A Personal Color Proofing System for Computer Generated Images

by Elizabeth Rosenzweig
B.A. Goddard College
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Submitted to the Deparment of Architecture
in partial fulfillment of the requirements of the degree of
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on Graduate Students

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ABSTRACT

Just as the invention of photography challenged the world's visual literacy at the turn of the century, so has computer graphics begun to reshape visual communication. Although still in its infancy, recently developed tools for visual communication have made computer graphics and electronic imaging accessible to a much larger number of artists and other professionals. The use of these systems has emphasized a new need for an automatic color image proofing system combining text and images in variable size. Such a system would ease the distribution of and acessibility to digital images with high quality and low cost.

This thesis describes the Color Proofer, a system that has been designed to meet these needs. This system includes a software package that performs basic image processing functions similar to basic darkroom manipulations, designed for color hardcopy. It also includes a system for creating halftone dot fonts to aid in the production of high quality color proofs. A typesetter capable of producing magazine quality color images and text is an integral component of the Color Proofer. The Color Proofer is designed for photographers and graphic designers who want high quality proofs of computer generated images.

Thesis Advisor: Muriel Cooper
Title: Associate Professor of Visual Studies

A Color Print from the Color Proofer

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INTRODUCTION

In recent years, the power of the computer has increased to allow for dramatic advances in data processing. With new speed and accuracy comes applications which were unthinkable only a few years ago. Nowhere are these advances more apparent then in the field of graphics. Computer processing and image generation have expanded the frontiers of visual communication. Simply by implementing algorithms, artists and other visual communicators may manipulate and/or create an almost unlimited variety of images in real time. Even the artist inexperienced with computers can create images with a menu driven paint system. The tools no longer limit the users' imagination; instead they push creativity to another frontier not unlike the early developmental stages of photography.

At the turn of the century, photography brought about a revolution, like the current developments in computer graphics, that challenged man's view of the world. By freezing and immortalizing images he could examine those images in greater detail than before. He could keep records and communicate ideas with accuracy that was previously unimaginable. In addition, the power of photography was made accessable to many people by its combination with the technology of printing. Published photographs allowed people to visit other lands, attend social functions or fight in a war by simply picking up a newspaper, magazine or book.

Even though computer graphics has now created a similar revolution by developing the tools that allow an increase in creativity similar to that of photography, the images have not yet experienced as wide a circulation. The merging of computer graphics with printing and publishing has encountered problems; it is not in the price range of most people and is generally inacessable.

Current output systems are inadequate to meet the challenges brought on by the advances in graphics. Current technology is too expensive and difficult to use. While contemporary electronic proofing systems are capable of producing color separations of images in a plate ready form, few of them are capable of producing a color proof of those color separations within a reasonable price range. In addition, the technology is still limited. Photographic hardcopy can produce high resolution prints from computer generated images but in a restricted format and size. Until now, no output system could produce a color proof that is a faithful representation of the final image displayed on the monitor or allows the user to control the size or format of that output.

This thesis presents the Color Proofer designed to fill these needs. It is a system with software and hardware components that:

- is easily accessible to a greater number of novice and experienced users.
- can create a low resolution halftone font.
- manipulate images with the aid of a frame buffer and images processing functions such as:

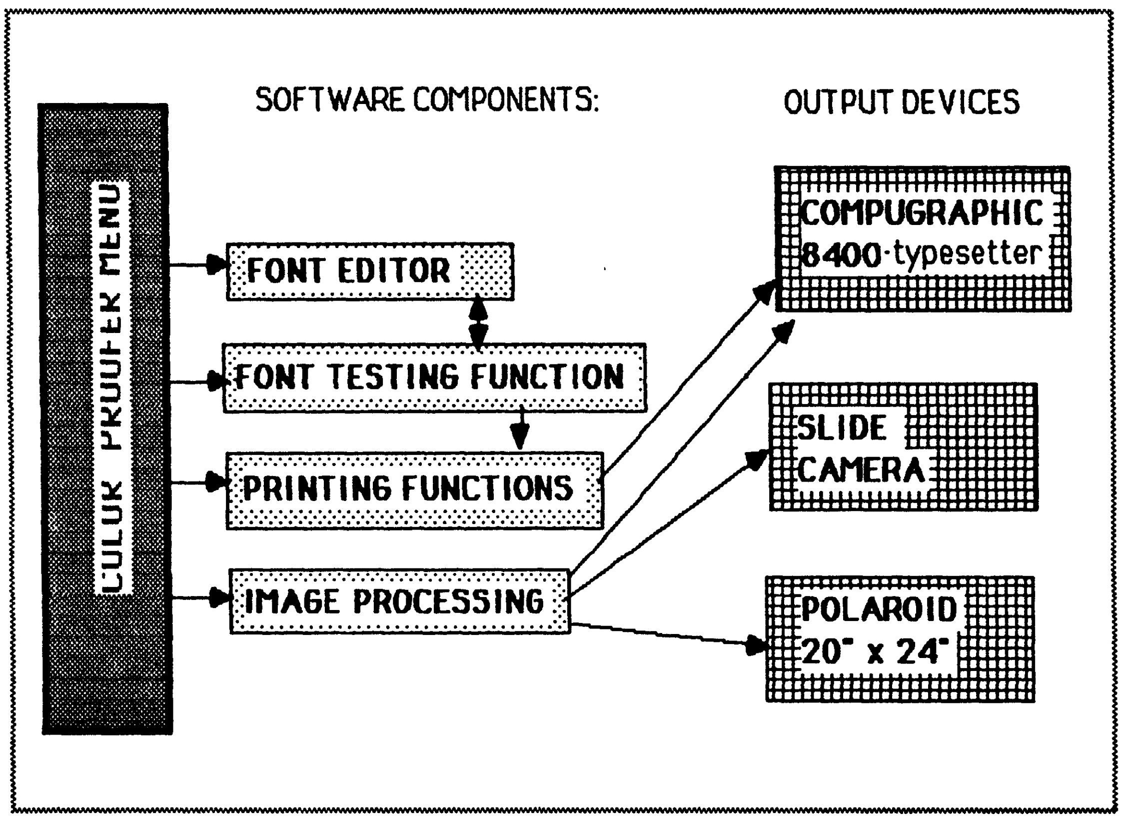
  color corrections in a variety of ways

  contrast correction.

- allows the user to control the size and format of the output.

- can produce output that is high contrast, low (30 dots per inch) or medium (130 dots per inch) resolution.
- can produce black and white color separations or full color images and text on a single page.
- can produce hardcopy much less expensively than current systems.

COLOR PROOFER COMPONENT DIAGRAM:



CHAPTER ONE: THE COLOR PROOFER

SYSTEM ENVIRONMENT

The Color Proofer was developed at the Visible Language Workshop (VLW), in the Media Laboratory at the Massachusetts Institute of Technology. The VLW is a graphics research laboratory that has pioneered in the personalization of design systems to combine text and images. A prototype designer artist system includes many basic image processing functions as well as a paint package and collage techniques, with real-time visualization. The Color Proofer extends personalized image proofing within this system.

The hardware system includes a Perkin Elmer 3220 central processing unit, a 32-bit mini-computer with 512K of core memory. Disk storage is a 300 megabyte "trident-type" drive with a high I/O bandwidth. Images are displayed with a Grinnell GMR-270 frame buffer with 512 by 512 resolution and 27 bits for color. These color bits are broken down into 8 bits per color channel and 3 bit for the overlay planes. Each color channel of red, green and blue is addressable independantly. Each of the 3 overlay planes can be addressed individually and contains one bit of color information.

The software is written in PL/1 and run on a Multics Operating System called Magic Six developed at MIT. Many of the software packages are run from a workstation composed of a data terminal, a high resolution RGB monitor, and a black and white monitor for overlay planes. Input devices include a digitizing tablet, a puck with four control buttons, and a digitizing camera for grabbing images.

The output devices for obtaining color hardcopy include an Image Resource Camera capable of producing 35mm slides or negatives or 4" x 5" film of any type. Additional, output devices include a Polaroid 20" x 24" camera and a Compugraphic 8400 typesetter (see figure 1).

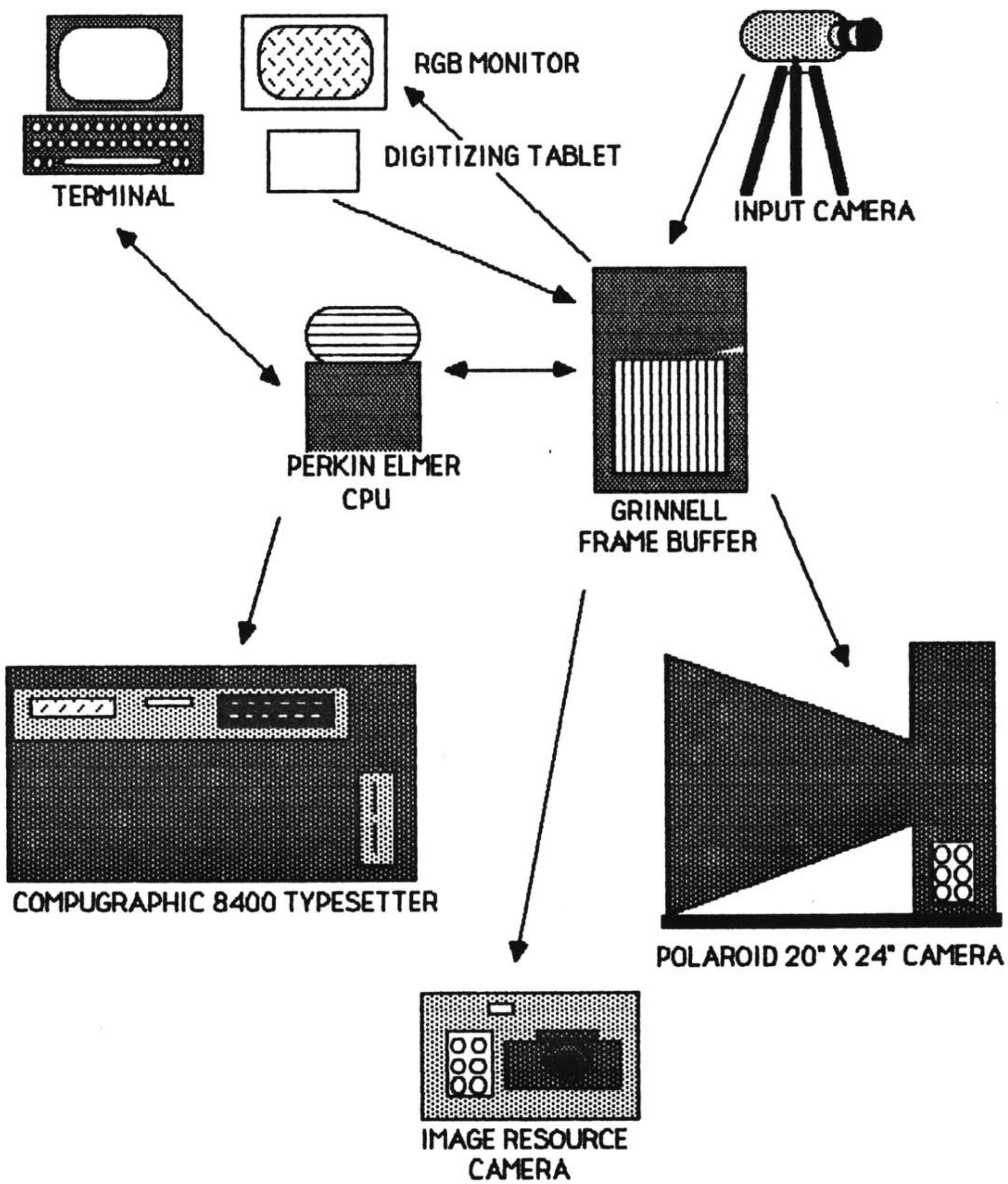


Figure 1. VLW System Diagram

THE COLOR PROOFER

Designed for a photographer or graphic designer to produce proofs of computer generated images,, the Color Proofer is capable of producing camera-ready color separations and full color proofs of halftone screened images. The Color Proofer provides these users with image processing functions, a Font Editor and communications with output devices.

IMAGE PROCESSING

The Color Proofer has functions which occur in analog for mechanical image production processes such as photographic dodging and burning, and bumping and flashing in the halftone screen process. These functions manipulate specific tonal areas of an image such as highlights and shadows. To compensate for distortion during the printing process, photographers manipulate their prints by holding back light in the highlights for darker effects or adding more light to shadow region for lighter effects. These methods emphasize local information stored in the negative that otherwise would not translate to the positive. This type of tonal region manipulation is also used in creating images with a halftone dot screen. In this process, where dots vary in size according to tonal area, the correct dot must be printed for the corresponding tonal range. Because of the nature of photographic substrate involved with making halftone screen images, problems periodically occur in highlight and shadow regions when an exposure is correct for the midtone regions but loses detail at the other ends of the tonal range. This problem is solved by making more then one exposure sometimes one each for shadows, highlights and mid-tone regions.

Many of the problems faced by photographers and graphic artists in the darkoom and with the copy camera are also present in the production of color hardcopy proofs and camera-ready layouts from digital images. The Color Proofer solves these problems with its function for contrast correction, which includes basic gamma correction and color correction.

THE FONT EDITOR

When a designer needs to create a halftone font that simulates a certain screen, the Color Proofer is robust enough to produce any type of font in any shape dot (see figure 2). The user can either create a new font or edit an existing one with the Font Editor.

