan), green (mix of cyan and yellow).

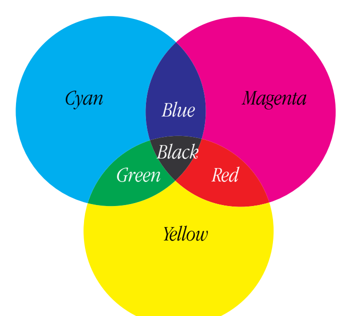
Halftoning - The process of using multiple pixels to create the illusion of more colors or grays.

Pixel - The smallest addressable element of the printer. A 600-dpi printer like the Color LaserWriter has 600-pixels per inch.

Color Printing

Color laser printers typically use four colors of toner—cyan, magenta, yellow, and black (often referred to as "CMYK")— applied in layers, to create color output.

Two of the three *primary colors,* cyan, magenta, and yellow, combine in equal proportions to create red, green, and blue, which are called *secondary colors.* (Black can result from equal saturations of all three primary colors; the practical result of this combination, however, is often a muddy brown color. Apple therefore uses a separate true black color.) Different amounts and combinations of the three primary color toners create the various colors other than black on paper.

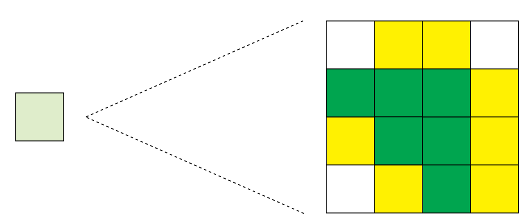


Primary and Secondary Printing Colors

Creating a Range of Colors Through Halftoning

Halftoning is the process of using multiple *pixels* to create the illusion of more colors or grays than the printer can actually output. Color laser printers use various halftoning schemes to create the entire spectrum of colors. The Apple Color LaserWriter uses a unique combination of halftoning techniques to achieve excellent color quality and continuity.

Most color laser printers are bilevel printers, meaning that they are only capable of turning each pixel either on or off for each primary color and black (C, M, Y, and K); they use a combination of different-colored pixels to provide more than the six primary and secondary colors.

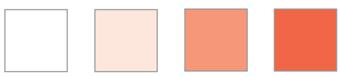


82% Yellow +38% Cyan =Light Lime Green

16 Pixels= 17 Levels/Plane=4,913 Colors

Synthesizing Colors Through Halftoning: This diagram shows how multiple pixels combine to create other colors in what is called a halftone cell. In this example, four yellow pixels and two cyan pixels combine to create a light yellow-green color. Other color variations would result from different combinations.

Halftone cell - An organized collection of pixels that are used together to create nonprimary or secondary colors.



Multilevel

Bilevel

Multilevel Printing Quality

Bilevel Printing Quality

The more colors that a printer can render, the more life-like the output, as shown in the multilevel printing example (top). With too few colors, images become "posterized," with visible transition points between colors, as shown in the bilevel printing example (bottom).

Number of Colors

The 16-element *halftone cell* used in the examples on the previous page can provide just 4,913 colors. Here is the formula for calculating the number of distinct colors a printer can produce.

$$\left[(\textit{number pixels/cell}) \times (\textit{levels of color or gray/pixel} - 1) + 1\right]^3 = \textit{number of colors}$$

$$\left[(\textit{16 pixels/cell}) \times (\textit{2 levels of color or gray/pixel} - 1) + 1\right]^3 = 17^3$$

Calculating the number of colors a printer can produce

The numbers of colors (number of pixels/cell × number of colors or grays/pixel) is taken to the power of 3 because there are three colors or physical layers of color (C, M, and Y). This factor does not include the separate color black.

The Tradeoff: Resolution Versus Number of Colors

It's evident that the number of colors a printer can render is critical to the quality of an image. Another key to quality is the size of the halftone cell. A larger halftone cell can produce more colors but allows less detail and shows larger visible "dots," or "grains" of color, which distract from the quality and content of the image. So, in printing, there's a central trade-off between the number of colors and the cell size; increased cell size makes more colors possible but allows less detail and bigger dots.

Bilevel Versus Multilevel Printing

The formula for calculating the number of colors possible includes the term "levels of color or gray per pixel." Laser printers known as grayscale or multilevel printers, like the Apple Color LaserWriter, can provide intermediate levels of gray or color for each pixel. These intermediate levels are called "gray levels" or "color levels" because they are not fully saturated with color or with black. The advantage of these intermediate steps is that they dramatically increase the number of colors possible within a halftone cell.

If the printer referred to in the previous formulas were capable of four gray levels per pixel (rather than two), the total number of colors possible would increase from 4,913 to 274,625.

Different Halftoning Techniques

A number of different halftoning techniques, or "screens," exist that get more colors from a printer. A screen simply makes use of combinations of pixels to create shades of color or gray. The three most popular types of halftone screens are:

- Dispersed-dot and *clustered-dot halftone screens*
- *Error diffusion* halftone screens (error diffusion is actually one example of a method known as random halftone screening)
- Line halftone screens

Cluster-dot screening - A halftoning method that uses multiple pixels growing from a small to a larger dot as the color gets darker. Cluster-dot screening is characterized by a polka-dot look.

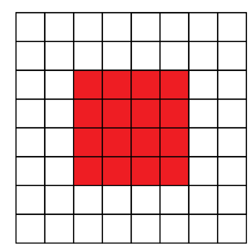
Error diffusion - A halftoning method that calculates the color for each pixel and then, to compensate for any error in color, carries the error to surrounding pixels to make the overall color appear correct. Error diffusion is characterized by a grainy look.

The following section presents the strengths and weaknesses of each of these methods, putting into perspective the advantages of the halftoning system used by the Apple Color LaserWriter.

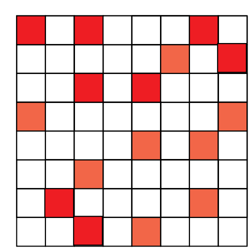
Dispersed-Dot and Clustered-Dot Halftone Screens

Dispersed-dot and clustered-dot halftone screens use a specified pattern of pixels in each halftone cell to represent different colors.

