INTRODUCTION

There is such a wide range of plotters and printers available in today's market that people purchasing color hardcopy devices need to understand the features and benefits that different hardcopy technologies offer. Today, color graphics systems are more widely available and easier to use. The increased availability of color technology is helping people obtain the benefits that color graphics can provide.

Color helps present complex information by adding another dimension to graphics. Recent academic studies have shown that using color graphics leads to greater comprehension and retention of information, which in turn leads to more persuasive presentations. Color graphics turn data into information by showing trends, patterns, and inter-relationships. Using color graphics can shorten meetings, save time analyzing data, and improve decision making.

This paper reviews color plotter and printer technology. This information can be used within the framework developed in "A Guide to Color Hardcopy Device Purchases," presented at SUGI-12, to help evaluate a color hardcopy device. This technology review will help users understand how different hardcopy devices can meet their needs for a color graphics solution.

GROWTH IN THE COLOR HARDCOPY MARKET

The wide variety of hardcopy devices available is due to the rapid growth of color graphics applications. The growth in the color hardcopy market can be linked to greater use of color monitors, more powerful computer systems at lower prices, and greater software support for color devices. An end-user survey by CAP International also showed a significant increase in the use of graphics between 1986 and 1988. CAP International's survey also showed that the leading technologies in end-user's future purchasing plans are pen plotters, laser printers, ink jet printers, and electrostatic plotters.

Manufacturers have responded to this growth by producing more sophisticated color hardcopy devices at lower prices. More intelligence is being built into hardcopy devices to reduce processing burdens on software. There are more color printers that use plain paper, with higher resolutions. The availability of color copiers has also made it easier to reproduce color hardcopy.

COLOR HARDCOPY TECHNOLOGY

Color hardcopy technology can be categorized into impact and non-impact devices. Impact devices are dot-matrix printers and pen plotters. Non-impact devices are ink jet printers, thermal transfer printers, electrostatic plotters, and electrophotographic/laser printers. Dot-matrix printers and pen plotters are in wide-spread use, and currently dominate the market for hardcopy devices. However, non-impact devices will have the greatest growth over the next 5-10 years due to advances in technology.

Another way to categorize color hardcopy devices is by vector vs raster technology. Vector or raster technology refers to how an image is drawn on the media/paper. Figure 1 shows the difference between lines drawn on vector devices and rasters devices. Vector devices produce complex images and shapes better due to their ability to control individual dot placement. Since raster devices produce complex images and shapes better due to their ability to control individual dot placement. Raster devices can also control the color of individual dots, they have color capabilities, such as shading, which are not possible in a vector device.

All raster color hardcopy devices use a subtractive color system to produce output. Printed colors are created by colorants that absorb certain colored light, and transmit the remaining light. The subtractive color system is based on the primary colors cyan, magenta, yellow, and black. Each colored dot represents a picture element (pixel) in the hardcopy image. Resolution in a raster device depends on the density, accuracy, and size of the dots placed. Line quality is influenced by the angle. Horizontal lines will always appear smooth. However, angled lines will have jagged edges due to the dot placement needed to form the line. Manufacturers improve line smoothness by increasing the dot density (dots/inch) or by increasing the accuracy of dot placement. A dot can actually be placed on top of the intersection of two dots using a technique known as anti-aliasing.

Vector color hardcopy devices produce superior line graphics such as charts and graphs, but their color capabilities are limited to the colors of the pen. Vector devices produce complex images and shapes better due to their ability to control individual dot placement. While raster devices can also control the color of individual dots, they have limited capabilities such as shading, which are not possible in a vector device.

Line quality in a vector device depends on the combination of addressable and mechanical resolution. Figure 2 shows how a vector line is drawn. When a pen plotter draws a line between points A and B, it is actually drawing to the points on a grid between A and B. The grid points are the points that are electronically addressable by the plotter. The distance between grid points equals the addressable resolution. A typical addressable resolution for pen plotters is 0.001 inches.

Most vector devices have mechanical resolution equal to addressable resolution. If the mechanical resolution is lower than the addressable resolution, then the pen plotter can not physically move the pen to all the addressable points (i.e. the smallest pen move mechanically possible would be greater than the distance to the nearest addressable point). Mechanical resolution is more difficult to control and plotters with higher mechanical resolution will be more expensive.