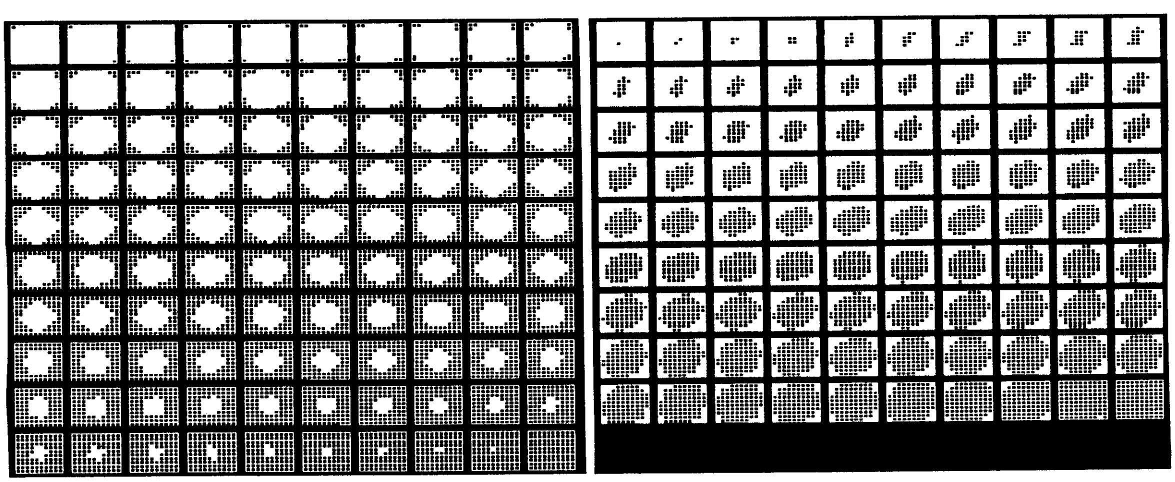


Figure 2. Experimental Low Resoloution Fonts

PRINTING IMAGES

Once the font is created there are several ways of testing it on the screen or as a proof with an image (see figure 3).

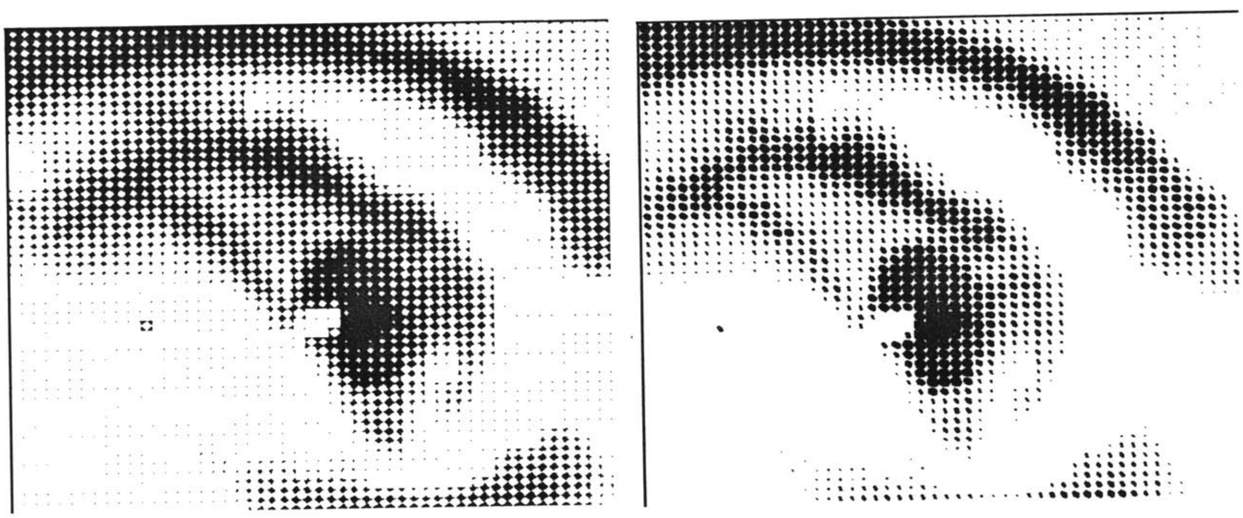


Figure 3. Fonts Tested on an Image

Proofing is done with an interface from the Perkin Elmer 3220 CPU with Grinnell GMR270 frame buffer to a Compugraphic 8400 typesetter(see figure). A user simply runs the programs to open the ports so that the machines can talk to one another (see Appendix 1 for details on the communications procedure). The central menu of the Color Proofer will ask the user to specify size and type of image to be set, (i.e. high contrast or halftone screen, and color or black and white) and then the utilities will send the necessary data.

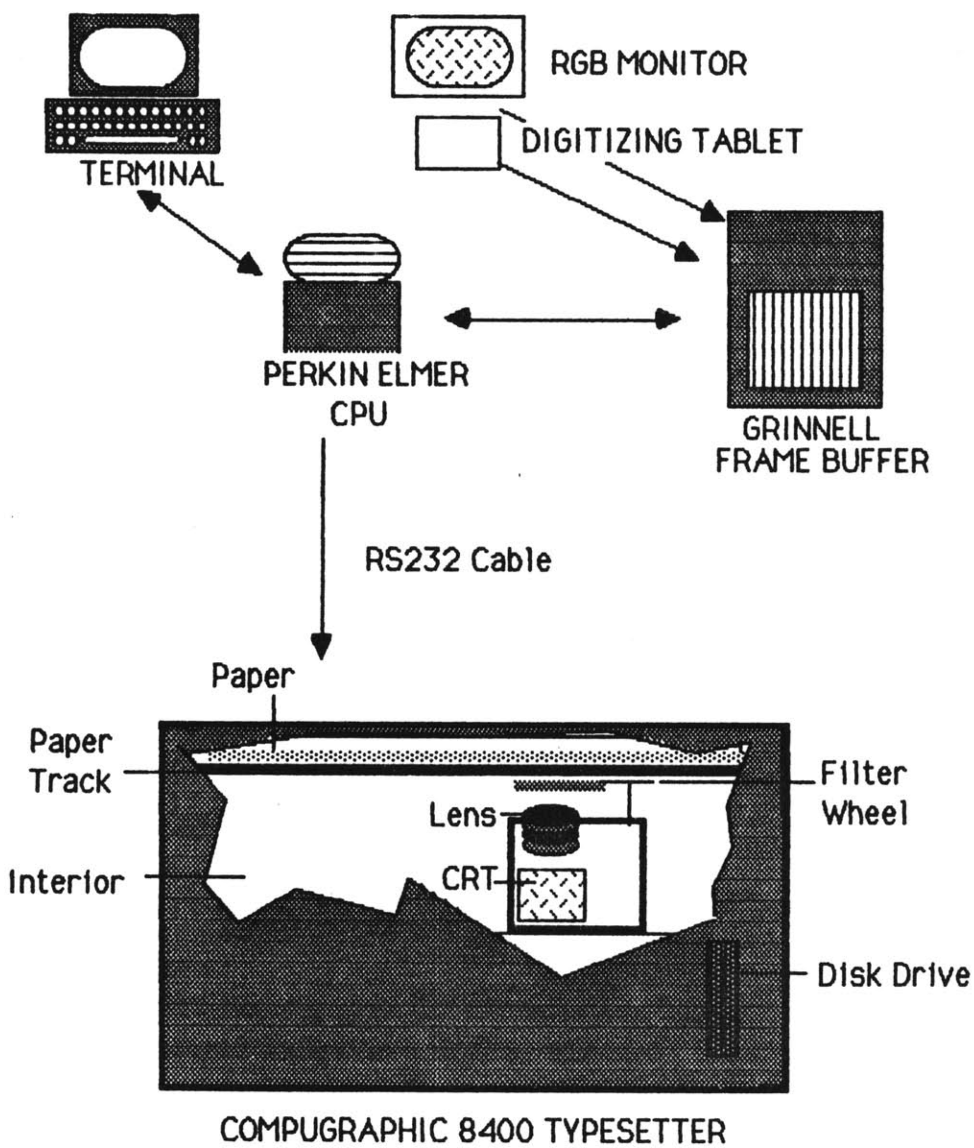


Figure 4. COLOR PROOFER System Diagram (typesetter detail).

Once image type is specified the system will print one pass of an image. When the user specifies a color image he will run three passes of an image to produce full color. The menu will ask what color pass is desired and the system will print the correct one.

Printing is accomplished by sending each color channel to the Compugraphic 8400; a 5" black and white CRT prints the image through an optical color filter that absorbs all color components except the one being printed (see figure 5).

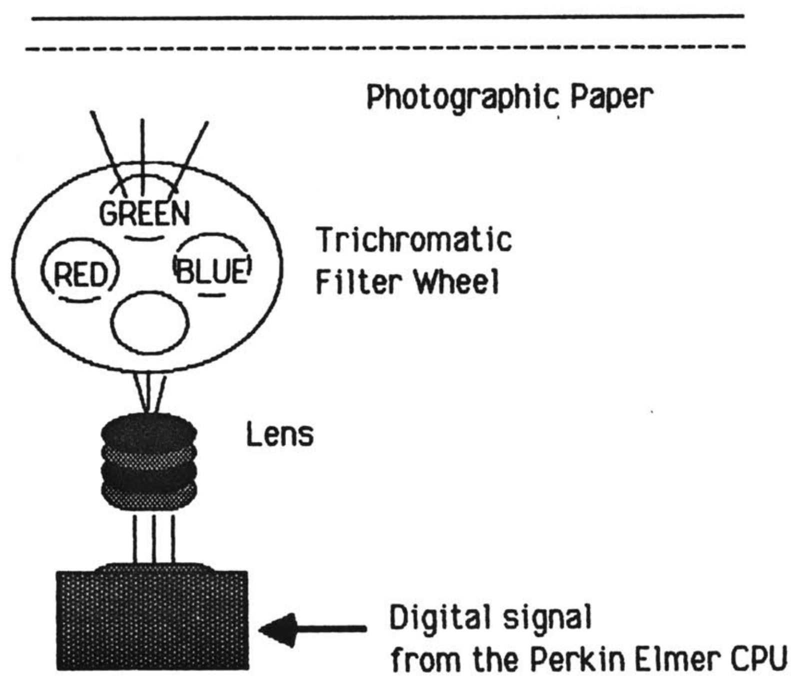


Figure 5. Detail of Color filter system in the Compugraphic 8400.

The CRT moves horizontally across the paper, exposing each raster; the paper move vertically through the typesetter to expose the next raster (see figure 6). After each color pass the 8400 will automatically send the paper backwards so it is ready to print the next color. Each color is offset at approximately 30^0 from the others. The only manual operations the user has to perform is changing the filter and setting the exposure for each color pass. When the procedure is finished the 8400 and the Perkin Elmer automatically close the port.

Overhead View of Paper Transport and CRT Movement in the Compugraphic 8400

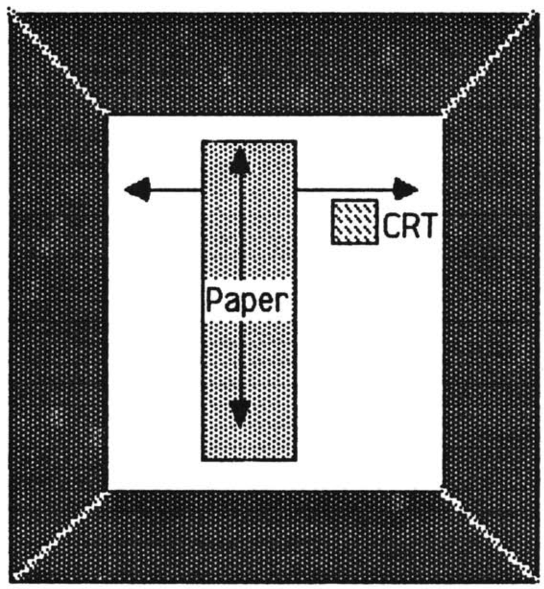


Figure 6. Paper and CRT movement.

Once the image is printed in the typesetter, the user simply has to run the image through the black and white or color processor. The image is developed in the traditional manner, which is still quite efficient and then it is hung to dry.

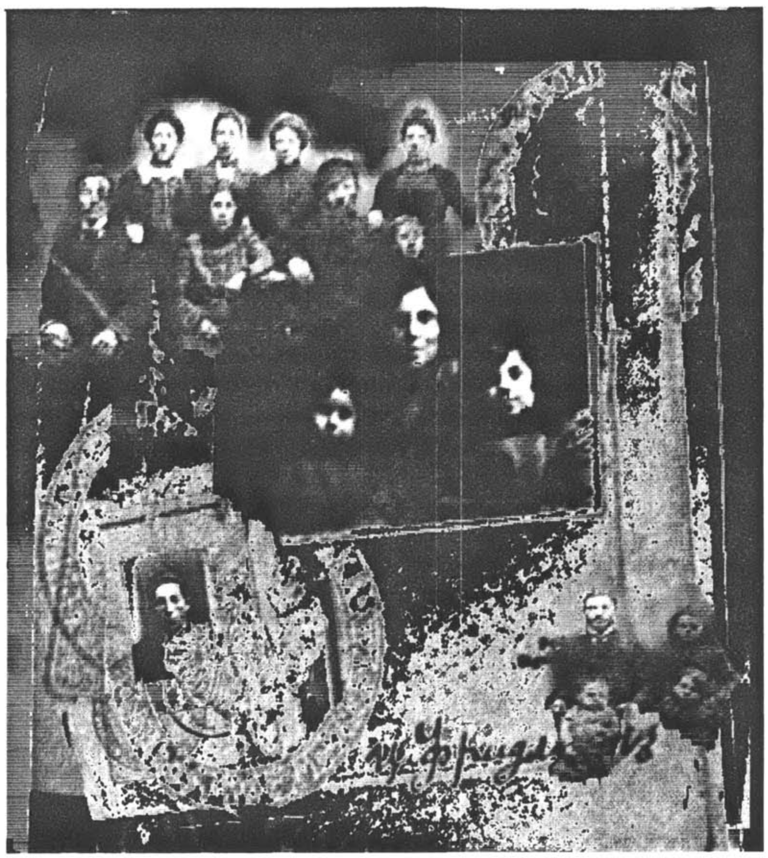


Figure 7. Medium Resolution Image (original on frontspiece in color)

THE MEDIUM RESOLUTION FONT

To produce medium resolution images with the Compugraphic 8400 a medium resolution font was designed. This was done initially in the Font Editor in a low resolution and then digitized by Compugraphic.

The low resolution fonts were a great aid in designing the resulting medium resolution font because colors, tonal range, edge characteristics and shapes of the characters could be tested in a real image . Some fonts were useful in themselves for special effects to create a given image with the desired effect.