The advantage of dispersed dot halftoning is its apparent higher resolution, which it accomplishes by spacing out the filled pixels. The dispersed dot example treats the entire halftone cell as two mirrored halves: The cell is 8×4 pixels in size but fills as though it were two 4×4 cells.



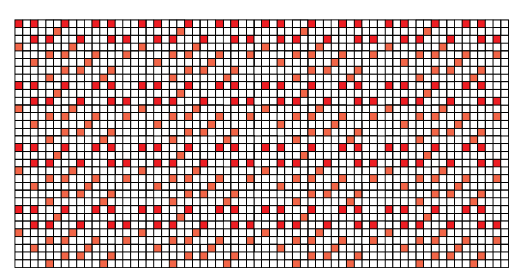
Clustered-Dot Halftone Screens



Dispersed-Dot Halftone Screens

There are several disadvantages to these patterns:

- They don't actually provide any more detail.
- With certain color tones, the interaction of the colored pixels creates distracting visual patterns, which cause users to see patterns of X's, O's, lines, and so on, rather than the colors and content as intended.



Example of Dispersed-Dot Halftone Screen Visual Pattern

Error Diffusion

Error diffusion and other "random" screening methods of halftoning can create the illusion of higher resolution. The error diffusion method calculates for each pixel the difference between the desired color and the nearest color the printer can provide. It then carries this "error value" to adjacent pixels, thereby increasing or decreasing their desired color values. This compensates for the error in color and makes the color over a large area appear correct.

The advantage of error diffusion screens (and other random screens) is that they make images appear to be higher in resolution. However, Apple chose not to use error diffusion in its Color LaserWriter architecture because of several disadvantages:

- Images can appear "grainy" in the light areas where pixels are widely scattered in light areas.
- Printing time can be slow because random screens—particularly those with better, more random algorithms—are very computation-intensive.
- Noticeable repeat patterns, or "worms," can appear if the pattern is less random.

Line-Screen Halftoning

Line-screen halftoning is a variation of cluster-dot screening. Line-screen halftoning offers these advantages:

- It yields high resolution and detail (in the direction across the line) because the line separation can be small.
- It minimizes the effect of registration errors in the laser engine.
- It can minimize mechanical artifacts in the laser engine.

The primary disadvantage of line-screen halftoning is that it must image very thin lines to create light areas. Because this is difficult to achieve on a laser printer, light areas often appear as white dropouts.

Apple's Color PhotoGrade

Color PHOTOGRADE

When it introduced Apple PhotoGrade (with the LaserWriter IIg) in 1991, Apple "raised the bar" in terms of print quality capabilities and expectations. The original PhotoGrade maximized print quality by laser modulation and unique halftone design. The same is true with Apple Color PhotoGrade, which in the Apple Color LaserWriter provides near-photographic color image quality equivalent to the output of a 2250-dpi bilevel printer.

Apple designed Color PhotoGrade to take advantage of the strengths of the Apple Color LaserWriter engine and Apple Contone Compression Technology. Apple's unique and comprehensive expertise in imaging made it possible to distribute technology between *firmware* and ASICs to achieve Color PhotoGrade.

Firmware - Software that resides in the ROM of the printer and is responsible for controlling the operation of the printer.

Because of its effective use of compression technology, Apple Color PhotoGrade can support a variety of halftoning techniques without sacrificing performance.

While many aspects of Apple Color PhotoGrade technology are proprietary, it is possible to discuss six major innovations that contribute to the technology.

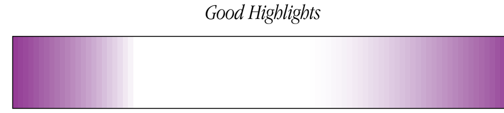
1) Achievable color continuity
2) Line/clustered-dot screening
3) High screen frequency—200 lines per inch (lpi)
4) Screen resolution scaling and filtering
5) Screening matched to compression techniques
6) Tuning for bright, vivid, and pleasing color results

Achievable Color Continuity

Apple selected the print engine for its Color LaserWriter based on its unique capabilities. Apple then conducted a series of tests to ensure that Color PhotoGrade would optimize and extend those capabilities. Just as monochrome print engines, on their own, can't render 256 grays per pixel (hence the need for the original Apple PhotoGrade), color laser print engines can't actually deliver 256 color or gray shades per pixel. A potential problem results: Manufacturers could base their print architecture on the incorrect assumption that a print engine, on its own, will provide 256 levels, while in reality the engine provides far fewer. The quality of images would then suffer due to a flawed print architecture based on an invalid assumption.

Rather than assume that the print engine itself would provide a certain number of levels, Apple conducted experiments to measure how many distinguishable gray shades per pixel the engine could actually achieve. Apple engineers applied these tests using various papers and under various environmental conditions. After determining the precise capabilities of the engine, Apple designed Color PhotoGrade to complement and augment them. This approach provides the customer with uniform and consistent print quality through the full spectrum of colors.

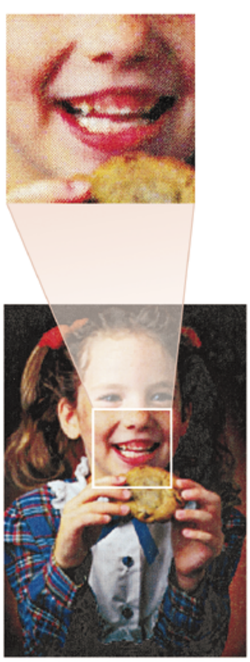
Good Highlights



Poor Highlights

Poor Highlights Versus Good Highlights

72-dpi Image Scaled to 600 dpi without Color PhotoGrade Filtering



Line/Clustered-Dot Screen

Apple Color PhotoGrade features a unique halftone screen design that takes advantage of the best features of both line-screen and traditional clustered-dot screen halftoning methods. It combines these features with the ability to modulate each pixel. The Apple Color PhotoGrade halftone screen design offers three key advantages:

1) In light regions, it behaves like a traditional 141-line, 45-degree, clustered-dot screen, which yields smooth highlights.
2) In darker regions (where other halftoning techniques have difficulty due to registration errors between color planes), it attains the properties of a 200-lpi vertical-line screen.
3) The screen growth of the black plane is in reverse order of the other color planes; this complementary growth results in richer, more saturated colors due to minimal overlap of black pixels with the pixels in the C, M, and Y planes.

