Align and Conquer—Moving Towards "Plug and Play" Color Imaging

Ho John Lee
<hjl@hpl.hp.com>
Hewlett-Packard Laboratories, Computer Research Center
1501 Page Mill Road, Palo Alto, California 94304 USA

Abstract

The rapid evolution of the low-cost color printing and image capture markets has precipitated a huge increase in the use of color imagery by casual end users on desktop systems, as opposed to traditional professional color users working with specialized equipment. While the cost of color equipment and software has decreased dramatically, the underlying system-level problems associated with color reproduction have remained the same, and in many cases are more difficult to address in a casual environment than in a professional setting. The proliferation of color imaging technologies so far has resulted in a wide availability of component solutions which work together poorly. A similar situation in the desktop computing market has led to the various "Plug-and-Play" standards, which provide a degree of interoperability between a range of products on disparate computing platforms. This presentation will discuss some of the underlying issues and emerging trends in the desktop and consumer digital color imaging markets.

1. Introduction

Color documents are reappearing in the 90's. Decades of advances in black and white copiers, printers, word processing, desktop publishing, fax machines, and other monochrome document handling technologies have enabled individuals to create, distribute, and manipulate text and graphics with unprecedented ease, but have resulted in the gradual disappearance of color in everyday documents. For example, deficits in accounting ledgers are now usually denoted with parenthesis ( ) rather than traditional red ink, and graphs are often printed with hash marks and patterns so they can be printed and copied in black and white.

Recent improvements in color printing, display, capture, applications and pricing have begun a resurgence of color use in documents for the office and home during the past few years. Unlike the early days of desktop publishing, however, the widespread adoption of personal computers and desktop publishing tools has already set high user expectations for the quality of black and white documents and graphics which are now being carried forward to color.

Unfortunately, some of the same problems which plagued desktop publishers in the 80's are now afflicting color imaging users in the 90's—complex and unpredictable software interfaces supported by a inadequate patchwork of system hardware. The consequence is that while the hardware and software available to users is *capable* of moderate to high quality color imagery, the results actually achieved are often poor to fair.

1.1 From Tools for Experts to Expert Tools

Traditional color imaging users have been willing and able to become experts on color and imaging techniques. Color imaging has been a central task in its traditional appiications, such as graphic arts, color offset publishing and printing, color film processing, and color television production. Professional color production tools have been designed for color imaging experts who are trying to achieve specific effects and appearances. These users have been able to invest in the equipment and training required to yield the desired results.

New, inexpensive computer technologies have placed color imaging capabilities in the hands of a broader user base who are not focused on color imaging as a primary task, but rather as an interesting or useful addition to an desktop computer system. These users are generally unwilling and/or unable to become color imaging experts.

A fundamental challenge for developers is to provide casual color imaging users with "expert tools" that can manage the interaction of devices, software, and user expectations to automatically render color imagery in a predictable and aesthetically pleasing way. Variability in the underlying system configuration cause problems, as users change input devices, output devices, output media, and software applications, but expect consistent behavior across all combinations.

1.2 Plug and Play? Color?

Plug and Play[1] is a collection of technologies developed by Intel, Microsoft, and other computer vendors to help solve the problems of system configuration and system administration, especially for consumer PCs. The original design of the IBM PC did not provide for automatic system configuration in its hardware or software, relying instead on an explicit specification of the contents ofthe system. This worked while IBM retained control ofthe PC architecture, but as it became open to many vendors, and the scope of its applications grew beyond its original intent, the absence of automatic configuration control and the resulting inconsistent behaviors became a serious weakness. On the positive side, the openness ofthe PC market resulted in a continually improving selection of new products and competitive pricing, which brought users and developers to the platform despite its shortcomings.

In contrast, the Apple Macintosh system was based on an integrated approach with a more complete definition of the interaction between hardware and software. Apple was also able to retain architectural control of the Macintosh platform, which protected it from incompatible implementations fiom other vendors. Consequently, Macintosh systems were easier for users to reconfigure and use than equivalent PCs, at a penalty of higher costs and a narrower selection of compatible products to choose from. The high level of system interoperability among 3rd party products helped make it attractive for many complex applications, notably desktop publishing and graphic arts.