Testing programs for the Font Editor were used to design the final medium resolution font. As a result, close examination of each character in the font, its relation to the other characters, and its appearance in the final image could be closely examined.

DISTRIBUTION OF FONT CHARACTERS TO PIXEL VALUES

The value of each pixel determines the font character to which it is assigned. Pixels in the frame buffer have values from 0 (black-light off) to 255 (white, light fully on). The experimental halftone font has characters ranging from 001 to 118. Unfortunatly these characters are not distributed linearly . The largest halftone dot in the font is numbered 101 and progresses down to 118. These dots are larger then the 10 by 10 matrix the font is based on. The next size character down from 118 is numbered 001 and progresses down to 099. Unfortunately, the character numbered 090 is to large for the highlight values of the surrounding characters and therefore can not be used.

Due to the nonlinear and somewhat arbitrary nature of the progression of the font a look-up table was created to assign pixel values to font values.

Since the extra eighteen characters on the shadow side of the font were larger than the matrix area of the rest of the characters, these darker characters were used sparingly for the pixel values 0 - 15 (in fact font characters 101 and 102 were not used at all since they were so large). The other 240 pixel values were distributed over the remaining 98 usable characters on the font. These characters were not distributed linearly because the difference in the characteristic curves of the two media reveals that the translation of values is not linear.

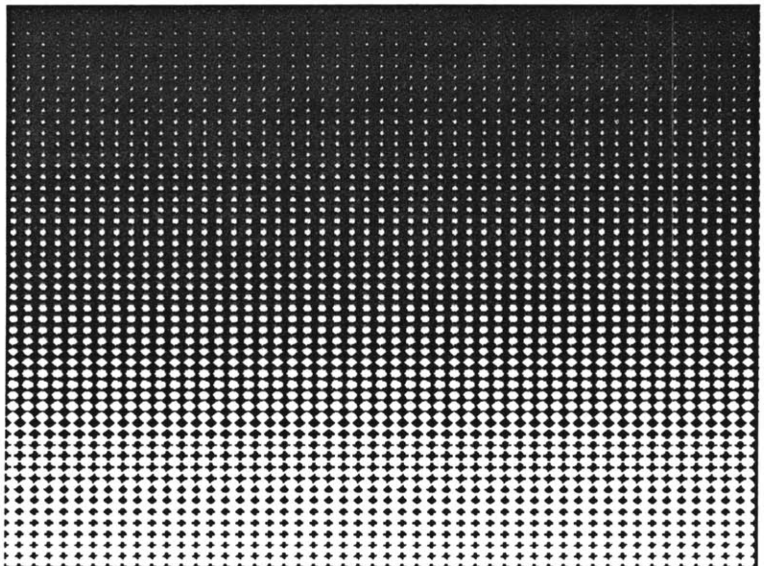


Figure 8. Low Resolution Font,(30 dots per inch) design for medium resolution font.

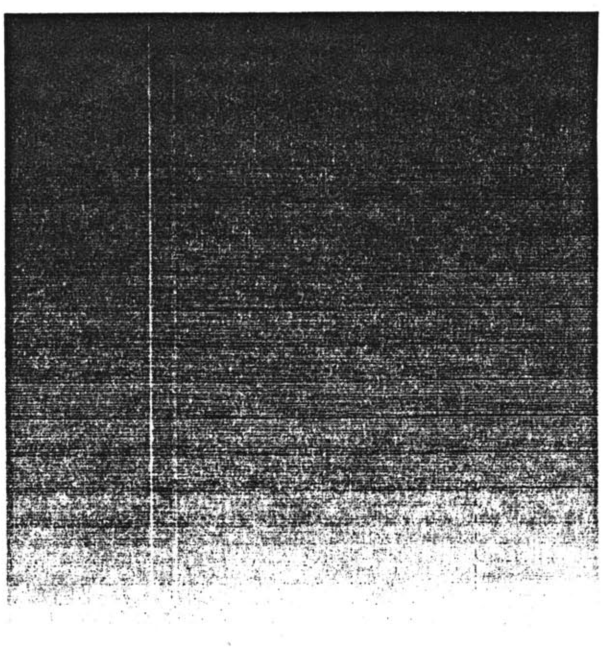
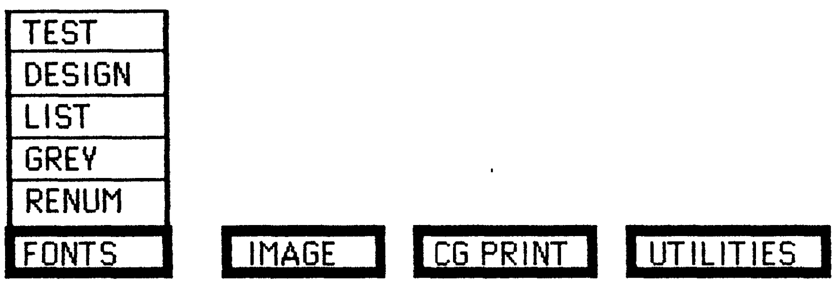


Figure 9. Final Medium Resolution Font (130 dots per inch).

COLOR PROOFER FUNCTIONS

The Color Proofer is a menu-driven system, accessed with a digitizing tablet and a puck. The bottom level of the menu has four categories, shown below.

The FONTS menu leads to all halftone font functions.



The DESIGN selection calls the Font Editor which produces up to 100 characters of halftone dot characters. The Font Editor can create fonts, save them, edit existing fonts and save the changes. The Font Editor is also a menu driven function can be used in the same screen as the workspace (see figure 10). The user can manipulate a ten by ten array of squares or pixels, representing the font. Each particle character, or halftone dot pattern, is shaped by turning each pixel to a desired threshold value. Each pattern of shapes, or each character in the font will correspond to a particular grey value in an image, a one to one correspondence is made and a tonal range can be simulated. A user can create a font by creating patterns of dots; a threshold value is assigned to each dot in the matrix. This threshold corresponds to a picture element (pixel) value on the frame buffer. This threshold values will turn on the pattern of all the font characters with lower threshold values when used to print an image. The halftone dots are distributed in a linear fashion; the first character produced is the first threshold used; each dot pattern is displayed at the corresponding grey threshold value. The second character is the second threshold value and so forth.

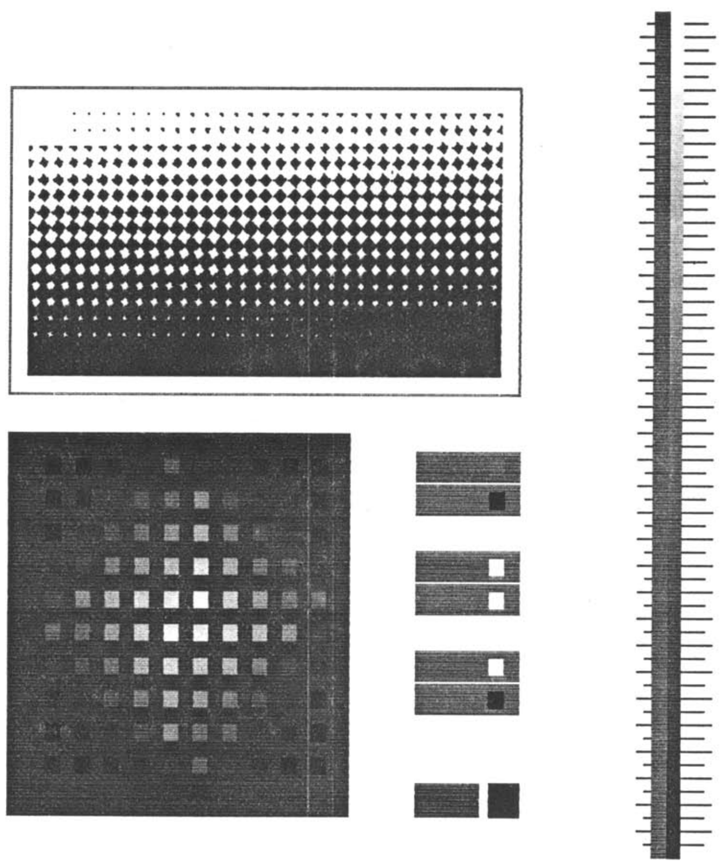
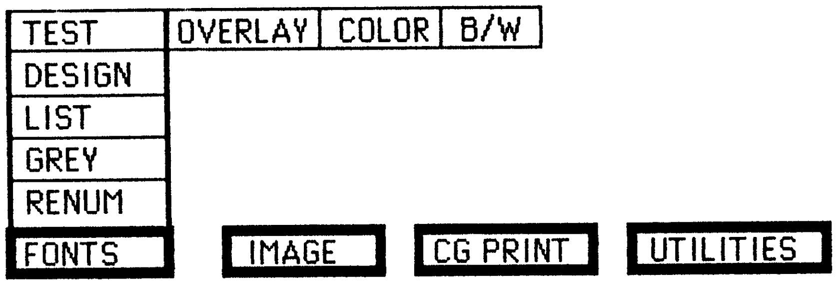


Figure 10. The Font Editor

The font editor displays a small greyscale version on the upper right region of the screen. This allows for instant proofing of the font on the screen. It will also display the threshold values on the terminal, in the 10 by 10 array, as well as indicating where the minimum and maximum value sit in the array. The lower left region of the screen displays the matrix and a sliding scale on the right of the screen allows the user to select threshold values. The middle of the screen contains the menu with selections for loading, saving, initializing and quitting.

The RENUMBER selection calls the function renumber font. The Font Editor distributes the threshold values in a linear manner; each threshold value has a one to one correspondence to the font created. This is a good method except when novice users produce a font with less than 100 values, or create a font that contains a few characters with the same threshold value. Renumber changes the distribution of threshold for each character. The existing font is distributes over a parabolic curve. As a result some image regions become truncated and consequently they may appear more contrasty. However this is useful for some images that don't have a high dynamic range.

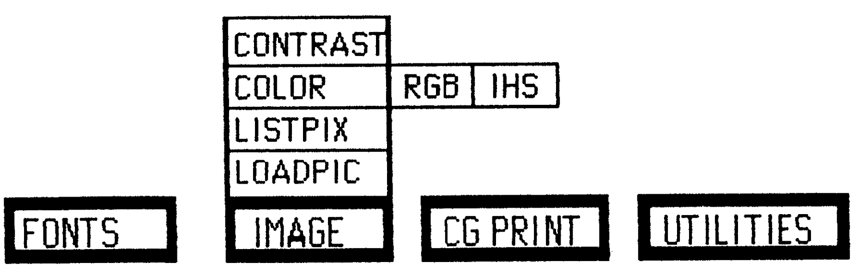
The GREY selection allows the user to view an entire font on the full screen. A greyscale representation of all 100 characters ranging from the smallest dot to the largest appears. This greyscale function displays each character in the font on a grid in the order of the threshold value. The lowest threshold values, usually 0 is display as its font character; the characters are printed in order to the highest threshold value which is usually 255.



TEST allows fonts to be tested in a low resolution situation. The user can choose a 50 by 50 pixel region of an image and test the font on the local region.

There are three different methods of testing the font, one the overlay planes, as color separations or in black and white. OVERLAY tests a font without writing over an image. This allows many fonts can be tested , one at a time, comfortably and quickly. The user may print any font and image on the output device in black and white or color; the halftone version of the image will be printed on the monitor. The Compugraphic 8400 is then sent the information that is displayed an typesetts that image.

IMAGE is the level with the basic image processing functions.



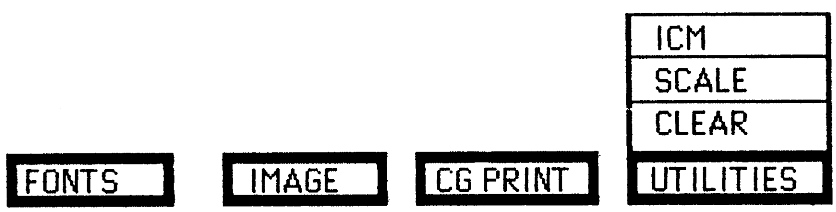
CONTRAST manipulates the contrast of an image. A prompt appears for an image area to be selected. Then the user is asked for threshold value to for comparison with the old value and a new contrast factor. The old pixel value is read and adds or subtracts the contrast factor to the old value.

COLOR lists the color spaces to work in. RGB is the primary system IHS is an alternative choice to RGB.

LISTPIX lists all the pictures stored on the disk.

LOADPIC prompts the user for a picture name to load onto the frame buffer.

UTILITIES contains the choices to test images.

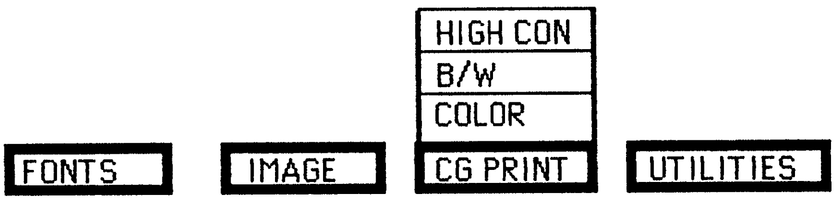


ICM initializes the color matrix, a lookup table specifying the color of each image.

CLEAR clears the screen.

SCALES displays colorscales for test images.

The CG PRINT menu contains the choices to print images on the Compugraphic 8400 typesetter. The choices include high contrast black and white, low resolution color and black and white halftone screened images.



To print an image the menu prompts the user for information about point size and color separation. The computer's work for this becomes virtually invisible .

USER SCENARIO

A graphic designer is laying out a brochure and has created an illustration on the image manipulation system. She wants to proof a color halftone image but needs to decide what type of halftone screen she wants to use for the image. Using the Font Editor, she selects a font and decides she wants a variation of it. Experimenting with the pattern and consequent grey scale of the font she plays with the results until she gets what she wants. To see what the font will look like when printed she tests it on the screen. Either she can test the font on the overlay planes without destroying her image or directly on her image to print a proof. In addition she can proof her image in a higher resolution in hardcopy and use the experimental font.