Screen Resolution Scaling and Filtering

Apple Color PhotoGrade augments Adobe PostScript™ capabilities by scaling and filtering images prior to halftoning. Often a PostScript printer receives images that are of lower resolution than the printer produces. When this happens, PostScript must scale the image to the proper resolution. For low-resolution images, this process involves simple pixel replication or simple interpolation. (For example, to print a 72-dpi image on a 600-dpi output device, by default PostScript simply replicates the same value multiple times to match the resolution of the printer—in this case, 72 dpi x 8.33 = 600 dpi.) As the example on the left shows, this creates “jaggies” in the image.

To avoid this problem, Apple Color PhotoGrade actually applies an optimal filter when scaling images—both magnifying and reducing—to maintain maximum quality. So low-resolution images, such as those from digital cameras, video capture boards, multimedia applications, and low-resolution Photo CD output, all look much better when printed with Apple Color PhotoGrade than with other printers.

Screening Matched to Compression Techniques

Unlike its competitors, Apple has made sure that its screening and compression techniques—that is, Apple Color PhotoGrade and Apple Contone Compression Technology—work together. Developing both together optimizes performance and quality and ultimately price as well. For example,*Apple Contone Compression Technology* divides a page into 150-dpi blocks; the *rendering* architecture anticipates this block size and can optimize the rendering process accordingly.

Apple Contone Compression Technology - Apple's proprietary compression technology, which dramatically reduces the amount of printer RAM required to print at 600-dpi with near-photographic quality provided by Color PhotoGrade.

Rendering - The process of converting the PostScript data sent from the host computer to compressed data in the memory of the Color LaserWriter.

Tuning for Bright, Vivid, and Pleasing Color

Apple has tuned its Color LaserWriter to produce bright, saturated graphics and text in addition to extremely high-quality photo-realistic images.

Apple maintains that its Color PhotoGrade provides the best overall print quality in the industry—even compared with other printers using the same engine. It offers an excellent balance of fine detail, many colors, consistency, and smooth gradients from light to dark.

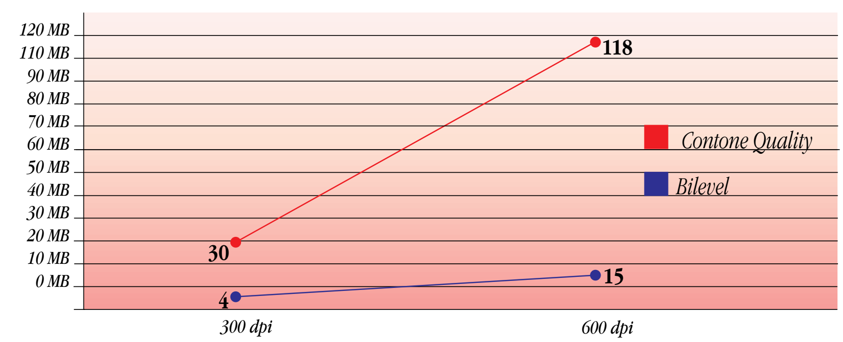
Scan of Comparative Print Sample: HP Color LaserJet

Scan of Comparative Print Sample: Apple Color LaserWriter with Color Photograde

Affordable High-Quality Color: Apple Contone Compression Technology

The Opportunity

Compression is the key to delivering high-quality yet affordable color by reducing dramatically the amount of memory needed to run the printer. Apple Contone Compression Technology makes contone-quality printing capability affordable. As the table below shows, offering contone-quality printing without compression would be infeasible due to very high RAM requirements.



RAM Requirements without Compression

The formula for calculating the number of megabytes of RAM required to store an uncompressed color page in printer memory shows why:

$$\frac{\left(\textit{page length} \times \textit{page width} \times \textit{horizontal dpi} \times \textit{vertical dpi} \times \textit{bits/pixel} \times \textit{number of color planes}\right)}{(8 \text{ bits/byte} \times 1024 \text{ bytes/megabyte})}$$

Calculating the Memory Required without Compression

Apple Contone Compression technology enables Apple to offer superior quality at affordable prices.

Where Compression Takes Place

As the diagram on the next page shows, there are two places in a printer where compression can take place: in I/O and in memory. The Apple Color LaserWriter employs both *I/O compression* and *memory compression*.

I/O compression - The process of compressing data on the host prior to sending it to the printer and then decompressing that data on the printer. The goal is to reduce the amount of data sent to the printer to reduce overall print time and improve overall network performance.

Memory compression - The process of compressing data on the printer so less memory is required in the printer to print a job. The Color LaserWriter utilizes Apple Contone Compression Technology to reduce the memory in the printer from 122 MB to only 12 MB.

I/O Compression

One goal of compression architecture is to reduce the amount of data sent to the printer. The Macintosh LaserWriter driver can send JPEG-compressed images directly to the printer. The printer then decompresses the data and sends it through the standard PostScript interpretation process. This greatly (10 - 30 times) reduces the amount of data that has to be sent over the network. For pages that contain large images, I/O compression is especially effective in reducing printing time and increasing network performance.