The ability for a computer system to automatically detect, install, and reconfigure itself for new hardware and software is now called "Plug and Play'', which is also the name of the specification and technologies now being promoted by the PC industry. Many of the challenges posed in desktop color imaging are related to broader issues in the PC marketplace addressed by the Plug and play initiative, and the need for usable color imaging tools far the masses leads to a case for "Plug and Play Color Imaging", in which the user can connect various components and applications together and consistently achieve satisfactory results.

1.3 Color Facsimile

One area in which an imaging system has been successfully deployed to the mass market is in group 3 fax. A key feature of fax technology is that it is simple to use despite wide variations in fax system implementations. One can obtain a fax machine, connect it to a telephone line or cellular phone, and send a black and white page to a receiver anywhere in the world with consistent results.

Fax users do not need to be experts on data communications, file transfer, image scanning, image printing, or data compression to use a fax machine. They simply insert a document, dial a number, and wait for their document to be delivered. Most fax user problems originate with the paper handling mechanisms rather than any part of the imaging or communications systems. One can think of fax as implementing a 1970's version of Plug and Play.

Fax technology has many useful attributes—it is a well-defined application, it is defined by a single standards organization, it has broad participation from industrial sponsors, it specifies the entire system from carrier modulation to file transfer protocols to image encoding format, and it provides a flexible negotiation scheme to allow systems with differing capabilities to dynamically build a usable end-to-end configuration. Its pervasiveness, consistency, and ease of use have made group 3 fax very popular, despite its relatively poor image quality.

The recently approved color extensions[2,3,4] to group 3 fax have added color capabilities to the fax standard. New documents describing the color space and color data representation within the fax session specify the interaction between color-capable fax machines, which now become a basic color imaging system. Color images of moderate quality can be transmitted from sender to receiver with no intervention by the operator, despite a complex imaging path.[5]

2. Color Management Systems

A number of color management systems (CMS) have emerged in the prepress market during the past few years, including TekColor, Kodak KCMS, Agfa Fototune, and Adobe Postscript Level 2. The primary function of a CMS is to manage the interaction between elements of a color imaging system through device profiles and a reference color space. The device profiles are used to describe the color properties of various input and output devices, relative to the reference color space. Color matching software