Before she produces a higher resolution proof she may want to perform some contrast corrections. The image on the screen has a low contrast ratio (shadow to highlights) and will appear to lose some detail in the final proof. The halftone screening process will give the image a little contrast, but not enough to suit her. Then she can use the Color Proofer image processing functions to correct the contrast or the color to get the desired effect.

Finally obtaining an image processed to her satisfaction, she wants to proof it. By running the color proofing program to read her image off the disk, she can print three color separations and produce a full color proof.

To prepare a presentation of her layout the Color Proofer will produce slides. However the images she needs are too dark and will lose some detail in the shadows when the slides are exposed. To make these selected regions lighter and still keep the rest of the tones at the same value she calls the Color Proofer image menu to change the contrast slightly and lightens only the shadows.

Since her film was too warm her image contained an excess of red. To change the color balance of the image and decrease the red, the Color Proofer's color correcting tool will manipulate the color in a variety of color spaces to cool down the colors.

When the slides are exposed, the shadows will contain all the information produced on the CRT and the colors are balanced correctly. What she designed on the screen was what she output.

CHAPTER TWO : BACKGROUND

The Color Proofer makes use of technology from photography, halftone screen printing, digital image processing and electronic image generation. In order to place the Color Proofing system in a context, it is helpful to know the background history of the technologies it incorporates.

TIME-LINE OF COMMUNICATIONS

1456	Printing-Gutenberg Bible
1837	Daguerre introduces Daguerrotype photograph
1839	Fox Talbot creates photographs from negatives
1853	Fox Talbot produces photoengravings
1880	Shantytown printed in *N.Y. Daily News*
1881	Ives develops cross-line screen for printing images
1898	Eastman produces the Kodak
1963	Sutherland creates Sketchpad
1980's	Xerox introduces Star, Apple introduces Lisa, Macintosh
1985	*Color Proofer*

PRINTING HISTORY

Images and text were produced on printing presses, with very laborious techniques dating to the beginning of the fifteenth century.

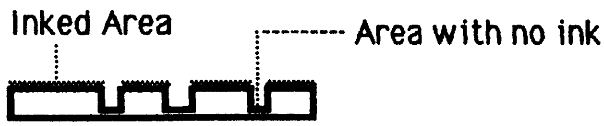
Johann Gutenberg mechanized printing and used moveable type to print the Gutenberg bible in 1456. He changed the technology that allowed for the development of printing images and text on a single page. Communication changed its form. Books, the domain of the priveledged, became more plentiful. Printing allowed larger editions of books to be distributed and literacy ensued.

Originally images were printed either by engraving or etching plates by hand using a fine pattern of lines or shapes to hold small amounts of ink and create the illusion of a tonal range. These were all done by master artists with years of training. They would either copy existing paintings (again done by master artists) or they would create originals on the plates. Thus the kinds of images and image makers were quite limited by the small number of artists. When books were created in the one of a kind fashion, the illustrations were drawn and colored by hand. Text and images were printed in black and then the illustrations were handcolored.

PRINTING SYSTEMS

There are three processes commonly used for printing: letterpress, gravure and offset lithography [1].

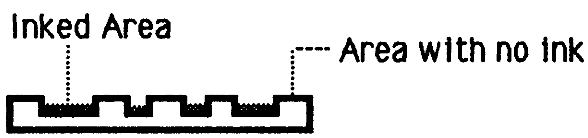
Letterpress is printed by a method called relief, one of the oldest of the printing technologies. Relief printing is done from cast metal type or plates, the printed area is raised above the nonprinted area. The ink rollers touch the raised area which is printed, no ink gets to the surrounding areas and they are not printed. Letterpress is the only method which can use type directly.



Cross section of a Letterpress plate

Figure 11. Letterpress Plate

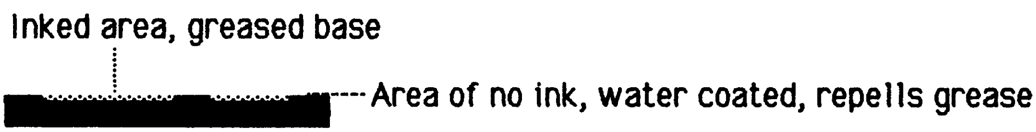
Gravure employs a method of printing called intaglio. In contrast to relief printing, intaglio uses depressed regions in a plate for the printing surface. Images are etched into a plate or copper cylinder whose surface represents the area that is not printed. Ink is applied to the surface of the plate and then wiped off, the depressed regions hold the ink which is directly transferred to the paper and an image is printed. Gravure is excellent for the reproduction of images because it can hold a very fine halftone screen on the plate and thus produce a highly resolved image.



Cross section of a Gravure plate

Figure 12. Gravure Plate

Offset lithography is a planographic process which means that both the printed and nonprinted areas of the plate are on the same plane. The distinction between the two areas are maintained chemically and based on the principle that grease and water do not mix. A plate is exposed photographically, on an emulsion that is water repellant; the surrounding surface, the area of nonprinting is grease repellant and water receptive; water is used to keep ink from the nonprinting area. Ink rests on the image area of the plate, and is transferred to an intermediate cylinder called the blanket. The image is then transferred or offest from the blanket to the paper and it is printed. A major advantage of offset lithography is the soft rubber surface of the blanket cylinder allows for a very sharp clear image on a variety of paper surfaces.



Cross section of Lithographic Plate

Figure 13. Lithographic Plate

Printing presses operate in a binary manner, they can either put down opaque ink or no ink. This operation can be represented mathematically by indicating areas of ink with a value of 1 and areas of no ink with a value of 0. Images and type can be represented digitally in the same fashion as printing presses.

HISTORY OF PHOTOGRAPHY

Photography brought about the revolution that challenged the existing visual domain. The people of the Renaissance were fascinated recording images with the Camera Obscura (dark room). These first darkrooms were designed to project an image on a flat surface through a very small hole on an opposite side of the room. Thus, the only light entering the room was through the pinhole. These images could then be recorded by placing paper under the projected image and tracing the object with a pencil. Eventually the dark room developed into a dark box (shown in figure 14). However this tool was that it was too large and bulky to be portable.

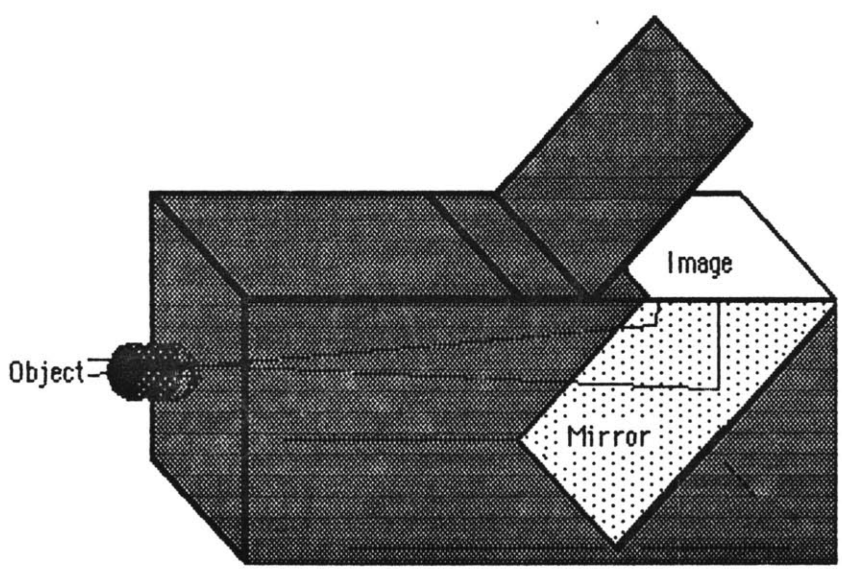


Figure 14. Camera Obsura.

The Camera Lucida (light box) was introduced in the early nineteenth century as a hand-held model of the camera obscura. It was portable enabling an artist to record images that anywhere he could go.

Finally the recording of images onto a substrate was introduced by Lois Jaque Mande Daguerre in 1837 and W. H. Fox Talbot discovered the negative photograph process in 1839 [2]. These findings introduced the technology for exposing and reproducing image with film. Both these men used silver crystals to expose an image with light. Today silver halide crystals produce an extremely fine grain layer of light sensitive emulsion that exposes continuous tone images. Today this process is still the highest resolution available to record images.

When George Eastman introduced the Kodak in 1898 he made camera vision accessable to the laymen. As in the case of printing, photography redefined the visual communication. People began to see the blurs in motion, and the strange and magical position that moving objects assume when they are frozen in mid-movement. The frame in photographs created new shapes and forms when objects were cut off at an edge. Photography provided travelers with evidence of trips and explorers with records of new discoveries.

PHOTOGRAPHIC CHARACTERISTICS

Sliver halide crystals that form different emulsion types react differently to light. Some emulsions have a high sensitivity to different wavelengths of light, while others have a lower threshold for exposure.

The nature of photographic images can be represented by H & D curves, or characteristic curves which represent the density of the film emulsion measured against Log of the exposure of the various tonal regions. These curves are useful for describing characteristics such as contrast, and shadow and shadow detail.

Photographic substrate's ideal characteristic curve that is logarithmic (see figure 15). The shadows start a little bit above 0 density, the point called "film base plus fog density" [3]. This is because even an unexposed piece of film will have a slight amount of density from the base of the film and the development process. After this region the shadow values almost plateau, a region in the curve referred to as the toe. After this the curve climbs through the midtones in an almost linear fashion. This means that the midtones of the region progress in an additive manner. Once the curve reaches the highlights it plateaus again in a region called the shoulder. As in the case of the shadows the highlights progress in a logarithmic fashion, where detail is harder and harder to decipher.

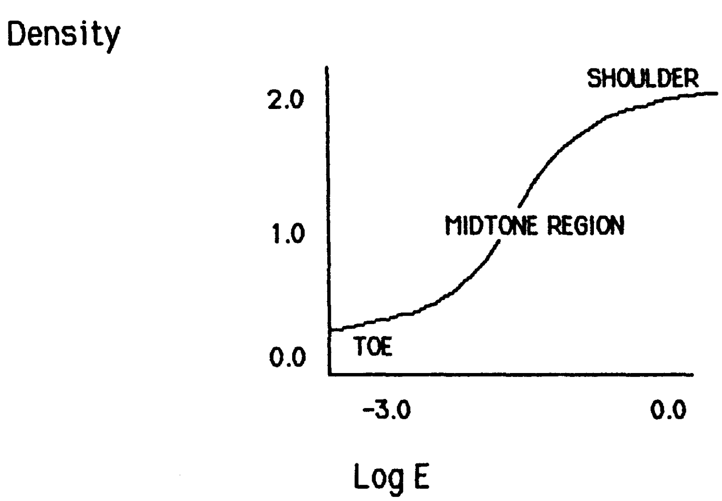


Figure 15. Photographic Characteristic Curve.

COLOR PHOTOGRAPHY

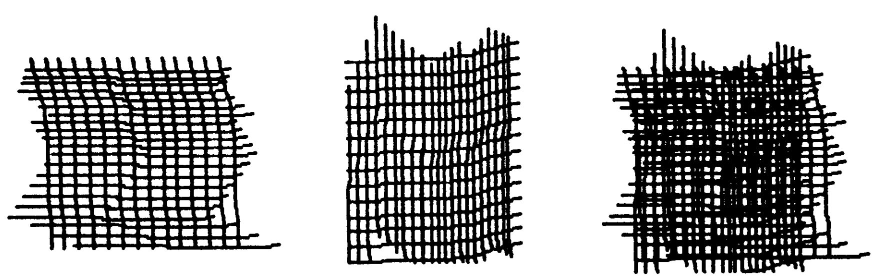
Ever since the invention of Kodachrome 35mm film, color photography has been accessable to amatuer and professional photographers. Images could be produced in color without going to the trouble of hand coloring. These color photographs could reproduce the real colors in the scene with a fair amount of accuracy.

Once photographers could produce color photographs, publishers had to develop methods of reproducing these color images with ink.

PRINTING PHOTGRAPHIC IMAGES

Printers face the problem of how to reproduce photographs which are composed of varying tones of grey . Since printing presses operate in a binary manner- they can only print ink or no ink. Varying shades of grey obviously require varying amounts of ink.

William Henry Fox Fox Talbot the inventor was the first to struggle with the problem of printing his photographs in ink. Fox Talbot began experimenting with methods of creating printing plates with light and chemistry. In 1853 he devised a process he called photoengraving [4]. Fox Talbot exposed a pattern through many layers of material on the substrate and then exposed the image over the pattern. The resulting image was composed of a fine pattern of varying intensity that corresponded to the grey in the original image. When this method was used to expose a plate, the pattern, or "veil" as Fox Talbot called it, (see figure 16) engraved patterns on the plate that held intensities of ink that corresponded to the amount of grey in the original image.

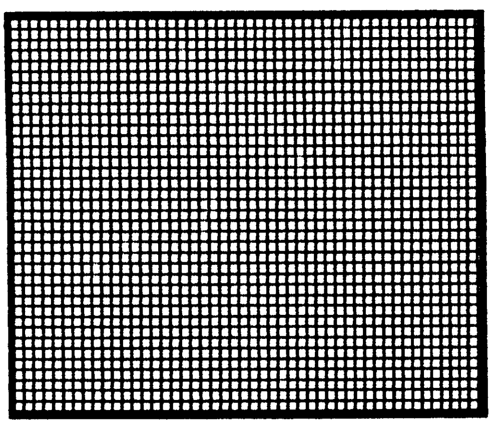


Original Pieces of material Veil

Veils created by placing pieces of material on top of each other.

Figure 16. Fox Talbot's Veil

In 1880 the *New York Daily News* printed a picture called "Shantytown" that used Fox Talbot's method. By this time another scientist, Frederick Ives was working on a screen that made Fox Talbot's veil obsolete. Fox Talbot had been having trouble with consistency with his veils that were created by layers of fabric, a highly irregular material. Ives developed the cross-line screen which he drew lines at right angle to each other on a piece of glass (see figure17). Thus he could expose this same screen on the plate before he exposed the image and count on consistantly producing a finely patterned image [5]. This pattern broke up the grey values so finely, that when used to expose a plate it would create fine grooves to hold the ink.