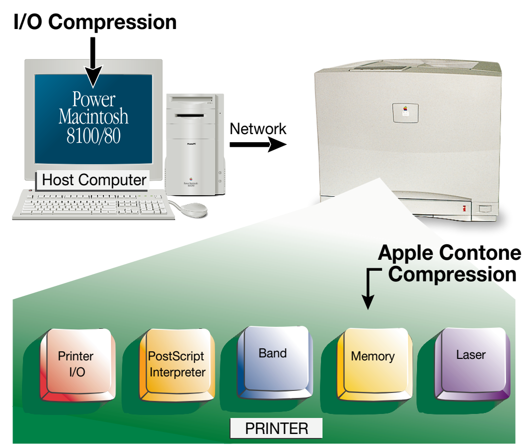
Memory Compression

A great deal of the memory in existing PostScript printers is taken up by the frame buffer. The frame buffer stores an entire rendered page prior to printing. This is necessary because a laser printer can't stop or pause once it has started printing a given page.

According to a "standard" frame buffer model—and without the innovations in Apple Contone Compression Technology—the Apple Color LaserWriter frame buffer would require 122 megabytes of RAM to print a high-quality page. Apple Contone Compression Technology reduces this memory requirement to just 8.1 megabytes.

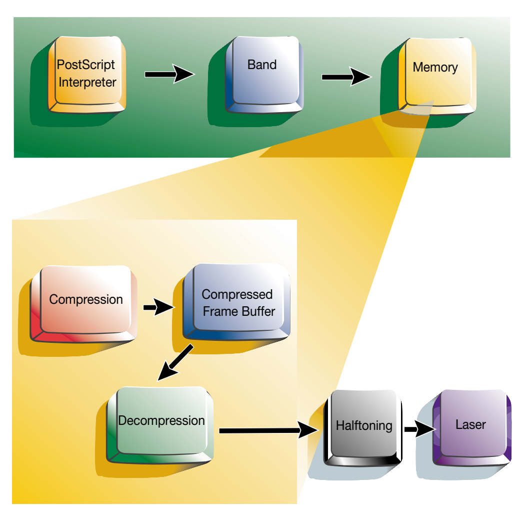
In the Apple Color LaserWriter, the PostScript interpreter renders each page on a band-by-band basis. Each band, as it's rendered, is compressed by the Compression/Decompression *Coprocessor* (CDC) ASIC and is then stored in the compressed frame buffer. Once all the bands in the page have been compressed, the printer mechanism engages as the Video Coprocessor ASIC decompresses the data, performs halftoning, and feeds it to the laser in real time.

For performance and reliability, hardware performs both compression and decompression. Without a Compression/Decompression Coprocessor, performance would be much lower. Without the Video Coprocessor, pages requiring a long time to decompress would not print correctly because it's impossible for software decompression and halftoning to keep up with the engine.



Where Compression Takes Place

Coprocessor - Hardware that offloads the main processor from performing specific tasks. The Color LaserWriter has several coprocessors such as the CDC - Compression/Decompression Coprocessor - which performs compression and decompression to reduce memory required in the printer.



Existing Compression Techniques Fall Short

Obviously, compression is a critical factor in affordably providing the quality available with the Apple Color LaserWriter. A number of existing compression methods—for example, JPEG and LZW—have been used effectively. But they

Compression methods are considered either "lossy" or "lossless."

A lossy compression method reduces memory requirements by taking out noncritical information. Done right, this can dramatically reduce memory requirements without changing the overall quality of the image/page.

A lossless compression method does not remove any image data, but rather finds a more efficient means of capturing it. While users can be sure that the data is exactly as it was prior to compression, compression rates are much lower with lossless methods.

are simply not capable of the compression performance called for by Apple's color laser printing architecture.

JPEG

The Joint Photographic Experts Group, or JPEG, compression system is a lossy technique that can greatly reduce the RAM space required for images. However, it greatly degrades the quality of text and lines, and its complex architecture makes it relatively expensive to implement. (Note: Although the Color LaserWriter does not use JPEG internally to compress the frame buffer, PostScript Level 2 printers can decompress JPEG-compressed source images and the Macintosh LaserWriter driver can send images that have already been compressed by JPEG.)

LZW

LZW compression - Lempel-Ziv-Welch (LZW) is a lossless technique that works for both text and images. LZW compression builds a table of value combinations; compression occurs where value combinations repeat.

Lempel-Ziv-Welch (LZW) is a patented lossless technique that works for both text and images. *LZW compression* builds a table of value combinations; compression occurs where value combinations repeat. Although it's capable of faster and higher compression than some other lossless techniques, LZW compression rates are still too low to support Apple's compression requirements.

Apple Contone Compression Technology

Because existing memory compression schemes were not adequate for the development goals for the Apple Color LaserWriter, Apple developed its own innovative compression algorithm. While much of Apple Contone Compression Technology is proprietary, the highlights are reflected in Apple's four primary goals for memory compression:

1) All pages print at the specified quality level; the printer will print all jobs without quality degradation.
2) The compression technology will make it possible to achieve superior, near photographic quality printing.
3) The compression architecture will take maximum advantage of the print engine's capabilities.
4) The compression technology is architecturally fast because it's implemented in hardware rather than software; it can compress a 120-megabyte page to 8 megabytes in 2 seconds.

The Innovations

In the process of developing and refining the original PhotoGrade and FinePrint™ technologies, Apple discovered a great deal about what the human eye can distinguish and what it ignores. Apple used these discoveries in the development of Apple Contone Compression Technology and Apple Color PhotoGrade. For example, testing showed that the human eye treats edges and interiors differently. With edges, the eye is very sensitive to position, smoothness, and resolution; with interiors and images, the eye is sensitive to changes in tone and color.

Three innovations are key to Apple Contone Compression Technology:

- It segregates interiors and edges.
- It compresses interiors differently from edges.
- It treats images as interiors.

Apple Contone Compression Technology analyzes a page and segregates it into edges and interiors. For edges, it retains position and sharpness at the expense of color depth. For interiors, it retains color depth at the expense of sharpness. This results in high compression ratios (approximately 15:1 with the standard memory configuration), sharp text and lines, and lots of colors for images and filled areas.