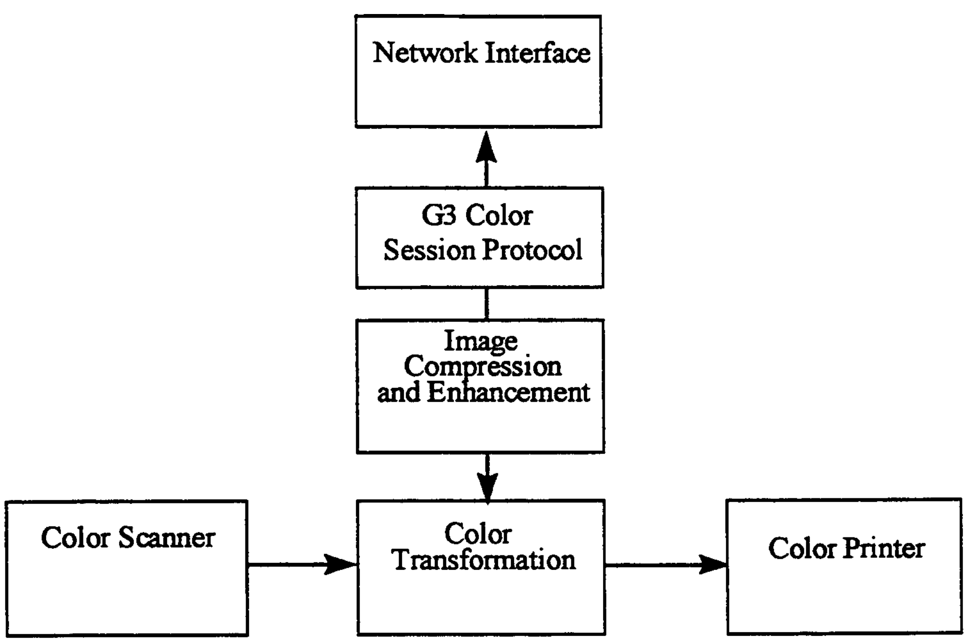

Figure 1. Block Diagram of Color Fax System

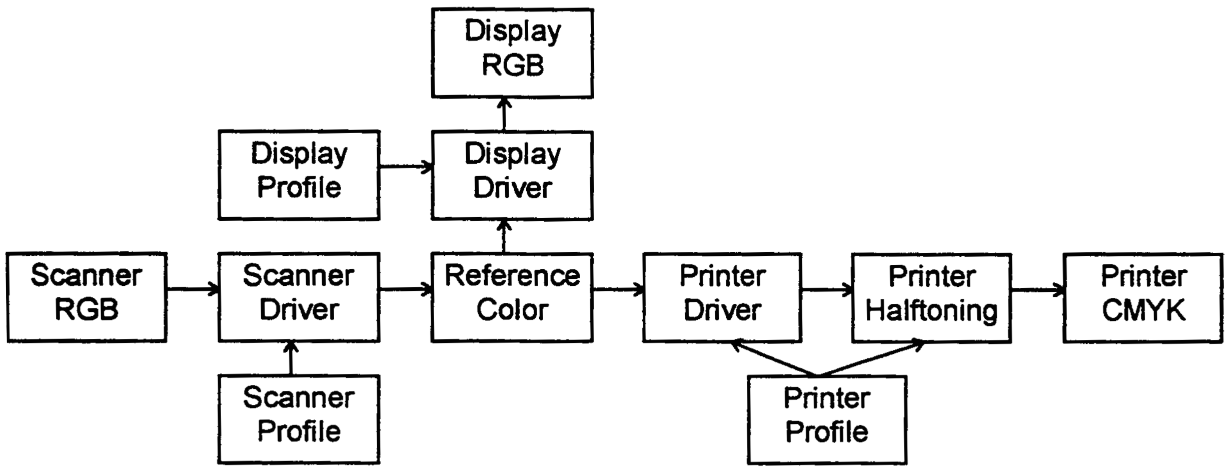

Figure 2. Interaction of Device Profiles and Reference Color Space in Imaging Path.

is then used to build a transformation from the source to the destination color space, using both colorimetric and perceptual techniques.

A block diagram of an imaging system using device process is shown in Figure 2. The device profiles are used with the device drivers to obtain a more portable representation of the color information. In practice, the image data may be converted directly to the target color space rather than to the reference color space to reduce the number of calculations and improve overall performance.

CMS's are being promoted by application developers and peripherals manufacturers, but will eventually require support by systems vendors. Microsoft has begun providing an integrated CMS called ICM[6] (Image Color Matching) with Windows 95, which may help broaden support for color management. CMS's are already available for the Macintosh (ColorSync) and SGI systems and are typically used with prepress applications.

2.1 Device Characterization—Profiles, Reference Color Space

There are a number of difficult challenges in implementing a color management system. Each device to be used with the system must be accurately characterized in terms of the reference color space, including scanners or cameras, displays, and printers. These devices are often moderately unstable, changing their behavior with time, temperature, humidity, power, media, and other uncontrollable variables. In a professional environment, variations can be addressed by spending more on equipment and periodically recalibrating the system, but this is not practical for a casual user. The International Color Consortium has defined a profile specification[7] in an effort towards promoting standardized device profiles for interoperability between CMS's fiom multiple vendors.

2.2 Configuration Management

Configuration management presents another serious problem for CMS's. In the past, successful implementations of color systems have mostly been proprietary, closed architectures fiom a single system vendor or integrator. There are a number of advantages in a closed system design, including the ability to specify or know the complete imaging path from input to display to output. Part of the success of the Macintosh has been due to its proprietary architecture,[8] which provided self-configuring capabilities well before the Plug and Play initiative. Other commercial color systems have been proprietary designs as well, such as color proofing systems and color copiers, avoiding the configuration management problem by not allowing any reconfiguration.

The vertically integrated, closed architecture approach does not work well in the PC market. The PC business has been characterized by rapid, Darwinian evolution of new products and capabilities as vendors and customers collectively try all permutations of every new technology. This has tended to make PCs more difficult to use than equivalent closed systems, as the system configurations are often unknown and untested, but has also accelerated the introduction of new products and services by reducing the technical and economic barriers to entering the market with a new idea.