Crossline screen created by etching opaque lines on glass.

Figure 17. Ives' Crossline Screen

Ives' method was so successful and reliable that we still use it extensively in print today. However today we use a screen of finely patterned dots, called a halftone screen. This screening method breaks tones down to tiny dots. Each dot corresponds to a grey value; the lighter (more white) the grey value, the smaller the dot; the darker the grey value (more black) the larger the dot is. This method takes advantage of the eyes inability to focus tiny objects at far distances. If the dots are too small, the eye can't resolve them and they appear to a continuous tone.

HALFTONE DOTS

The conventional method of obtaining halftone screened images is a photographic process produced in a process camera. A sharply focused continuous tone image is projected onto high contrast lithographic film, through a slightly defocused halftone contact screen. The intensity of the light exposing the film is modulated by the array of regular dots on the screen. The size of the dots is regulated by the amount of light projecting through the screen. Since light travels in straight lines, each part of the original image reflects a different amount of light through the screen and produces a different size dot on the film. This dot is proportionate to the reflective brightness of the original image [6].

Thus, the halftone dots in the final positive print get larger as the light becomes less intense, the highlight areas of the original image will reflect a higher intensity of light and produce a pattern of small dots that do not touch (see figure 18) . Shadow areas in the image reflect less light and produce a pattern of dots of high density which touch the other dots and produce a black area in the halftoned image. The density or size of dot is referred to as "dot percentage". This means that a full size dot, that touches its neighbors and produces a solid black area is a 100% dot ,the lightest dot printers can generally print is a 10% dot and a middle grey value is represented by a 50% dot.

The size of the dot is directly proportional to the amount of light that is being projected through the screen. The more light that is reflected off the image and onto the screen the larger the dot in the negative screened image. When translated to a positive, the highlights contain the small dots and the shadows contain the larger dots.

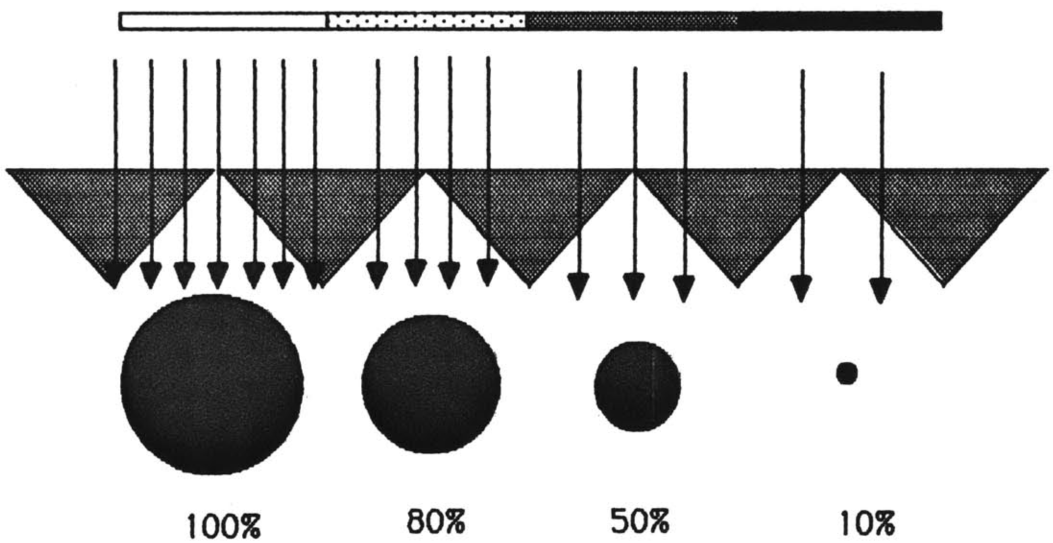


Figure 18. Light transmitted through a halftone dot screen.

These halftone dots percentages function in a manner very similar to binary encoding of images for use in computer graphics. Since they are binary in nature they can be translated into numbers the computer can process.

The Color Proofer relies on this binary coding of images. The Color Proofer reads the digital information about the grey values in the image translates this information into halftone dots which the typesetter prints on photographic emulsion.

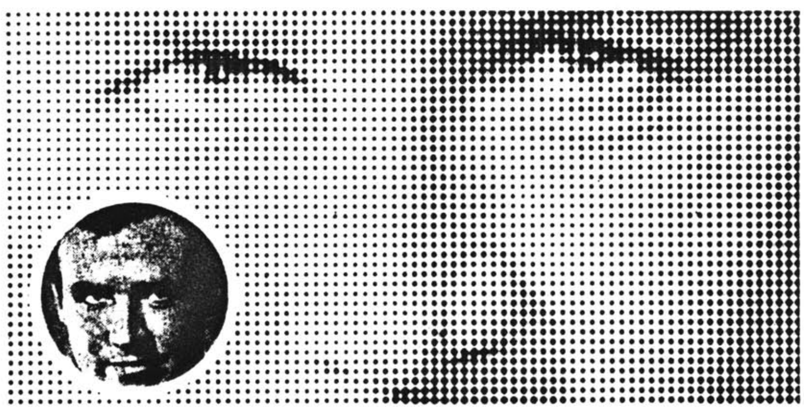


Figure 19. Halftone screened image and detail of corresponding halftone dots.

Pocket Pal, International Paper Company

COLOR PERCEPTION

In order to design a system for matching colors from one image to another it is helpful to understand the nature of color, light and some of the psychophysiology of human color perception.

Sir Isaac Newton began experimenting with light and color in 1660. One of Newton's most revolutionary discoveries, that led to much of the present knowledge of human perception is the concept of spectral light. He noticed that when he directed a white light through a prism the light rays split into the colors of the spectrum (shown in figure 21)[7]. In other words, white light is actually a composite of many colors.

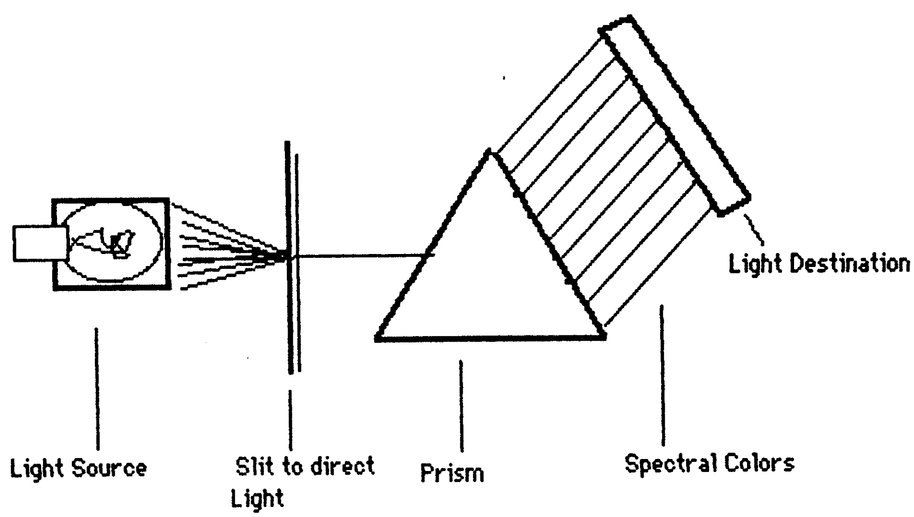


Figure 21. Newton's Experiment with Spectral Colors.

Newton experimented further and discovered he could block off sections of the spectrum and project a light that appeared to be a single color. Newton showed that two colors can be physically different (different wavelengths) and appear to observers to be the same color.

These discoveries provided the basis for many color matching systems today. A color system may produce the entire spectrum by using combinations of only a few colors.

Visual perception rests on many factors. The eye is sensitive to different levels of light intensity, wavelength and frequency of light. Visual perception is also dependent on the viewing distance from the object; how far the light can carry visual information has to travel is directly linked to the intensity of the light. Light enters the eye through the cornea, proceeds through the pupil and travels to the retina where an image is formed, (see figure 22).

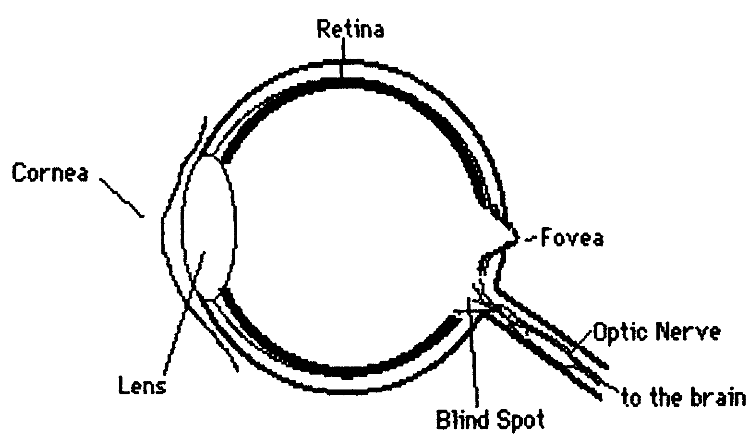


Figure 22. The Human Eye

The retina contains a distribution of two kinds of photoreceptors which sense light and then send signals to the brain containing information about this light. These two kinds of receptors are called rods and cones. Cones contain light sensitive pigments that read information about high intensity light and color. The cones are centered around a depressed region of the retina called the fovea, the point of most acute vision. Rods are the cells that contain light sensitive pigment which are receptive to low levels of light. Rods read information about contrast and shape in objects. The information read by the cones is sent to the brain where it is combined with information from the rods to produce images.

Systems can be designed for color matching that exploit the psychophysical properties of the eye. Theories have been developed that are based on the primary color receptors found in the cones. Color reproduction systems such as printing, photography and television are based on these same theories. Halftone screening methods of reproducing images are based on the theory that the rods have a low threshold for spatial resolution. The dots are so small the eye can't resolve each one, so from the proper distance the eye averages the dots and they appear to be a continuous tone.

COLOR THEORY

To control and correct color it is helpful to understand the relationships between colors and how primary colors, add, subtract or mulitiply to produce other colors.

The tristimulus theory is based on the fact that there are the eye has three color sensitive photoreceptors which intereact to produce all the colors. Tristimulus values refer to the amounts of three reference stimuli required to match colors.

Grassman's Law states that since the eye responds linearly to color, three independant variables are necessary and sufficient to produce a color match. The second law for defining color primaries is that no two can combine to match the third.

ADDITIVE COLOR

Red, green and blue are the primaries called additive. These primaries are added to blackness (no light) to mix and produce a color. Additive color mixing is essentially a linear process, when two primaries are added together , as Cowan says, "their sum is a a color at the color space point which is the vector sum of point corresponding to the two component lights" [8]. This linearity makes it a simple system to use and is used for color television and raster displays for computer graphics. These technologies deal with transmitted light or light that is added to blackness. In color video display monitors light is transmitted through primary colored phosphers that add together to create other colors. Additive primaries are our main concerns with the frame buffer used in the Color Proofer.

SUBTRACTIVE COLOR

Cyan, magenta and yellow are the primary compliments of red, green and blue respectively. These primaries are subtracted from white to form a result. Subtractive primaries are created by passing white through filters. Since these are products of primaries, instead of linear additives they are much harder to measure and control. Subtractive primaries are used in many hardcopy devices that employ color photographic emulsions, or systems that deposit ink on paper such as ink-jet printers or Color Xerox. These systems are concerned with relflective properties of light. Light is reflected from the paper through the dyes, activating them and creating colors. The Color Proofer uses subtractive primaries when printing photographic hardcopy of the digital images.

COLOR SPACES

Color primaries can be represented in various three dimensional spaces. One method of representing additive and subtractive primary space is in a Cartesian Coordinate system. Primaries are vectors along an original axis black for additive and white for subtractive. Any color produced by these primaries can be represented as a vector sum of the primary components. No color primary can sit on a vector that intersects a vector originating at the other two primary.

A color cube (figure 23) shows the additive primaries sitting on axis originating at black. On a diagonal vector, opposite black is its compliment white. This vector contains the greyscale, all the values between black and white, where all the primaries are equal. The three axis originating at white end at the subtractive primaries, cyan, magenta and yellow. A diagonal can be drawn between any additive primary and its subtractive compliment to find all the colors in the range of these primaries. Colors are specified by their location in this cube and their proximity to a certain axis.

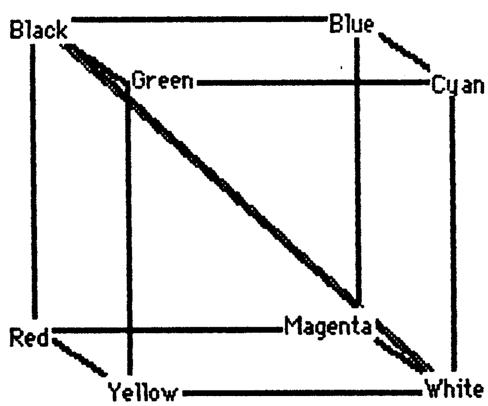


Figure 23. Color Cube

The above cube system in figure 23 is the color space in which most graphics hardware works. This system has a few drawbacks. It is unsuitable for interactive systems because it is not intuitive; most people do not think of color in terms of red, green and blue. Most people first notice a color's hue; the wavelength at which a color absorbs light.

Then other characteristics become noticeable; these are saturation, the amount of light white light reflected by the printed color and luminance, the value of the amplitude. Thus, this additive system of this cubic model is limited. Unfortuneately these limits are inherent in the hardware.

For more flexibility in control colors an alternative model may be used to convert the cubic color space into a more workable geometry. This is a cylindrical space and represents the color components hue, saturation and value (HSV) indicated in figure 24.