Two other measures of vector line quality are repeatability and accuracy. Repeatability refers to a vector device's ability to move a pen to a pre-determined point. Poor repeatability is noticeable in circles that do not close, and connecting lines that do not meet. Accuracy refers to how exactly a vector device can position one endpoint with respect to another point. Accuracy is specified as the maximum distance between the desired endpoint and the actual endpoint drawn. Poor accuracy is noticeable when parallel lines do not appear parallel (exact spacing between two lines).

Resolution in a raster device depends on the density, accuracy, and size of the dots placed. Line quality is influenced by the angle. Horizontal lines will always appear smooth. However, angled lines will have jagged edges due to the dot placement needed to form the line. Manufacturers improve line smoothness by increasing the dot density (dots/inch) or by increasing the accuracy of dot placement. A dot can actually be placed on top of the intersection of two dots using a technique known as anti-aliasing. Covering that intersection results in a smoother line. Both alternatives of increasing dot density and placement accuracy result in higher hardware costs, and longer times to process an image.

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Dot matrix printers are used when people want fast color hardcopy and they do not care about the resolution or quality of the output. Color dot matrix printers are their very low cost, and ability to work with plain paper. The main disadvantages of dot matrix printers are their limited color capabilities, and noisy operation.

Ink Jet Printers

Ink jet printers produce color hardcopy by spraying a stream of ink droplets from a multi-nozzle head onto the media. The ink jets are moved relative to the page to create multi-color images and characters in a single pass. A continuum of color is achieved by spraying color dots so small that the individual elements cannot be resolved. Light reflected from the adjacent colors is mixed in the observer's eye to create a single color. A range of color is achieved by varying the patterns and amount of each color.

There are two general systems for generating ink droplets: continuous stream, and drop-on-demand systems. Continuous stream systems spray a stream of ink into a gutter which recycles the ink. Ink droplets are deflected from the stream and onto the media by acoustic or electrostatic excitation. Ink is pumped out of the nozzle at rates of 50,000 per second. Continuous ink jet systems are expensive and complex to maintain, but provide high throughput. Drop-on-demand systems only pump ink through the nozzle when needed. In a thermal ink jet head, an electric signal is selectively pulsed, heating the ink supply, and causing a bubble to form. The expanding bubble forces a drop of ink out of the nozzle and onto the media. Most drop-on-demand systems employ print heads with multiple nozzle arrays and fire each one as needed. Drop-on-demand systems offer lower cost, higher reliability, and a smaller footprint (take up less space) than continuous stream systems.

Ink jet printers have the ability to merge text and graphics while maintaining good throughput and color reproduction. The main advantages of ink jet printers are their low hardware costs, excellent color capabilities, and quiet operation. Although ink jet printers will work with plain paper, special paper must be used to obtain the highest quality output. Special paper minimizes ink bleeding as it is absorbed by the media. The main weaknesses of color ink jet printers are the need for special paper, and high cost for high resolution (>200 dpi) devices.

Early ink jet printers developed a bad reputation for clogged nozzles. Recent advances have eliminated those reliability problems. Future developments in ink jet technology are expected to provide lower prices, and greater throughput. Variable dot size technology to create "almost-photographic" color reproduction capability will also be more widely available in ink jet printers.

Thermal Transfer Printers

Thermal transfer printers use a heated pin head to melt inked wax from a special ribbon onto paper. Individual elements of a page-wide head are selectively heated to create images. For color hardcopy, the thermal transfer ribbon consists of three successive colored sheets. There is one sheet for each primary color: cyan, magenta, yellow. The inked-wax melting process is repeated three times; once for each color. A continuum of color can be achieved by manipulating dots of ink in the same manner as ink jet technology.

The main advantages of thermal transfer printers are their low cost and quiet operation. However, they are relatively slow in producing only text and expensive to operate. Each colored sheet of the thermal transfer ribbon can only be used once even if only one dot of ink was removed from the ribbon. Thermal transfer printers also require special glossy (very smooth surface)
paper. The limitations of the thermal transfer ribbon and special paper result in a very high cost per page of color hardcopy.

Future developments in thermal transfer technology are expected to lower prices, and increase throughput rates. Thermal transfer devices should also work with plain paper in the future.