Memory Requirements

This table indicates the specific amount of memory required by the system and compressed frame buffer for each of the three paper sizes the engine supports.

	Frame Buffer	System Memory	Total RAM
Letter	8.1 MB	3.0 MB	12
A4	8.3 MB	3.7 MB	12
Legal	7.8 MB*	4.2 MB*	12

**To support the legal-sized frame buffer in standard mode, the Apple Color LaserWriter uses a higher compression technique and only the C, M, and Y color planes. With an additional 4 MB of memory (16 MB total), the Apple Color LaserWriter can achieve the same quality with legal-size pages as with letter and A4 sizes using all four color planes (C, M, Y, and K).*

Apple Contone Compression Technology provides superior, near-photographic-quality printing. It compresses the 120 megabytes of data normally required for a page into just 8 megabytes of RAM—a compression ratio of 15:1—yet still preserves excellent overall print quality for text, lines, graphics, and images.

Apple Color LaserWriter Controller Technology

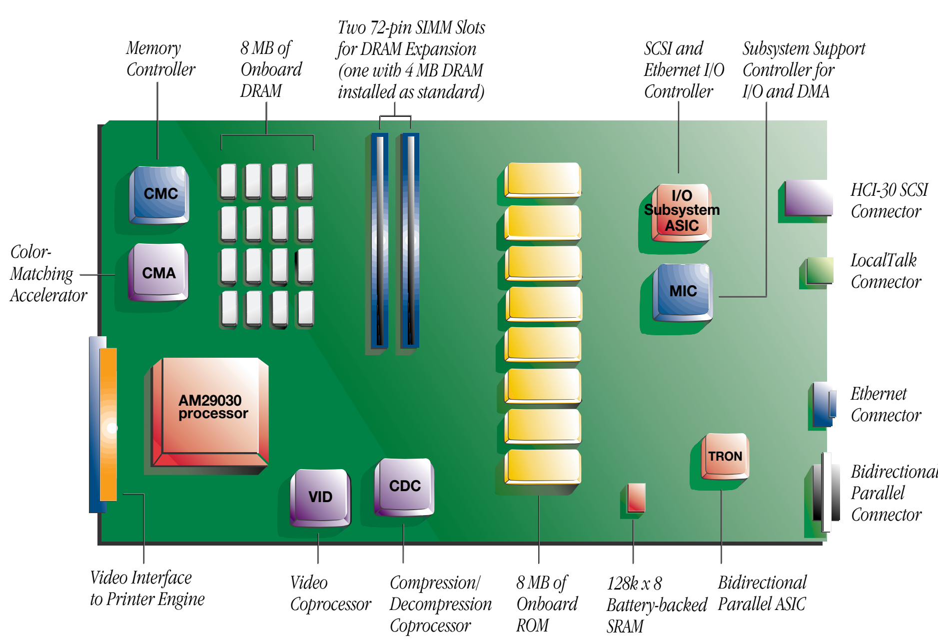
The development of Apple Color PhotoGrade and Apple Contone Compression Technology represent substantial technological breakthroughs. However, because these technologies require very sophisticated image processing, Apple had to ensure equally substantial breakthroughs in the Apple Color LaserWriter controller architecture to manage throughput.

To accomplish this, Apple merged the development of two strategies in controller design:

- A high-performance CPU and memory subsystem with an I/O platform supported extensively by *direct memory access* (DMA)
- Coprocessor ASICs that handle the most complex image-processing functions and offload the CPU

Direct memory access - DMA - Allows the movement of information within memory without using the main processor.

What resulted from these merged strategies was the development of six Apple-proprietary ASICs for the Color LaserWriter—three for system and I/O support and three for image coprocessing. All told, these ASICs contain more than 150,000 gates.



System and I/O Support

In order to provide contone-quality output, the Apple Color LaserWriter controller must generate and then compress large amounts of image data. (During the print process, the frame buffer is described by 32 bits of color information per pixel.)

To help manage this data movement, the Apple Color LaserWriter controller supports a fast, multiway DRAM and ROM subsystem. One of the Apple-designed ASICs controls this DRAM subsystem as well as system bus arbitration. The Apple Color LaserWriter CPU is a 30-MHz AMD29030.

The I/O subsystem supports Ethernet, LocalTalk®, IEEE1284 bidirectional parallel port, and SCSI. Apple's interface controller ASIC performs direct memory access (DMA) for all I/O channels, as well as timers and other system functions.

Apple partnered with Texas Instruments—a leader in IEEE1284 technology—to develop the bidirectional parallel controller ASIC. This device supports not only "nibble mode" back-channel transfers, as do other printers, but also the very fast ECP mode. (ECP is capable of megabytes-per-second transfer rates. The Microsoft driver with Windows 95 will reportedly support ECP mode.)

Coprocessor ASICs

Because the Apple Color LaserWriter controller architecture is based on a coprocessor model, the main processor can offload certain complex and time-consuming calculations or processing to the appropriate coprocessors. Once programmed, these coprocessors become autonomous intelligent bus masters. This means that they can read instructions and data from main memory and, where appropriate, return results to memory or drive the print engine.

Each of the three coprocessors in the Apple Color LaserWriter are special-purpose processors that can complete their assigned tasks much more quickly than a general-purpose CPU.

Video Coprocessor

The Video coprocessor ASIC drives and controls the printer engine. When printing a page, Video reads in two-dimensionally compressed blocks of the contone frame buffer.

The Video coprocessor decompresses the blocks "on the fly" from the page buffer to reconstruct the original page buffer data. It then applies Apple's proprietary hardware halftoning and Color PhotoGrade laser control to the engine.

Compression/Decompression Coprocessor

The Compression/Decompression Coprocessor (CDC) can also rapidly compress or decompress a frame buffer in any of the supported compression ratios. The CDC uses information about each small, two-dimensional block of the frame buffer to decide how to compress the information in that area; it then returns a compressed representation of the frame buffer to memory.