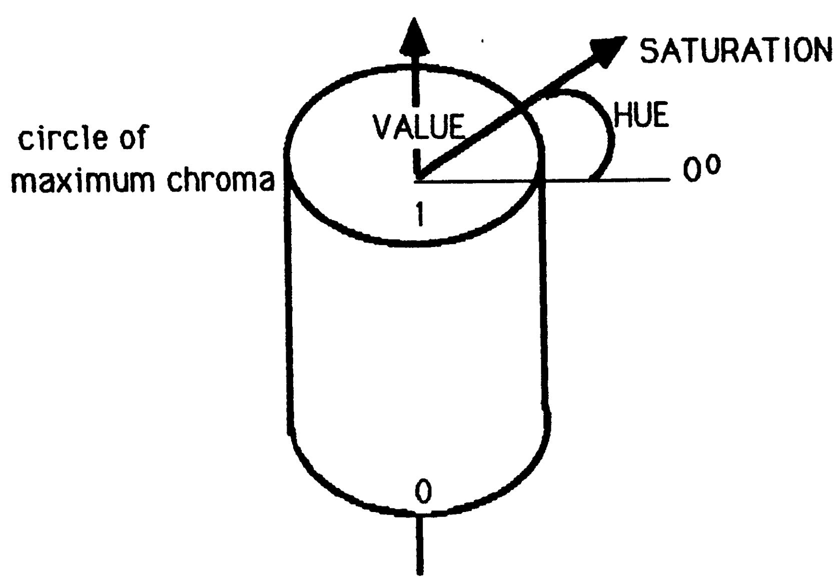


Figure 24. HSV Cone.

The HSV space can be described in the following manner:

HUE = 0 (angle)

where 0^0 = RED

120^0 = GREEN

240^0 = BLUE

SATURATION = radius

VALUE = height

Hue can be defined by the percentages of the three components of hue, Red, Green and Blue. C_1 and C_2 are obtained by subtracting the smalled component from the larger ones (see figure 25).

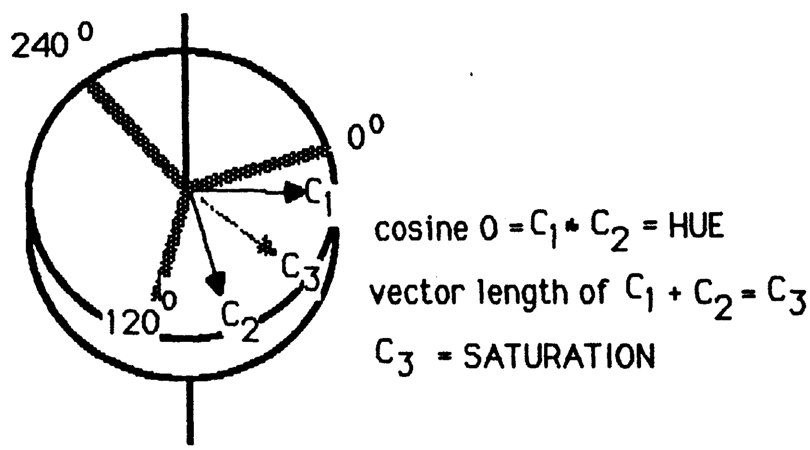


Figure 25 Slice of HSV Cone

Since the additive primaries RGB are the system that the frame buffer uses the Color Proofer provides the option of switching to the HSV primary system. The procedure takes RGB, translates it to HSV,(see appendix 3 for the algorithm), allows the user to manipulate the colors and then converts the values back to RGB. Thus colors can be manipulated more accurately and thereby obtaining better color matches.

COLOR SEPARATIONS FOR HALFTONE DOT PRINTING

Color separations are used to reproduce color images. The Color Proofer uses a method of obtaining color primaries based on the tristimulus theory and Grassman's law (see page 39). This software incorporates additive and subtractive primaries by exposing additive colors on a substrate that uses subtractive dyes.

Photographic systems produce halftoned screened color separations. This is done by exposing a sharply focused image through a slightly defocused halftone screen and then through a color filter that is the same primary as the desired separation. This filter holds back almost all color in the image except that primary and lets through only components of a color that contain that primary.

Thus each color separation (red, green and blue, which translate to cyan, magenta and yellow in photography) and produces a print made up of halftone dots that correspond to the grey values of the image. A full color image is produced by printing each one of the primary color separations on top of the others. In order to achieve full resolution each color separation must be printed slighted off center from the previous. This avoids the problem of a pronounced dot and grid patterns, and aids in taking advantages in the eye inablity to resolve low spatial registers.

The Color Proofer produces color images using these methods. Color separations of the digital images are sent to the typesetter and exposed on photgraphic emulsion by a black and white monitor through a primary color filter. This activates the compliement primary dyes which are contained in the emulsion. Each separation is printed slightly offset one another and when combined produce a full color image.

These full color halftone images produce a mosiac of 8 basic colors:

- black where three subtractive primary dyes overlap
- white where there are gaps or no exposed dots
- cyan, magenta and yellow when only one dot is showing
- red when magenta and yellow overlap
- green when yellow and cyan overlap
- blue when magenta and cyan overlap [9].

The other component colors from the spectrum are produced by laying down smaller dots of primaries, composing a color from varying components. The limitations to this method come in the form of incomplete color rendition many colors cannot be matched accurately.

The Color Proofer solves to these problems by correcting the color before the exposure. The additive subchannels in the digital system are converted to the HSV space described previously and the correction is performed with these primaries. This system provides a more exact color match to the original that is closer to the natural system used in the cones of the human eye (see page 37). When the optimum color match is acheived the color primaries are convert back to the RGB additive primaries, displayed and printed in the normal manner.

RGB to HSV conversion methods can also be used to obtain a correct color match after inputting images into digital memory. All these color theories can be repesented mathematically in a computer to aid in obtaining a high quality color image.

CHAPTER THREE: FOUNDATIONS FOR THE COLOR PROOFER

COMPUTER GRAPHICS

When Ivan Sutherland invented the Sketchpad in 1963, he introduced the concepts of creating images with computers. This hardware and software system could help the user draw a straight line, draw shapes, reproduce them and even merge them together. From this the technology came systems such as Apple's MacIntosh or Lisa for any novice or experienced user. Other systems have made computer graphics a recognized art form, a tool for creative image making.

During the last 15 years applications have linked, photography, graphic arts and computer graphics together in input/output of image creation, manipulation, page design and electronic halftone screening and platemaking systems. Frame buffers display complex images and text and cathode ray tubes (CRTs) expose images on photographic emulsion. Output are concerned with high quality hardcopy of images and text on a single page. The Color Proofer solves this problem by providing a color proofing system that has the potential to produce text and full color images on a single page.

DIGITAL IMAGE CONVERSIONS TO HARDCOPY

To understand the problems faced with printing digital images stored on frame buffers and displayed on a CRT an explanation of these devices may prove to be helpful. A 24-bit frame buffer, like the one used in the Color Proofer, hypothetically has a linear sensitometric response (straight line characteristic curve); a cathode ray tube has a convex curve. This difference presents problems when the digital image is printed on photographic emulsion with its S-shaped curve or printing presses with their limitation of color reproduction (see figure 26). Color and gamma correction becomes an important function when transmitting images from one medium to another.

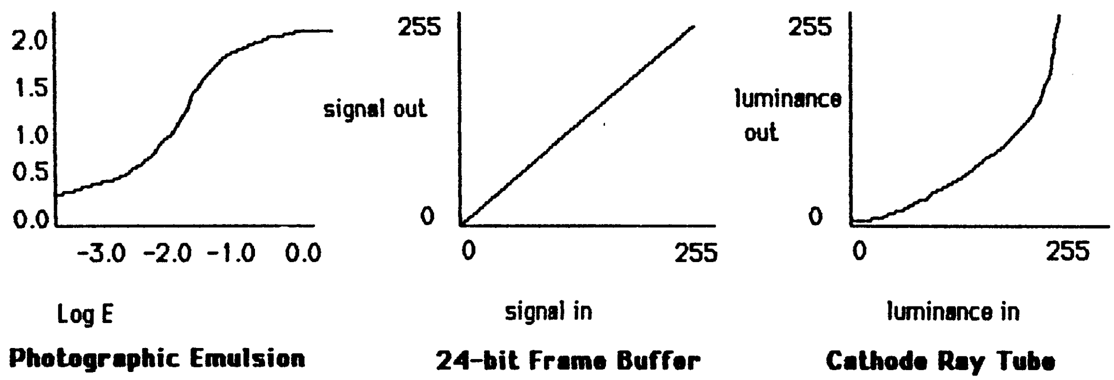


Figure 26. Characteristic Curves

Various software algorithms have been developed in the field of image processing for image manipulation and specific corrections [10]. These functions help to obtain high quality images for viewing on display devices and for reproduction in hardcopy.

HARDCOPY

Hardcopy of computer generated images originated as line drawings from a printer plotter. This device operates by moving a variety of colored ink pens on paper with a mechanical arm. As hardcopy devices developed the dot matrix printer was introduced. This device uses a matrix of dots to print alphanumerical characters as well as graphical characters.

Today, computer output devices take advantage of many photographic and printing technologies. Ink-jet printers use methods similar to printing presses to put ink on a page. These devices read an image which is encoded as digital information and decode it into the proper form for the image to be printed.

Ink jet printers spray a fine pattern of dots of ink onto a piece of paper. The dots acquire a pattern similar to halftones and also simulate continuous tones. Full color images are produced by ink-jet printers by printing three or four color separations on top of one another(the fourth color is black for better color saturation). The size of the dots of ink is controlled by spraying the ink between two electrodes which charge it and control the size.

A reasonable resolution can be obtained by the ink-jet printing method but the color saturation is generally not a close representation of the original image. Hitachi has recently produced the InkJet Color Plotter Model HJP-1610 which prints images at 400 dots per inch and produces highly saturated color. The only drawback to this system is its cost, which is well above the budget of an average publishing house.

In the search for high resolution hardcopy it is no surprise many color systems use photographic methods. They are the most accurate for reproducing the viewed image. Systems such as Matrix or Image Resource cameras produce slides by exposing color separations of images from a black and white CRT, through color filters, onto photographic emulsion. The quality of these systems is very good, but it takes much experimenting with hardware color balance controls to obtain an accurate reproduction. Once a proper exposure and color balance is found for each type of film and image, a slide can usually be made fairly quickly. In addition to this the drawbacks to these systems is their limitation in format; Matrix and Image Resource will do 35mm or 4" x 5", some of the models will do 8" x 10 " prints. Neither system allows an image to be cropped, or a region of the image enlarged. Even though these systems employ the photographic method of reproducing images and are therefore high quality, they are still limited in their use as a hardcopy device.

Laser printers take advantage of the photographic technology by exposing photographic emulsion with a laser. These are generally very high resolution since they expose digital data on photographic emulsion, but cost is prohibitive in many cases.

Recently systems have been developed to produce camera ready or plate ready hardcopy of page layouts or color separated halftone screened images or line copy. These prepress systems offer black and white proofs of the color separations with text or full color proofs . They are restricted in the amount and variety halftone font they use as well as their lack of ability to proof a color image in conjunction with text. They use technology derived from the printing industry, such as typesetters and electronic cameras.

IMAGE PROCESSING

Software solutions try to solve the problems related to the production of hardcopy. Here the most common functions are edge sharpening, gamma correction, color correction, cropping, and regional manipulation. The goal of image processing is to aid in the process of image enhancement, especially for digital systems designed for image transmission, display or production of hardcopy. Image processing views images as numerical arrays and simply performs mathematical functions on these arrays.

A common method method of mapping color or intensity for image processing , using a frame buffer as an image store is through a software color-map or look-up table. A color-map or look-up table is inserted between the images and the visual display [11]. The look-up table is a function which maps the configuration of image memory bits into new configurations that are presented to the visual display. A 24-bit frame buffer, that allocates 8 bits per color, like the one used with the Color Proofer, contains a color map that has 256 tones for each color channel.

Ed Catmul suggests an algorithm, using look-up tables to control the density of each color channel and correct for the distortion found in transmitting an image from one medium to another. He states that "one (may) correct the distortion by using a desired intensity value as an index into a table which has a new value to compensate for the non-linearities"[12] .

Catmul's algorithm employs reflected densitometric readings from a RGB test scales printed on a particular emulsion type; it compares them with reflectance readings from the original color scale on the CRT. The readings from the print are plotted and compared with the plotted curve of the CRT. The values on the averaged curve become the new values indexed into the look-up table. The test scales are redrawn with the new table as the next test sample. The process is repeated until the average of the curves is linear. Once the system is calibrated for each emulsion type by taking readings directly from the test prints, the resulting look-up table are stored to be used for any future emulsion.

Kevin Dore Hunter did a thesis in 1980 at MIT that was concerned with the problems related to printing color photographs from a CRT [13]. These problems arise because the dyes in color photographic emulsion have a different sensitivity to colors then the human eye does. Hunter uses of Catmul's algorithm but found some complications with it . The algorithm doesn't take into account the difference in perception between the eye and the photographic emulsion. To simulate the eye's logarithmic nature and compensate for the small differences that is discernable in the relectance area of the darker regions as opposed to the brighter ones" [14] a testscale with data points that are logarithmically spaced perform a better matching test. Unfortuneatley this data is extremely difficult to interpolate and therefore Hunter suggests a testscale with data points that are exponential in the lower (darker) regions and linear in the higher regions.

Hunter uses this variation off Catmul's algorithm for color by creating three look-up tables, one for each primary. This method of color compensating is based on the tristimulus theory (see page 39). The three stepwedges used each contain one color component that is varying and the other two components are constant. These test scales are measured with a densitometer and calibrated independantly. Once they are properly calibrated a greyscale can be producd from the combined tables and there should appear no shift in hue over the range of the greyscale.

Hunter found this method to solve most of the problems of the observed color shifts but it didn't solve the whole problem. There is a limit the image data can be manipulated; if the table is modified too much or the data compressed, the dynamic range of the image becomes greatly reduced. Hunter found a solution to this problem through the use of optical filters which won't compress the data since it operates on the light transmitted by the CRT, not on the digital data.

Optical filters filter out the undesired color components thereby a compensating for cross exposure errors and the dyes overlapping sensitivity . These filters do have a limit; if they are designed to only let the part of the spectrum through they want and nothing else, they are be so dense that not enough light would get through to expose the paper. Dense filters would need a high exposure and this creates problems with obtaining high enough film speed and images becoming grainy yielding grainy poor resolution. Generally optical filters can correct the errors enough so they are a sufficient solution to color correcting problems. The Color Proofer makes use of optical filters when exposing the color emulsion in the typesetter.