Electrostatic Plotters

Electrostatic plotters operate by passing a roll of dielectric paper over a page-wide electrostatic head. The dielectric paper has a conductive coating on one side of the paper. As paper moves over the head, individual styli selectively place electric charges on the paper to create a latent image. Then the paper passes through a liquid toner, where oppositely charged toner particles are attracted to the latent image. Finally the toner solvent is removed and the ink particles are fixed to the media.

In a color system, this image formation-toner transfer process is repeated four times; once for each primary color (CMY) and once for black. Using this four color process, electrostatic plotters have excellent color reproduction ability. The four step process can take place with either 1 or 4 writing heads. Electrostatic plotters with one head charge the paper, pass it through a toner station, fix the ink, and then back up the paper for the next color pass. Electrostatic plotters with four heads only have to move the paper forward once. The four head system is faster, but more expensive.

The main advantages of electrostatic plotters are their very high throughput rates, high resolution (400 dpi), and excellent color reproduction capability. However, current color electrostatic plotters are very expensive. These devices are mainly used in high-value applications, or shared-peripheral environments. Electrostatic plotters also require frequent toner and solvent replacement. High humidity conditions can influence the quality of the output. Solvent fumes from the liquid toner can create a problem in office environments. Future developments in electrostatic technology will focus on cost reductions. As electrostatic plotters prices decline, they will begin to compete with pen plotters.

Electrophotographic Printers

Electrophotographic printers use an optical device to create a latent image on a photoconductive drum in the printer. The most common optical device used is a laser. The laser beam is aimed at a multi-faceted mirror that scans the beam across the drum to create a latent image. The sensitized drum rotates through a dry toner which is electromagnetically attracted to the latent image. After the toner is transferred to the media, the media goes to a fusing station where the toner is melted onto the media.

A breakthrough in electrophotographic technology occurred when Canon developed a semi-conductor laser and metal mirror to reflect the laser signal. Using a metal mirror instead of glass mirrors was a cost breakthrough. The Canon print engine also uses a special lens to compensate for deviations in scanning. The special lens helps lower the reflective requirements of the system, making use of a metal mirror possible. However, the key element of any electrophotographic system is the controller that rasterizes incoming data, and controls the scanning beam and rotating mirror.

The most common electrophotographic devices are laser printers and copiers. Presently, there are no color electrophotographic printers on the market. The heat and pressure used to fuse toner to the media tends to contract the media and move dots of ink from their original position. Consequently, accurate placement of dot on dot color is very difficult. Although electrophotographic printers only provide monochrome output, they are available at high resolution (300 dpi) and throughput speeds as fast as 20 seconds per B&W page. Future developments should lead to lower priced devices. Work with cold fusing techniques and other advances should lead a color electrophotographic printer in the near future.

The features of these different hardcopy devices are summarized in figure 4.

CONNECTIVITY

Connectivity describes how the various components of a computer system are connected or interfaced so users have a graphics solution instead of individual hardware components and software. Connectivity completes the solution created by hardware and software. A simple connectivity example is the RS-232-C serial interface between a micro-computer and hardcopy device. A more complex example is how the code (called a driver) in a software program sends data to a hardcopy device. Connectivity is a key part of system performance because it completes the graphics solution and helps the hardcopy device operate at maximum performance.

The interface that is used to connect a hardcopy device to a computer can influence the device's throughput. In some systems the interface connecting the computer to the hardcopy device can be a bottleneck for data transfer. The interface cannot send data through as fast as the hardcopy device can accept it. Listed below are maximum data transfer rates for common hardcopy interfaces.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Data Transfer Rate (Bytes/Second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS-232-C</td>
<td>2000</td>
</tr>
<tr>
<td>Centronics</td>
<td>30,000-50,000</td>
</tr>
<tr>
<td>HP-IB (IEEE 488)</td>
<td>30,000-50,000</td>
</tr>
<tr>
<td>Ethernet</td>
<td>100,000</td>
</tr>
</tbody>
</table>

Faster data transfer from the computer and software program to the hardcopy device means greater throughput. Users should check whether features are supported by their systems, including the software. In some cases, a hardcopy device may offer a fast interface like Centronics or HP-IB, but the software program being used may not be able to send data over that interface.

The software program being used is a key part of connectivity. All graphics programs contain sections of code which drive your monitors and hardcopy devices. These portions of code are called drivers. Hardcopy throughput and quality can be influenced by how those drivers are written by software developers.