The CDC's decompression is functionally identical to that in the Video ASIC. On complex pages, however, it returns the decompressed results back to main memory rather than drive the engine in real time. Such conditions don't cause an additional loss of data but may require extra decompression and compression cycles in order to process some parts of the page.

Color-Matching Accelerator

Users of color laser print technology value color matching because they can count on predictable and consistent color output. Apple is the first to bring fast and high-quality color-matching capability to the desktop with the introduction of the Apple Color LaserWriter and ColorSync 2.0.

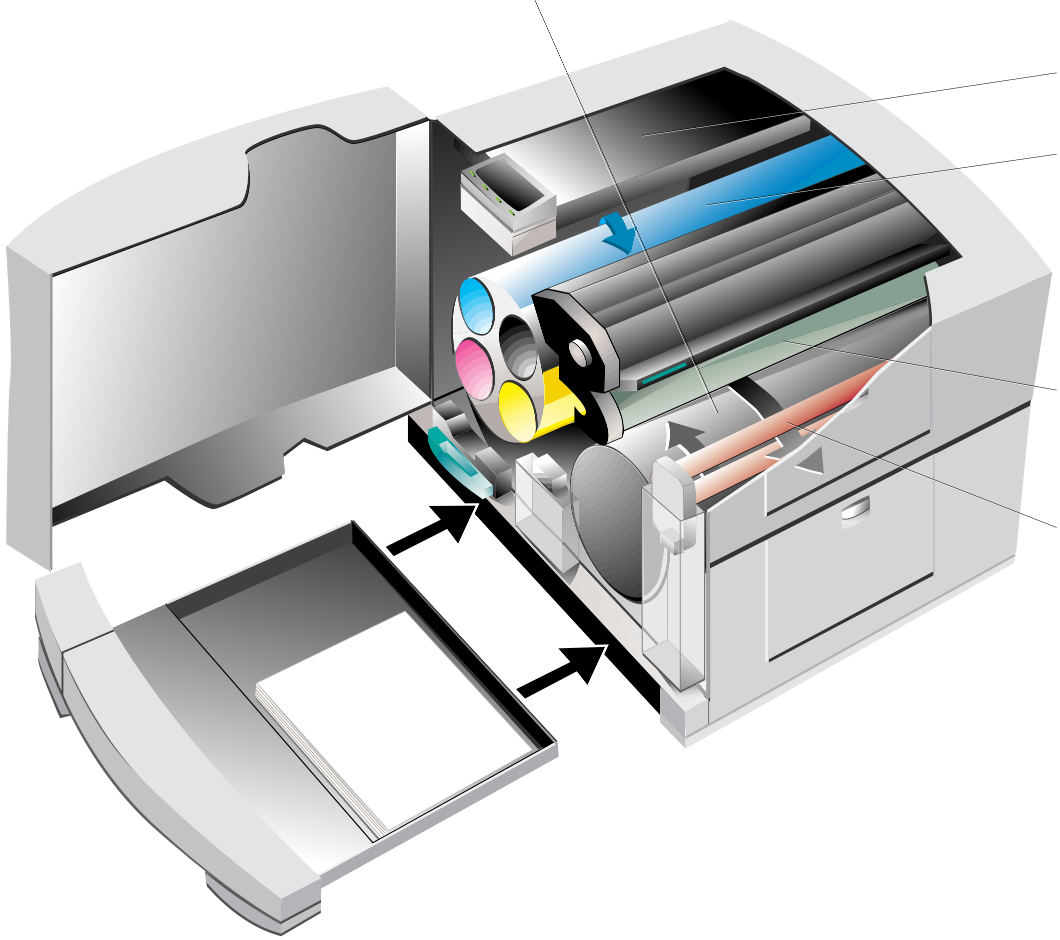
Apple accomplished this technological breakthrough by dramatically accelerating the color-matching process. (This process has typically been carried out by the general processor; because it is very computation intensive, color matching can slow down the whole printing process significantly.) By selectively incorporating the most computation-intensive and time-consuming parts of color matching into an ASIC called the Color-Matching Accelerator (CMA), Apple accelerates color matching very cost effectively. The CMA can execute an otherwise complex and time-consuming interpolation process very quickly without stealing cycles from other processes. With the Color-Matching Accelerator, there is little performance penalty to having color-matched output.

Apple Color LaserWriter Engine Technology

The Color LaserWriter Printing Process

Color printing inside the Apple Color LaserWriter:

1. *The transfer drum receives the paper from the paper tray cassette. The paper is clipped onto the transfer drum at one end and held around the drum by an electrostatic charge.*



2. *The controller sends a compressed page to the Video coprocessor.*

3. *The toner carousel rotates to bring the appropriate color toner cartridge into contact with the organic photoconductor (this "contact" is between the toner developer rollers and the organic photoconductor); toner jumps from the toner charge (negative) to the organic photoconductor (a greater negative charge).*

4. *The organic photoconductor transfers each color plane of the image to the paper wrapped around the transfer drum.*

5. *The fuser rollers receive the paper from the transfer drum and use leaf pressure to permanently bond the toner to the page and release it to the top tray or face-up tray.*

True 600 dpi Versus Pseudo-600 dpi

The Apple Color LaserWriter is a "true" 600-dpi printer because every aspect of its architecture is designed to a 600-dpi specification. In addition, its multilevel capability can assign levels of color or gray (rather than simply on or off) to each pixel, thereby further enhancing print quality.