Image processing is incorporated in systems such as the Electronic Darkroom developed for the Associated Press by the Cognitive Image Processing Group at MIT. The Electronic Darkroom is primarily concerned with images that are transmitted over the AP wires, but it also outputs the image in a simulated continuous tone fashion [15]. The functions performed by this system include filtering for effects such as contrast control and edge sharpening, as well as cropping and local region corrections. A well developed system, it is quite efficient at transmitting and manipulating black and white digital images.

This Electronic Darkroom is an example of the influence of image processing on the photographic industry. Photographic editors can quickly edit many photographs. This system helped to automate the field of photojournalism. An image can be shot and developed on one side of the country and then published in that evening's newspaper on the other side.

ELECTRONIC PUBLISHING

Electronic Publishing is a field that encompasses all the aspects of automating the print and publishing industry. Electronic Publishing workstations usually include hardware and software to perform high resolution input and output of text and images, page makeup, formatting, as well as image processing.

INPUT SYSTEMS

To get an image into an electronic camera, typesetter or a computer it must first be input into that device. If the device is digital, images are converted into an array of binary values; if the device is analog the image may have to be photographed.

The Vidicon tube camera, one of the original input devices projects an image through a lens onto a picture tube. A raster sweeps across the face of the tube and reads the projected image and then stores the intensity of the each pixel. Initially the data is stored in analog form and is recorded as shades of grey. This data can either be read to an output device to be printed or converted to digital data which subjects the grey values to a thresholding procedure. Thresholding is a technique used to separate continuous tone images into binary representations by comparing a value to a threshold: when the value is lower then the threshold it will be black and if it is higher then the value will be white. After thresholding, the data is recorded in bits (0 or 1) or bytes (0 to 255), depending on the system.

Flying spot scanners input images by focusing a light beam on a specific location which is then tracked in raster patterns. These rasters store information about the intensity of the light in the image; initially this data can be stored as analog shades of grey or subjected to thresh- olding and converted to digital data.

Facsimile devices are used in graphic arts to transmit text and images and also to transmit photographs recieved as contone images for wireservices. Facsimile devices are also used to transmit camera ready layout to printing sites where plates are made. Facsimile devices are also used as scanners and reproduction devices, which scan an image and then transmits it to other sites. While some facsimile devices transmit analog, most convert the signal to digital data. If output is to photographic emulsion the these devices record continuos tone (referred to as "contone") images and need to recognize grey values. If the device outputs to a digital device or a printer that only lays down solid blacks then it needs only recognize black or white. The images are then subject to thresholding and stored to be manipulated and transmitted.

INPUT / OUTPUT DEVICES

In 1975 ECRM introduced the Autokon electronic camera. It could input contone images and directly output them on photographic emulsion in line drawing or screened image form. The Autokon input images from a flying spot scanner from a rotating mirror which deflects the coherent light beam from a helium neon laser [16]. The same beam that initially recorded the image almost (not quite) simultaneously prints it. The original Autokon had dial controls for image reduction and enlargement, for lightening and/or darkening any tonal region of the image. Halftone screening of these images was produced by a temporary storage of the data in digital memory and then translated it to halftone characters. The screens were limited to 65, 85 and 110 dots per inch.

ECRM modified the Autokon so it could store data in digital forms and be processed by a computer and used with another device such as a typesetter. The new model 1000 is a menu driven system, capable of interfacing with many digital devices, and has many new features. The Autokon 1000 can control contrast in specific tonal regions, create special effects and print a halftone screened image at 144 dots per inch.

To mechanize traditional platemaking techniques for printing presses, platemaking devices were developed. These are generally integrated hardware and software systems. An image is scanned in and a plate can be made directly from it, without the use of an intermediate negative. Production time is saved because the negative needn't be stripped (touched up with opaque paint and paper) to hide cut marks and developing errors. Attempts to find the right kind of light to expose plate result in problems; a very bright source light is needed, at this point a reliable and cost effective solution in questionable. In fact the question has been raised if these devices can produce plates as fast and cheaply as regular methods.

In 1975 Afterposten a Norwegian Company in conjunction with Eocom of California produced the Laserite Facsimile Network which scans camera-ready pasteups and burns a plate from it 8 miles away. Since the light source they used was not reliably constant they simply produced negatives at times when the light was to dim. The system was successful for transmitting camera-ready copy but the need arose to bypass the typesetter and pasteups. The developers wanted to create the image and text together as well as produce a camera-ready copy, a negative or a plate.

TYPESETTERS

The automation of setting type began with the invention of photocomposition. This entailed projected font characters through master characters stored on a master disk (in fact a rotating wheel) onto photographic film. Around 1950 Photon Corporation was formed and produced the "first generation" of photocomposition devices [18].

A "second generation" of typesetting machines used cathode ray tubes for display and a TV camera to scan the master images. Finally, the "third generation" of typesetters could store the master characters digitally , using the computer and to expose them with a cathode ray tube. Recently intelligence has been added to these machines so they can be programmed to accept commands for formatting, type size and specific fonts.

The Compugraphic 8400, used in the Color Proofer, is a third generation typesetter. It scans the paper with a CRT, exposing a raster at a time in the horizontal direction and then moving the paper in the vertical direction to print the next raster .

IMAGESETTERS

Developments in image processing and electronic publishing have produced imagesetters, machines that work with text and images together. Imagesetters are usually modified typesetters used in conjunction with workstations that incoporate high resolution input and output devices, digital memory page layout and/or image manipulation functions.

The advantage to typesetting images is the ability to compress data. Each character can be described by only one 8 bit byte for a continuous tone image with values ranging from 0 to 255. A regular system might need as many as 100 bytes to cover the same black and white area.

Only recently research in imagesetting systems have began to yield some useful products. As Electronic Publishing becomes increasingly cheaper and more efficient, imagesetters will become more widely used in the industry because of their much needed functionality.

SYSTEMS FOR PRINTED MATTER

The first system capable creating and outputting text and images was released in 1983 to the *Observer Dispatch* in Utica, N.Y. This system includes a Hastech front end for page composition and layout, an Autokon camera for digitizing images and a raster image processor by Eocom to send signal to a Laserite platemaker.

The first production of graphics with a typesetter was developed by Information International Inc. (called Triple-I) for *U.S. News and World Report* [19]. A Triple-I Videocomp 500 was used because it operates in a full face mode, which means that the paper remains stationary. This allows images and text to be exposed randomly on a page and avoids the use of reverse leading, which is time consuming and unreliably accurate for image production. This system scans images and writes them to disk, with the Atex system could store them the same as text in blocks.

The CRT scans the page and stores the intensity of the image and stores the intensities as an 8-bit byte, with the values ranging from 0 (no light) to 255 (light fully on). The CRT then assigns the hexadecimal value of the byte to a halftone cell and prints the dots using a 110 dots per inch screen.

The Videocomp stores the halftone characters digitally in the typesetter, just like the alphanumeric fonts and therefore can print them the same way.

A color typesetting system also developed by Triple-I could scan in four color separations of each image with scanners by Hell or Crosfield. When transmitted the black printer contains the text and the black separation. The printers can process colors, cyan , magenta and yellow and print them, either as line art or screened images, at the traditional 45% angle. Dot shape and angle was researched in order to find the optimum combination to obtain greatest edge sharpness and color. This process, called Infocolor is used by Newsweek.

In order to produce the color separations Infocolor exposes the image through a filter of the opposite color primary, all the colors not within the range of the primary are suppressed.

In 1934 Kodak began to research color scanners which make color separations directly from the original copy. The Kodak system was supposed to create halftone screened images but sold its patents to Time Inc. in the 1940's. By the 1960's Time's subsidiary company Printing Developments started producing color scanners with the new transistor technology. In the 1950's Dr. Rudolph Hell of Germany developed a color scanner; by the 1970's he showed that color scanners were capable of high quality imagery. Initially these devices were analog and by the 1980's they were developed as digital devices.

Color scanners developed as concurrent scanners and writers.

These scanners could perform electronic functions such as color correction, unsharp masking to aid in edge enhancement and sizing, for enlarging and reducing.

Color correction is an important feature in any system that converts colors from one medium to another. In this case, printing presses can't reproduce the full range of colors shown in a photograph. To be printed the tonal range must be compressed and with a minimum loss of detail. Photographers and printers controll this process manually when making halftone screens; they selectively added more exposure to particular tonal regions of an image; this method is called "dodging and burning" in photography, or "bumping" the contrast and "flashing" the image.

Selective use of chemistry can also achieve some of these corrections. Undercolor removal and unsharp masking for edge enhancement are other printer techniques to achieve these results. Now electronics are replacing these mechanical processes with automation.

PREPRESS WORKSTATIONS

A few major companies (Hell, Crosfield, DaiNippon), lead the graphic arts industry in the manufacture of input and output scanners for very high resolution separations.

Scitex, an Israeli firm transposed their computer graphics experience in textiles and mapping to the graphic arts world. They introduced an electronic console which allowed the user to interactively visualize, alter, and manipulate the color separation of images which were input and output on various high resolution scanners.

Subsequent enhancements to these principles were produced by the major producers of color scanners. These companies combined electronic image processing with such layout capablities as electronic airbrushing, image manipulation, collaging, rotating, scaling as well as the superimposition of images. Text was scanned in and handled as images.

The next development (Scitex Vista) interfaced front end text, editorial systems and graphics input scanners to a work station which allowed real-time visualization and manipulation of both text and graphics.

Another generation of lower cost systems (Eikonix and Imagitex) is currently emerging.

High resolution output devices, which interface to these prepress layout stations for offset printing are either digital laser driven drum or flatbed scanners. The standard method for engraving Gravure cylinders is a Helio-Klischograph pioneered by Dr. Rudolph Hell of Hell GMBH.

Recent developments in output devices include plastic engraving (Crosfield) and electron beam engraving (Hell).

Low end proofing devices are few. The Autokon was the first low cost, flatbed medium resolution scanner with limited image processing capabilities and still the standard for the low end of the market.

High end color proofing devices and systems are both white light and laser image text setters, writing to conventional photographic materials. In this transitional stage the industry standard remains the conventional Chromalin process and the press proof.

The Color Proofer provides more flexibililty. A computer generated image can now be printed in any standard photographic output device. The Color Proofer performs color, contrast and basic size controls with an easy-to-use software package. It also performs image processing functions and takes advantage of optical filters to maintain proper color balance.

The Color Proofer can proof color images printed with the halftone screen method. Designers, photographers and illustrators can now use a system for viewing full color images, made from prepress color separations. The Color Proofer can produce a proof sheet of low resolution, personally designed halftone fonts, as well as a printed image using these fonts.

The Color Proofer is offered as the next next step in the development of output devices. Designed to meet the needs of artists and designers working with electronic imagery and publication.

Future Work

As we know, with any research project of this size new ideas come up as the project is being developed. Fortunately the Color Proofer software and menu system is written in a modular fashion and can easily support future development.

A piece of software could be written that correctly exposes each color pass. The procedure would be based on the fact that the hardware exposure setting would be constant. The software would simply ask the user how many times to expose the image for each color. This would help automate the system since the user wouldn't have to manually change the exposure.

Image processing could be done to filter out some of the noise that appears when an image is printed in medium resolution. An image could be run through a software filter. This filter would know where noise occurs in the image as a result of the hardware and correct the data so that it prints clearer.

Finally, a random dot font. The idea is to use a font that would generate a slightly different character each time it printed a tone, thus it would simulate a photograph; silver halide crystals are actually random dots. A method for implementing this would be to create a variety of semi-random fonts and then randomly select them. So, each time an image is printed a different font would appear.

CONCLUSION

The fields of electronic publishing, image processing and color hardcopy have shown some remarkable developments over the past few years. Today, systems are produced that will compose pages, create images, process images that are input from other sources and output them in high resolution. The high quality systems are usually expensive and not always easy to use. Operating these systems requires time-consuming training. High quality output system produce either black and white images in conjunction with text, or full color proofs without text. The market exists for a middle range system that provides high quality hardcopy with text, in an easy to use environment, at a low cost.

The Color Proofer points to an easy and inexpensive system that allows text and high quality color images to be printed on a single page. The Color Proofer is easy to use; it is geared for graphic designers and photographers, novices or experienced users in an enivronment that is familar to them. The Color Proofer will produce prints in variable format, at an extremely inexpensive cost. Including software to perform image processing and can be used in conjunction with a page makeup system.

The Color Proofer uses a Compugraphic 8400 typesetter; designed for text only. Printing images require accuracy not normally found in such machines. However the Color Proofer succeeds in producing full color images, of a satisfactory resolution, with minimal noise.

Computer graphics is creating a revolution by allowing an artist or inexperienced layman to create images in forms previously unimagined. Computer graphics not only aids in image creation, but extends the field of communication; images are created that look natural but are fictional.

The Color Proofer helps personalize the tools of computer graphics. It extends the functions of various image manipulation and computer graphics packages by allowing a user to create images and output them in various forms. The Color Proofer points to a new generation of systems that are easy to use, inexpensive to operate and accessable to users inexperienced with computers and while allowing for the enhancement of creativity.

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APPENDIX ONE

COMMUNICATION PROCEDURES

Communication between the Compugraphic 8400 and the Perkin Elmer 3220 is provuded by a utility package. These procedures are virtually invisible to the user.

The Compugraphic 8400 has a set of commands for both parallel or serial interfaces. The Perkin Elmer interfaces the Compugraphic through a serial port, an RS232 cable, allowing use of the slave command set.

CHARACTER TRANSMISSION

The MCS8400 command set offers two methods of transmitting characters, the "Short Character Format" for a 1-byte transmission and the "Long Character Format" for a 3-byte transmission. Byte 1 of both identifies the character to be typeset. [20].These values are sent as hexadecimal values with an internal I/O subroutine in the Perkin Elmer, called "iocs$put_chars".

The "Short Character Format" must contain a high order bit of 0. The horizontal position of the character to be typeset is calculated automatically from the last known horizontal edge. The MCS8400 will typeset the next character beginning at the following edge.