A driver may not be written to take advantage of intelligence built into the hardcopy device. For example, if a driver does not take advantage of a roll-feed plotter's ability to automatically advance paper, then the user must walk over to the device after they finished their first plot, and advance the paper for the next plot. A driver can also be written to minimize the amount of data that is sent to a hardcopy device. By minimizing the amount of data that is sent to a hardcopy device, the software program can maximize throughput. For example, some pen plotters contain the intelligence to fill in a polygon with a pattern or solid color with only a few software commands. However, some drivers do not use that intelligence and will send all the data required to tell the plotter exactly how to move the pen. Sending all the pen movement data instead of using the plotter's built-in intelligence will slow throughput.

Consequently, connectivity is the final technology issue in evaluating a color hardcopy device. Connectivity completes the combination of software program, computer, and hardcopy device to provide a color graphics solution.
KEY ISSUES FOR SAS/GRAF USERS

- Plotter vs Printer: A pen plotter provides high quality line graphics at a reasonable price. Color printers will provide faster throughput, especially if your hardcopy is dominated by text. Some highly complex plots that could take a pen plotter half an hour to produce could be printed in several minutes. However, a color printer will cost two to three times as much as a plotter for comparable line graphics quality. Pen plotters have always produced high quality transparencies. Advances in media technology now permit transparencies to be produced on all color printers.

- How much color reproduction capability is needed? The most common SAS/GRAF applications involve charts and graphs, a device that can produce eight colors should be appropriate. You will need a color printer to produce realistic looking color pictures, but it may be an expensive feature that is unneeded.

- How do pen speed and acceleration influence plotter throughput? Pen plotter throughput is highly dependent on the type of graphics being produced. For hardcopy with a lot of area fill and long line strokes, pen speed is important. Pen speeds around 30-40 inches/sec. are considered fast. For graphics with a lot of short line drawings (characters, short strokes) pen acceleration is important to quickly get the pen up to full speed. Pen accelerations around 5-6 g's are considered fast. It is important to match the pen speed and acceleration to the type of graphics that will be produced. A pen plotter with high pen speeds, but low acceleration would have problems drawing short line strokes because it would take a relatively long time for the pen to reach full speed each time it changed direction.

- How to improve productivity while plotting on a micro-computer? For most users, they only usually send data faster than plotters can plot it. Current micro-computers do not have the (multi-tasking) ability to run several sub-routines concurrently. PC users may have to wait until the plotter is finished plotting before they regain control of the PC and they can begin another task. An external buffer can be placed between the computer and plotter to help users regain control of their PC sooner. A pen plotter is a piece of equipment that temporarily stores information being sent from the computer to the plotter. Once the computer sends all the data to the buffer, the buffer takes care of sending the data to the plotter, and the PC can start another task.

- What are the advantages and disadvantages of the most common hardcopy device interfaces? The most common interfaces today for color hardcopy devices are RS-232, Centronics, HP-IB, and video interfaces. The interface is the pipeline for data from the computer to the hardcopy device. The RS-232 serial interface is the slowest of the four interfaces. RS-232 is slow because it sends bits of data in series (one after the other). However, RS-232 is supported by almost every software package, and computer system. Centronics and HP-IB interfaces are faster because they can send bits of data in parallel. However, some computers and software packages cannot send data through those interfaces. A video interface connects to a monitor instead of the computer. A video interface captures the analog signal from a monitor and sends it to a hardcopy device. The advantage of a video interface is that it is easy to use and does not require software support to work. The disadvantage of a video interface is that it limits hardcopy to the resolution of the monitor. The video interface does not permit hardcopy modifications (e.g. merging images into documents, scaling images) and it performs very poorly at producing text-only hardcopy.

- Can you attach an asynchronous ASCII device (plotter) to a synchronous EBCDIC device? (IBM mainframe): Protocol converters let you attach SAS/GRAF devices to EBCDIC devices. There are two types of protocol converters: printer emulators, and cluster controllers. Printer emulators are less expensive, but you need one for each ASCII device/plotter you connect to the system. Cluster controllers are more expensive, but you can connect several ASCII devices to one. Many EBCDIC/IBM environments already have a cluster controller on the system to support their ASCII terminals. In this situation, a printer can be attached between the system and terminal in eavesdrop mode, but not all plotters support eavesdrop configurations. Before you purchase a protocol converter, determine which one is supported by your software packages.