While several laser printers available today are listed as 600-dpi printers, some of them can be said to be "pseudo-600 dpi." To design a true 600-dpi printer, a manufacturer must take all of these factors into account:

1) Addressable resolution: The controller must be capable of representing data as a 600-dpi structure.
2) Horizontal resolution: The laser must scan at a frequency that forms 600-dpi pixels in a horizontal direction; clock speed (that is, the timing of the laser pulse) must be tuned to a smaller and finer frequency.
3) Vertical resolution: The printer itself must be able to step all of the development processes in 600-dpi increments (including the *organic photoconductor* [*OPC*], the developers, and transfer to paper); some manufacturers pulse the laser at 600-dpi but leave all other processes at 300 dpi.
4) Edges: The matching of 600-dpi horizontal and vertical resolution produces very clean edges. This is most apparent with angled lines and the edges of text, especially halftone text. Pseudo-600 dpi machines produce jagged edges due to the mismatch of vertical and horizontal resolution.
5) Spot size: Both the diameter of the beam and the sensitivity of the drum must support a 600-dpi spot size. Manufacturers who adapt the laser, and even the step size, to 600 dpi but still use the same printing process as in their 300-dpi models are drawing a larger spot.
6) Toner particle size: A 600-dpi printed spot size is between 60 and 80 microns in diameter; toner particle sizes may vary from 4 to 12 microns in diameter; the smaller the particles the greater the fidelity to 600-dpi resolution.

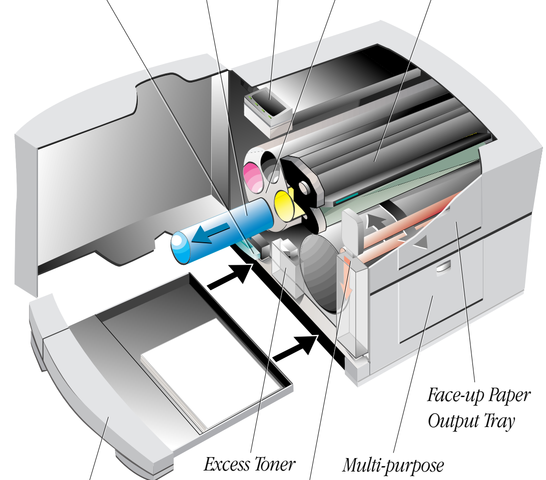
OPC/photosensitive drum - The OPC (organic photoconductor) is a light-sensitive drum that reacts to laser pulses and attracts toner to these areas.

Apple addressed all six of these criteria in designing its Color LaserWriter, making it a true 600-dpi printer.

Easy Setup and Maintenance

Because many Apple users are accustomed to the simple setup and ease of use of existing black-and-white laser printers, it became a challenge to provide comparable ease and simplicity in the Apple Color LaserWriter. True to Apple practice, the user experience drove the design, which resulted in optimized access points in a sightly larger footprint.

- The engine provides one-side access for adding paper, retrieving output, installing cartridges, and clearing jams. This reduces the amount of space required around the printer to operate and maintain it.
- All toner consumables are contained in enclosed cartridges—not bottles or tubes that can spill easily—for clean and easy handling and installation.
- High-reliability components, along with the engine design, minimize end-user interaction with the engine.
- Graphical LED panel shows users when a consumable needs replacement and where to replace that item.



Apple Color LaserWriter Features and Consumables

Mono-Component Toner System

Before addressing the merits of a mono-component toner system, it makes sense to review the more common *dual-component toner* technology. In a dual-component system, two elements are involved in delivering toner to the page: the toner itself (colored bits of plastic), and a chargeable carrier (usually iron-based). The two are mixed together in the toner cartridge. The carrier is designed specifically to respond to the charge process, and the toner is designed only for delivering color. Once the carrier has delivered the toner to the OPC and then to the page, it drops off. The dual-component system is simple in that developers can focus on each component for its specialty: charge or color. However, it is ultimately more complex. It involves two elements rather than one, and therefore requires more consumable items and user interaction. Print quality on a dual-component system versus a mono-component system remains a topic of debate.

Dual-component toner - The color laser technology that uses two separate powders; colored toner and a charged carrier. With dual-component systems the carrier bonds to the toner and transports it to the paper. Because the carrier and toner are separate, these systems tend to be more complex to maintain.

In a *mono-component toner* system, the color and charge agent are one and the same substance. A great deal of physical and chemical research goes into discovering what reliable color substances will also react favorably and predictably to the charge process. Apple's development of a mono-component system derives from this goal: ease and reliability for users. The Apple Color LaserWriter engine design reflects a great deal of experience with dual-component systems that work well given a lot of user interaction. The mono-component toner system in the Apple Color LaserWriter helps make it a low-maintenance printer for the multiple-user office environment.

Mono-component toner - A system where color and charge agents are combined, reducing the number of consumables required and simplifying maintenance.

Auto Color Calibration: Toner Density Control
One of the attributes most important to the quality of a color laser printer is color consistency. This requires that color be right to begin with and then consistent over time and under various environmental conditions. It's possible for a technician to recalibrate the printer frequently (this involves updating the printer's adjustments according to relative humidity, toner life, and so on). High-end color copier/printers require this interaction and frequent calibration maintenance. But this is a user-intensive process for which few people have the inclination, interest, or training.

The Apple Color LaserWriter has an auto recalibration feature also known as Toner Density Control. It functions by laying out solid and halftoned color patches on the drum and measuring them, then adjusts itself to maintain color consistency. The goal of Toner Density Control is simply this: That over time, the printer will behave the same rather than differently. With ColorSync technology establishing on-average color accuracy, Toner Density Control ensures that that average doesn't change over time.

The recalibration function is in the printer engine itself. It occurs automatically at power-up, after the replacement of toner cartridges, and after every few hundred pages. It takes about a minute and a half to complete.

Apple Value-Added Software

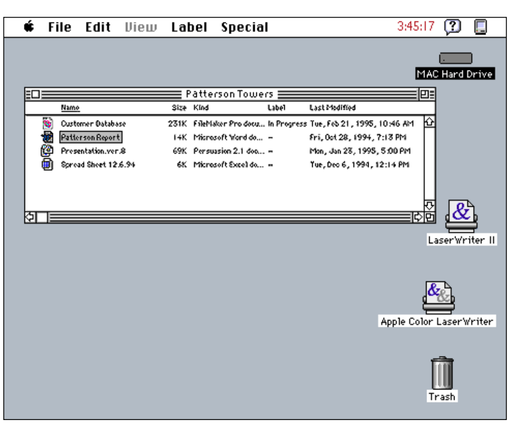
Imaging Device Protocol (IDP) - A foundation technology that allows printing to continue concurrently with other operations.