The "Long Character Format" must contain a high order bit of 1 in Byte 1 and a high order bit of 0 in Byte 2. The remaining 7 bits of Byte2 are the High order bits and the 8 bits of Byte 3 are the low order bits of the argument specified in 1/18 point increments. The argument designates the horizontal position of the character relative to the left edge of the paper.

FUNCTION COMMANDS

Function commands are transmitted with the "Long Character Format" only. They all must contain a sequence of 3 Bytes which consists of a command byte and two argument bytes. These arguments must be included, whether or not they are required by the command.

The sequence of commands necessary to communicate with the 8400 are as follows:

Function	Hexadecimal Command
Initialization	
Ten nulls	00
Start of Take	808001
Initialize Reverse	858000
Set Point Size	87
Point Size	variable -- in 8 point increments
Set Font (User ID number)	variable-depends on font
Picture Loop	
for each raster	
Send Character	001, 002 . . . 118 (font characters)
Horizontal Position	variable-depends on pixel location in the raster
advance to next raster	
Vertical Move Forward	89
Distance	variable-depends on scale
End setting picture	
Reverse	
Vertical Move Reverse	8a
Distance	variable-depends on picture size
End of Picture Loop	

<u>Close</u>

End of Take	818000

End procedure

APPENDIX TWO

PROGRAM LISTINGS

The main menu for the Color Proofer is found in the directory ">u>liz>cg>s". The user simply has to type proof, the menu will appear on the upper monitor. Once in the Color Proofer, any function in the package can be accessed.

The Communication package is written in a modular manner and is broken down into basic functions for the most flexibility . These programs are found in the directory ">u>skarfing>compugrafix".
The internal functions are :

init_comp_port.pl1 - opens a port from the Perkin Elmer to the Compugraphic 8400

init_comp_slave.pl1 - Sends the initial commands in hexadecimal values to the Compugraphic. These commands includes start of take point size and font number.

lite_dot.pl1 -reads the pixel value of the image and separates it into red, green and blue values.

even_lighter.pl1 -takes the byte value that represents the color and matches it to the corresponding character in the font.

color_pixer_disk.pl1 -sends the hexadecimal values that represent each font character, to the Compugraphic. It also moves the Compugraphic to the next vertical postion so the next raster can be printed. This function then loops back to send raster.

bopp_comp_slave.pl1-closes the port to the Compugraphic when the job is done.

All of the above utilities give the user an option of sending high contrast or halftone images in black and white or color.

APPENDIX THREE

ALGORITHM FOR COLOR TRANSFORMATION

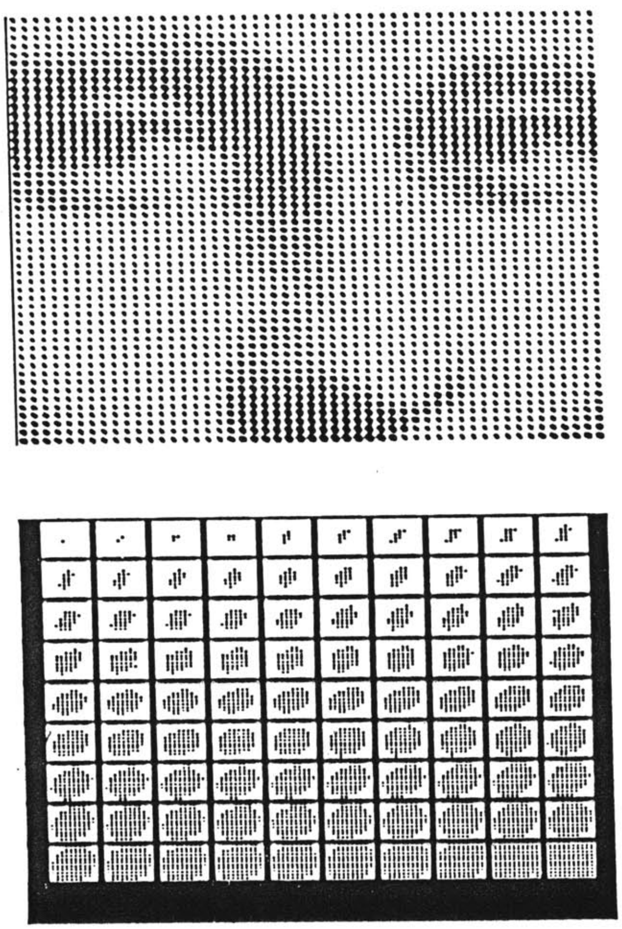
RGB to HSV [Foley & Van Dam]

```
procedure: RGB_HSV (r,g,b,real; var h,s,v real);
    {given: r,g,b , each [0,1]}
    {desired: h in[0,360], s and v[ 0,1], except if s=0,
    then h =undefined which is a defined consonent whose value is
    outside the interval [0,360]}
begin
    max = MAXIMUM( r,g,b);
    min = MINIMUM (r,g,b);
    v:= max;  {value}
    if max <>0
        then s:= (max - min)/max                    {saturation}
        else  s:=0;
    if s = 0
        then h := undefine
        else      {saturation not zero, determine hue}
            begin
                rc:=(max-r)/(max-min);  {rc measure "distance" of
                                         color from red}
                gc:=(max-g)/max-min);
                bc:=(max-b)/max-min);
                if r = max then h:=bc-gc  {resulting color between
                                           yellow and magenta}
                else if g = max then h:=2+rc-bc  {resulting color be-
                                                  tween cyan and
                                                  yellow}
                else if b = max then h:=4+gc-rc;  {resulting color be-
                                                   tween magenta and
                                                   cyan}
                h:=h*60;
                if h<0 then h:=h+360
            end  {chromatic case}
end    {RGB_TO_HSV}
```

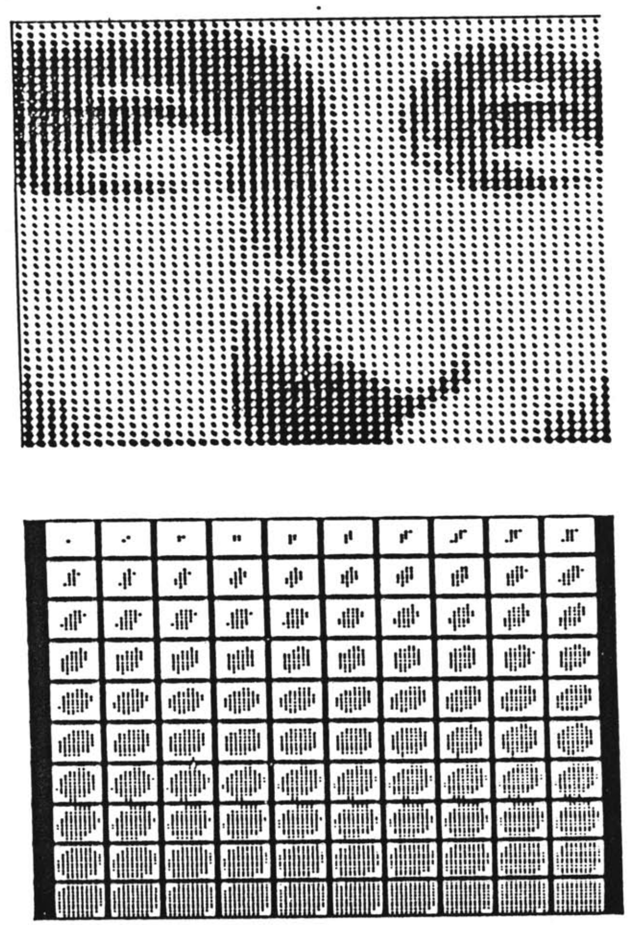
```
procedure  HSV_TO RGB(var  r, g, b: real;  h, s, v: real );
     {Given: h in [0, 360] or undefined, s and v in [0, 1]}
     {Desired: r, g, b, each in [0, 1]}
begin
     if  s = 0
          then
               if  h = undefined
                    then
                         begin
                              r:=v;
                              g:=v;
                              b:=v;
                         end
                    else  ERROR     {error if s = 0 and h has a value}
                                    {chromatic color: there is a hue}
          else
               begin
                    if  h = 360 then  h = 0;
                    h:=h/360;
                    i:=FLOOR (h);
                    f:=h-i;

                    p:=v*(1-s);
                    q:=v*(1-(s*f));
                    t:=v*(1-(s*(1-f)));
                    case  i of
                      0: (r, g, b):=(v, t, p);
                      1: (r, g, b):=(q, v, p);
                      2: (r, g, b):=(p, v, t);
                      3: (r, g, b):=(p, q, v);
                      4: (r, g, b):=(t, p, v);
                      5: (r, g, b):=(v, p q);
                    end   {case}
               end   {hue}
 end   {HSV_TO_RGB}
```

APPENDIX FOUR

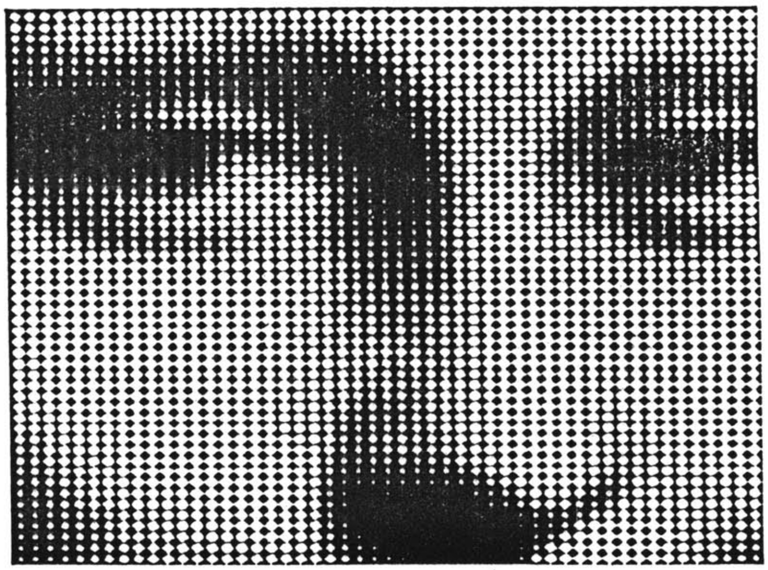
EXAMPLES OF HARDCOPY

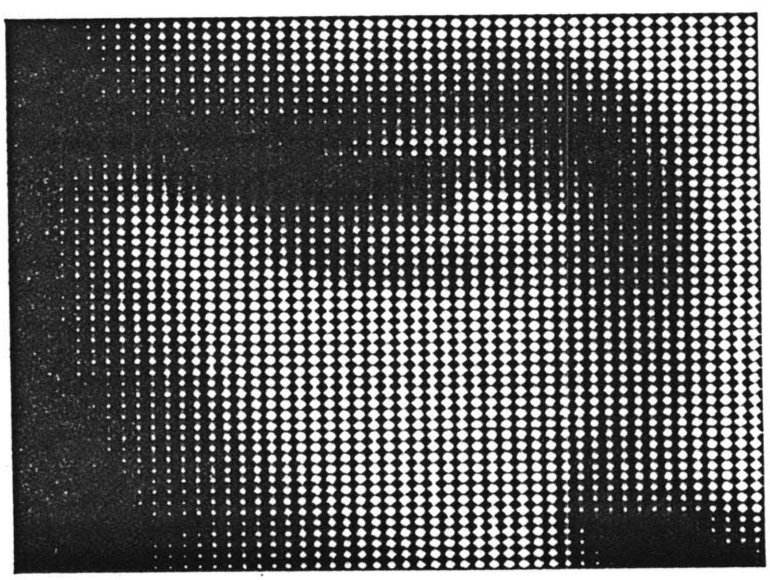


Eliptical Font



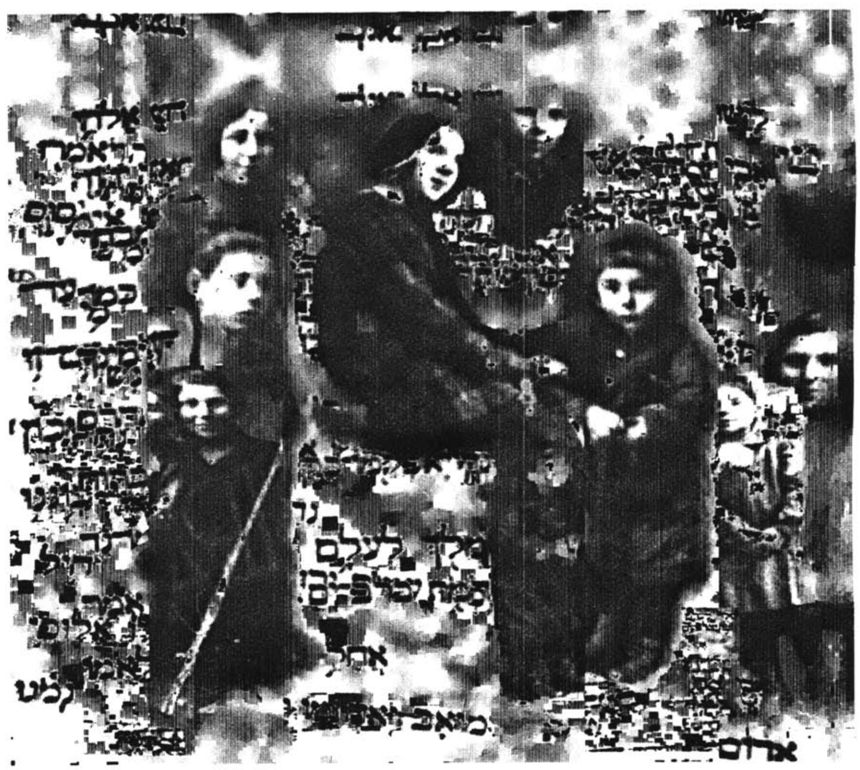
Renumbered Eliptical Font





Contrast Correction

Variable Size



A Final Picture

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As usual, if I start to list all the people who helped me with this thesis, the list would go on forever. There are a few, however that I have to thank.

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Finally, the biggest thanks goes to Jason Kinchen. Quite frankly words are not enough to describe the support he gave me; without his efforts this thesis would not have been what it is.

Thanks.