- Which color hardcopy devices can double as text printers? SAS/GRAF users may want to use their color hardcopy device to print the results from statistical analyses, program listings, tables, and reports. An ink jet printer will provide the best combination of color capability and fast text printing. A dot matrix printer will also print text quickly, but its color capabilities cannot match an ink jet printer. Pen plotters and thermal transfer printers will be much slower in producing a page of text.

- What resolution is needed for professional looking hardcopy? Quality is an individual judgement. However, 300 dots/inch B&W hardcopy is considered "near-letter quality." High-end laser printers will offer 300-600 dots/inch. Electrostatic plotters generally offer 200 and 400 dots/inch resolution. A printer will have to approach 1000 dots/inch to match the line graphics of a plotter. Some printer offer higher resolution on the vertical axis. Since most letter strokes are vertical, increasing vertical resolution provides a better looking text. The best solution is to compare sample output similar to the type of graphics you usually produce, from the different devices being evaluated.

- Printer trade-offs: Ink jet and thermal transfer printers offer the best combination of color quality and price for color printers. An ink jet printer will produce strictly text faster than a thermal transfer printer. Most thermal transfer printers have slow text speeds, but their hardware is very simple and reliable. Both printers require special paper to produce the best quality output. Electrostatic plotters and electrophotographic printers cannot provide high quality color output at a reasonable cost. Although dot matrix printers are inexpensive, their output is not presentation quality and they are noisy.

CONCLUSION

Color graphics users can choose from a wide range of color hardcopy devices and technologies. By understanding plotter and printer technology, users can interpret hardcopy specifications, and determine how the features and benefits of different devices can meet their needs for a color graphics solution.
Figure 1

RASTER

VECTOR

Figure 2

Mechanical same as Addressable
(both = 0.001"

Figure 3

Figure 4

Color Hardcopy Devices

<table>
<thead>
<tr>
<th>Technology</th>
<th>Features</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dot Matrix</td>
<td>1-8 colors,</td>
<td>proven technology, low cost,</td>
<td>poor color quality, no control of</td>
</tr>
<tr>
<td></td>
<td>~3 min. per print,</td>
<td>reliable, uses plain paper</td>
<td>color brightness, noisy</td>
</tr>
<tr>
<td></td>
<td>low to medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pen Plotter</td>
<td>2-10 colors,</td>
<td>high resolution, variable media,</td>
<td>print speed, low for text, no</td>
</tr>
<tr>
<td></td>
<td>3-&gt;10 min. per</td>
<td>low cost, reliability</td>
<td>control of color brightness or</td>
</tr>
<tr>
<td></td>
<td>print, high</td>
<td></td>
<td>saturation</td>
</tr>
<tr>
<td>Ink Jet</td>
<td>unlimited color,</td>
<td>colors and shades available, low</td>
<td>special paper needed for</td>
</tr>
<tr>
<td></td>
<td>1-5 min. per print</td>
<td>cost hardware, quiet, merge</td>
<td>best quality, image durability</td>
</tr>
<tr>
<td></td>
<td>4 min. to high</td>
<td>text with graphics</td>
<td></td>
</tr>
<tr>
<td>Thermal Transfer</td>
<td>unlimited color,</td>
<td>low cost, hardware, reliable,</td>
<td>high cost of supplies, difficult</td>
</tr>
<tr>
<td></td>
<td>1-4 min. per print</td>
<td>4 min. to high quality</td>
<td>to control color brightness,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>special paper needed</td>
</tr>
<tr>
<td>Electrostatic</td>
<td>unlimited color,</td>
<td>high throughput, high resolution</td>
<td>high cost, needs special paper,</td>
</tr>
<tr>
<td>Laser</td>
<td>less than 1 min.</td>
<td></td>
<td>emits toner fumes, reliability</td>
</tr>
<tr>
<td></td>
<td>per print, med. to</td>
<td></td>
<td>problems</td>
</tr>
<tr>
<td>Electro-</td>
<td>primarily B&amp;W</td>
<td>high throughput, low B&amp;W cost per</td>
<td>very high cost for color devices,</td>
</tr>
<tr>
<td>photo-</td>
<td>devices, med. to</td>
<td>copy, uses plain paper, quiet</td>
<td>uncertain color quality and line</td>
</tr>
<tr>
<td>graphic/</td>
<td>high quality</td>
<td></td>
<td>accuracy</td>
</tr>
</tbody>
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BIBLIOGRAPHY


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