The Apple Color LaserWriter is the first product to use a new Apple architecture that adds more value to the overall printing experience. Many features of the new architecture leverage Apple's ability to modify both the controller software and the host software. Following is an explanation of these new features, which will form the foundation for a whole new class of features and enhancements in the usability of network printers.

Imaging Device Protocol

Imaging Device Protocol (IDP) is a foundation technology that allows printing to proceed concurrently with other operations. Standard PostScript printers deal with just one job at a time. Because most other printers treat status queries the same as they do a print job, a query can't take place while a printing job is in progress. With IDP, users don't have to wait for one print job to finish before sending another job, making status queries, or configuring a printer over the network.

Apple has developed and integrated IDP into the PostScript environment.



Desktop with Printer Icons

This provides the foundation from which drivers and utilities can provide enhanced status and query features while the printer is busy printing jobs. The immediate benefit with IDP is the ability to save time by processing multiple PostScript jobs concurrently; future printers will offer users even greater feedback and administrative control.

JPEG in the Macintosh Printer Driver

Apple has integrated support for JPEG compression into the Macintosh LaserWriter driver in order to boost performance when printing large images. When a document contains JPEG-compressed PICTs, the driver sends them as compressed images over the network to the printer, where they are decompressed. This can dramatically improve overall print performance because much less data travels over the network and the host doesn't have to decompress the image. For example, an 8-megabyte image compressed at a ratio of 10:1 takes much less time to send and print.

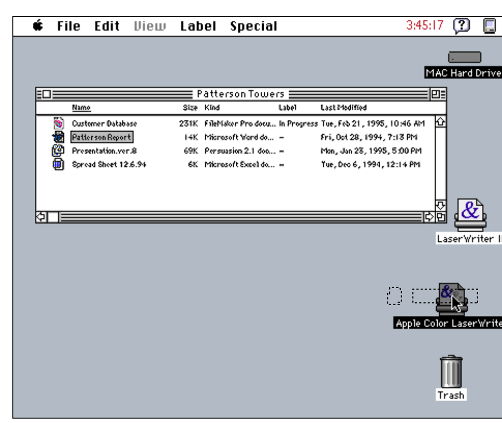
The Desktop Printer Extension

Apple has taken the *Desktop Printer extension*—one of the elements of the GX Desktop Printer architecture—and made it available to non-GX users. The Desktop Printer extension provides users of Apple printers with several useful capabilities.

Desktop Printer extension - Enables Macintosh users to select a printer without using the Chooser, print to multiple printers at once, and drag print jobs to an icon of the printer.

Select a Printer Without Using the Chooser

In a network environment (especially one that includes a color printer), users often switch printers either to print on an idle printer or to take advantage of unique features of a particular printer (color, fax capability, special paper, and so on). With the Desktop Printer extension, users can create desktop icons of commonly used printers. Instead of using the Chooser to change printers, users can do so by using the printer icons on the desktop; they can also use the printer icons to change their default printer.



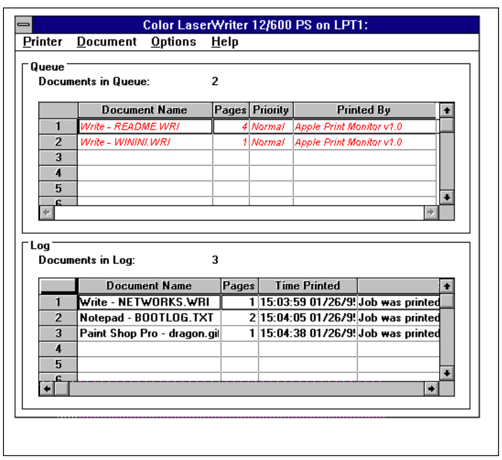
Drag and Drop

Drag-and-Drop Print Jobs

With desktop printers, users can also drag a print job from one like printer to another (meaning, for example, from one PostScript printer to another). A user can send a print job to the default printer, open that desktop printer icon, and then drag the job to another printer of the same type.

Send to Multiple Print Devices at Once

The Desktop Printer extension also enables users to print concurrently on multiple print devices. For example, a user can print a presentation to an Apple Color LaserWriter and, at the same time, fax a copy to a LaserWriter 16/600 PS printer in Europe (using the PS Fax Card). Without the Desktop Printer extension the user would have to wait for the first job to print, then use the Chooser to select the fax-capable printer in Europe, and then print again.



Printer-Based Queue for the Windows Driver

Apple is committed to adding value to Windows-based systems so that Windows users can also take advantage of the unique Apple-designed innovations in the Apple Color LaserWriter. To this end, Apple is shipping Apple PrintMonitor for Windows with the Apple Color LaserWriter. This application uses IDP and bidirectional communication to provide Windows users on networks with access to useful printer information. They can get print job status feedback or view the printer queue of any Apple Color LaserWriter in the network using a "Chooser-like" selector. A printer queue is a view of all print jobs—not just one user's—on a given printer. This information is important to users. For example, if they check the queue and find that there are many jobs ahead of theirs, they can decide to switch to another printer, print later, or simply wait. Unlike the standard Windows print system, which gives users limited feedback only on their individual jobs, Apple's software provides feedback on all jobs on the printer.

IDP-Based Utility—Status and Concurrent Status

Value-added software for both Macintosh and Windows also includes Apple Printer Utilities. These allow users to send multiple PostScript jobs concurrently, set a variety of printer parameters, and configure the printer remotely. Both the Macintosh and Windows versions of this software use the IDP communications path; this improves performance and enables them to configure the printer even when the printer is busy. As IDP functions expand, access to Apple Printer Utilities features will also expand.

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