3. Some Shortcomings of Color Management

Color management systems have been most successful so far in well-defined environments where all ofthe components are provided or tested by a single vendor, and the system configuration is fairly stable. Desktop publishing applications such as Adobe Pagemaker or Quark Xpress are now designed to take advantage of 3rd party color management tools. By defining and promoting a set of requirements for color interoperability, application developers have been able to achieve good results with a variety of equipment, especially when only one set of imaging applications is used.

Many of the shortcomings of current color management systems have little to do with their color science aspects. Some of the largest usability problems are poor system performance, lack of contiguration management, and imaging effects which not accounted for in the CMS model.

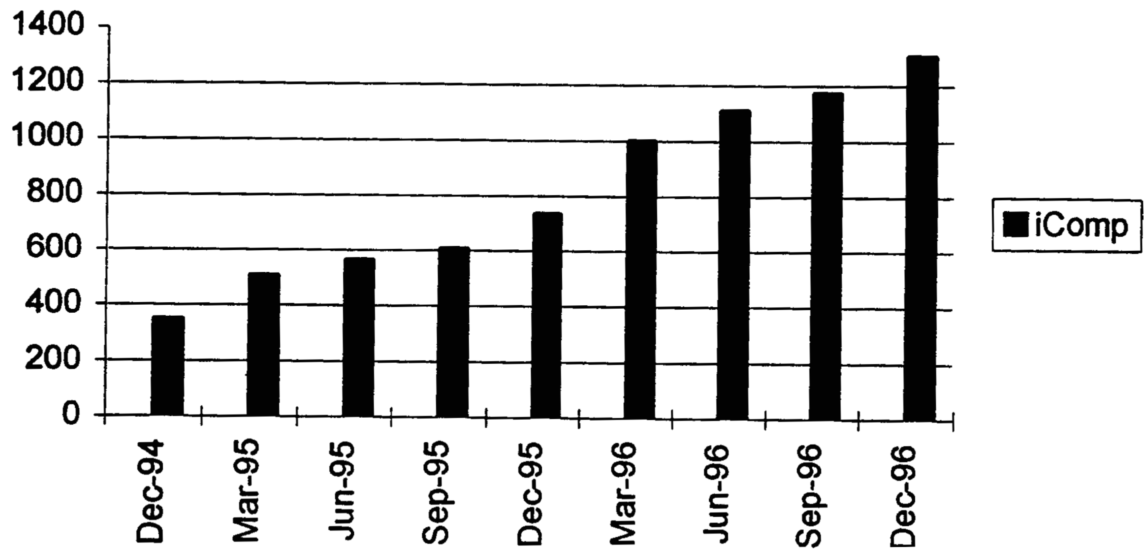

Figure 3. Historical and Estimated DeskTop PC Performance.[9]

3.1 System Performance

Accurate color brings with it potential requirements for additional processing and memory storage for color transformations, interpolation, and scaling algorithms. Most current are not tightly integrated, which leads to poor performance due to software overhead and redundant copying and transformation as data moves through the imaging path. This effect will diminish over time due to continuing increases in computer performance, which is roughly doubling in speed every year as shown in Figure 3, and as color imaging systems become more commonplace, which will lead to development of more efficient, standardized processing stages which are less demanding on hardware resources.

An important consequence of low system performance is that a fully configured CMS is often too slow for everyday use by casual users on current desktop systems. This leads to users turning color management facilities on and off, compounding a related problem, poor configuration management.

3.2 Configuration Management

The absence of reliable configuration management leads to differences between the assumed and actual system configurations. Achieving predictable color results requires a detailed and accurate description of the imaging path. Consumer and office desktop systems, on the other hand, are used with a variety of software and hardware rather than a single integrated package as in professional applications. Each application and driver may individually provide a pleasing result, but their behavior whencombined together is often uncoordinated and unpredictable.

Many applications and hardware drivers attempt to provide color management and contiguration controls, but do so in away that is mutually incompatible, typically assuming that no other coior facilities are present in the system. Turning on all the "best" mode flags for a collection of PC imaging applications and drivers can easily result in a worse image produced with more effort than the result of turning all enhancements off. The large speed penalty and unpredictable results associated with using an uncalibrated color correction software currently lead to enable and disable color processing stages in a hit or miss attempt to "improve" their output image.

Other problems are introduced as system peripherals are changed, adjusted, upgraded, or simply age. Computer displays are particularly vulnerable to changes in viewing conditions, aging and knob adjusting, and printers are routinely loaded with different media and ink, all without any easy feedback path to color management resources. These can easily be addressed in a professional environment through regular calibration , but present problems for the occasional user.

3.3 Unmodelled Imaging Effects

A number of non-colorimetric effects are difficult or impossible to take into account in any imaging system. Professional users minimize these problems by defining an imaging path and restricting the allowable changes to it, which makes it consistent and predictable. On the consumer and office desktop, however, it is more difficult to limit the use of the system to a well-defined set of software and peripherals, as users switch between word processors, presentation graphics, desktop publishing, and entertainment applications using an assortment oflow cost input devices and printers.

A number of effects are difficult or impossible to model. Device- and observer-dependent characteristics such as printer, sensor, or display dot size and shape, halftoning pattern visibility, viewing conditions, ink/media interactions, gamut matching, paper fluorescence, and rendering intent, are not easily described within a device color profile, if they can be described at all. Systems currently deal with these effects by ignoring them, by avoiding them, or by attempting to guess at the "best" solution with information about the application or device.

3.4 What You See Is Not What You Want

The ultimate goal of digital color imaging is usually *not* to achieve the most accurate reproduction through the imaging path, but rather to achieve the most pleasing output image. Differences in device capabilities in a color imaging system, for instance, gamut and resolution, mean that what you see is often not what you want. For instance, the image input, output, and display may have significant differences in their color gamut, making it impossible to accurately preview the output on the display. New nuorescent and metallic inks present an simple example of this.

Inexpensive color printers have become widely available during the past few years. Driver software such as HP's ColorSmart[10] now usually provides some kind of"vivid color" option for presentation graphics, which moves the output colors to more saturated values with reduced halftoning visibility, rather than preserving color fidelity. This is a example of "user preferred color reproduction", in which the color processing attempts to produce a "better" output based on the user's intended application. True color fidelity is not possible because of differences in device gamuts.

4. Some Emerging Opportunities for Plug and Play Color

The migration of color imaging technologies from the professional to the consumer arena presents a number of opportunities for a Plug and Play approach to color imaging.

4.1 The Internet—Web Publishing and Printing

During the past two years, the internet Web has gone from the realm of esoterica to pop trend to commercial frontier. While early academic and research users were content with hyperlinked text and simple palette color images, the adoption of the Web as a consumer and commercial medium has accelerated the movement towards more sophisticated document content as magazine publishers and retail vendors go on-line. Printed magazines, advertisements, and mail-order catalogs have traditionally been designed by graphic artists and art directors who have had control of the final appearance ofthe printed document. In the on-line environment, the document creator is decoupled from the presentation mechanisms, making the final result unpredictable.

The need for more predictable output from on-line documents is driving enhancements to HTML (Hypertext Markup Language), the basic interchange format for Web browsers, and is also creating demand for portable document representations such as the PDF (Portable Document Format) used in Adobe Acrobat. The graphic and image content of the Web is increasing rapidly as more professional and commercial publications go on-line, increasing the need for stable and predictable color reproduction. The Web is intrinsically platform-independent designed to operate across a variety of hardware and networking environments. A major challenge to providing quality color imaging over the Web is in providing a well-defined imaging path not only from the local browser to its display and printer, but also from the remote server to the local browser.

4.2 The Intranet—Corporate Document Distribution to the Desktop

In parallel with the expansion of the public Internet, private data networks within organizations are rapidly being adopted for distributing internal documents ranging from personnel policy and benefits manuals to engineering documentation to sales and marketing literature. As in documents published for the external Internet Web, there is a broad range of delivery environments which may be connected to a corporate Intranet.

4.3 Digital Photography

Consumer digital photography presents an interesting challenge and opportunity for color imaging because it is an area in which users already have a strong set of expectations based on years of experience with film-based photography. A $10.00 disposable camera and $10.00 of photo finishing will yield 24 color prints of moderate to high quality with no intervention by the user. Current consumer digital cameras such as the Kodak DC40 cost over $500 and can make an arbitrary number of color prints of poor to fair quality after significant effort by the user. It is clear that the ability to connect any digital camera to a imaging application, printer, or other device, and achieve a pleasing level of image quality would be a great achievement from a number of perspectives.

The overall image quality of both consumer and professional digital imagery continues to improve as new marking technologies and media become available and camera sensor resolution and dynamic range increases. However, a major obstacle to achieving a good "photographic" experience in the digital world is the current unpredictability of the digital color reproduction process. In the traditional film world, cameras, film, and photo finishing have gone through many years of refinement, automation, and cultural adjustment, which allow the typical user to take a picture, process the film, and receive predictable results. Film-based photography has very wide tolerances and graceful process degradation, which help make it robust. In the today's desktop environment, even the basic processing path from image to print requires substantial intervention, and the limitations of currently available sensors, printers, and desktop computers leave very little margin for error. The combination of high cost, low process tolerances, and a high rate of user intervention remains a significant obstacle to consumer digital photography.

5. Summary

Successful implementation of any color imaging system requires an accurate description of the entire imaging path, making configuration control and accurate device profiles one of the fundamental tasks for plug-and-play color imaging. The emerging Plug and Play standard may provide a useful framework for promoting automatic system configuration, including color. The addition of color management as a standard desktop system feature will also ease the configuration problem.

System performance, a moderate issue for professional environments, is currently a critical one for casual color imaging users with limited patience and processing power. The problem will gradually be solved as desktop systems become more powerful standardization of color processing leads to more efficient, integrated hardware and software implementations, and applications require less user intervention in general.

Wide acceptance of color management systems, standardized device profiles, and automatic configuration management will still leave many difficult problems unsolved, as color management and configuration control is *necessary* but not *sufficient* for predictable and pleasing color appearance. Perceptual and intent-based rendering techniques will continue to provide image quality improvements as applications become more focused and user expectations are better defined.

Bringing color imaging systems to the mass market presents many interesting technical, economic, and social challenges. Closed, proprietary color imaging products can quickly offer working solutions to niche and vertical applications which benefit fiom a single unified view of the world. As color imaging moves into the mainstream, however, the trend is towards open, interoperable systems based on broadly accepted standards which evolve from solutions to specific user needs.

This pattern can be observed in the history of a wide range of technologies, from railroads to automobiles to computers to the Internet, and is a consequence of the economics of technology businesses. It is not sufficient to have the "best" technical solution until that solution presents sufficient value to the prospective consumer, which often requires the development of related infrastructure. An "Align and Conquer"[11] approach—forming domains of interoperable technologies among participants in the marketplace based on mutual self-interest—permits an infrastructure to emerge while leaving room to explore many potential solutions simultaneously.

Plug and Play, ICC profiles, Web publishing, digital photography, and the economics of mass market computing are currently (1995) of interest to largely disparate constituencies. The challenge of delivering stable, high quality color imaging to the desktop will require finding and developing alignments of benefits that spans them all, and ultimately the end user.

References

1. Microsoft Corp., Hardware Design Guide for Microsoft Windows 95, Microsoft Press, 1994.
2. ITU-T Rec. T.81/ISO/IEC 10918-1 (JPEG), Information technology—Digital compression and coding of continuous-tone images.
3. ITU (Q.5/8 Rapporteur), Amendments to ITU-T Rec. T.30 for enabling continuous-tone colour and greyscale mode for Group 3, COM 8-43-E, June 1994.
4. ITU (Q.5/8 Rapporteur), Amendments to ITU-T Rec. T.4 to enable continuous-tone colour and greyscale mode for Group 3, COM 8-44-E, June 1994.
5. G. B. Beretta, K. Konstantinides, D. T. L. Lee, H. J. Lee, and A. Mutz, Implementing a Color Facsimile Machine, *Proc. 11th Non-Impact Printing Congress*, November 1995, Hilton Head, South Carolina; (see page 256, this publication).
6. A. King, Inside Windows 95, Microsoft Press, 1994.
7. International Color Consortium, *ICC Profile Specification*, Version 3.2, November 20, 1995, International Color Consortium.
8. Apple Computer, *Designing Cards and Drivers for the Macintosh Family*, Addison-Wesley 1992.
9. Intel Corp., http://www.intel.com/proc/pix/icomp.html
10. Hewlett-Packard Co., http://www-dmo.external.hp.com/peripherals/printer-copiers/tech-briefs/colorsmart.html.
11. D. Kline, *Align and Conquer*, Wired, February 1995, pp. 110-117, p. 164.

☆ This paper was previously published in *SPIE,* Vol. **2658**, p. 236 (1996).