Edge Pixels: the Effect of Scanning Resolution on Color Reproduction

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As a result of the digital revolution, many journal articles have been written on the technical aspects of digitization. One of the most documented facts is that increased scanning resolution means greater legibility of the text and fine details of the digital file. However, little has been written about the fact that increasing the resolution also results in better color reproduction, and it is this issue that this paper will address. While the differences in color reproduction between high resolution scans and lower resolution scans are subtle, they can be quantified and illustrated graphically using the histogram feature of Adobe Photoshop (an image processing software package). This article begins by reviewing the principles of scanning after which several color images, both color and black and white, scanned at increasing resolutions, will be presented to support the author's thesis.

INTRODUCTION

The digital revolution has unleashed a barrage of journal articles that have dealt with many of the technical aspects of digitizing paper-based images and text. For instance, in a major study, Cornell University, Xerox Corporation and the Commission on Preservation and Access (CPA) undertook a collaborative effort to test a prototype system for recording the text of deteriorating books as digital images (Cloonan 1993, Cohen 1993). Among other things, the study concluded that 600 dots per inch (dpi) scanning and printing results in a high quality paper replacement for brittle textual materials (CPA 1992).

Yale University has also undertaken a study to digitize fragile materials. This project is being carried out in three phases. The goals of the second phase are to assemble, test, and evaluate the basic operating elements of imaging architecture (Conway and Weaver 1994). As a result of this research, it was determined that the optimal scanning resolution for capturing full legibility of microfilm and photographs is 600 dpi (Conway and Weaver 1994).

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The Bodleian Library at Oxford University is currently working on two separate projects to scan photographs. Gartner (1994) briefly describes the process of digitization and the impact of scanning resolution on text legibility. In another article, Kenney and Conway (1994) discuss four issues related to digitization: 1) system functionality, 2) storage media deterioration, 3) digital image data quality, and 4) integrity of sources. Their treatment of scanning resolution is in terms of black and white text, that is, the ability of the scanner to capture the fineness of detail and the legibility of print. Furthermore, Cohen (1993) also touches upon scanning resolution as it relates to the legibility of text. Tilton (1994), on the other hand, discusses scanning resolution in terms of the display size of the digital image. That is, he comments upon the relationship between screen resolution and magnification ratio in order to determine the proper scanning resolution for a digital image.

Cartolano, Gertz and Klimley (1995) determined that full legibility of 1 mm text can be achieved if the original image is scanned at 200 dpi in 24 bit color. They stated that "once the full information is captured at the highest resolution required for full capture, it should not be necessary to re-scan in the future, since no information would be added by scanning at a higher resolution" (Cartolano et al. 1995, 11).

It is this sentiment, which is implicit in all the articles mentioned so far, that is challenged in this paper. That is, information that is vital to the integrity of the digital image will be added if the image is scanned at a higher resolution. That information manifests itself in the form of better color reproduction, which is of critical importance if the image is meant to be an access copy of an archival document.

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While a review of eight articles could hardly be called a complete examination of the relevant literature, two related trends do appear. First, one of the best documented facts in these and similar articles is that increased scanning resolution results in greater legibility of the text and fine details of the digital image. This is not in dispute here. However, the second trend that emerges from these articles is that the discussion of color reproduction tends to focus on issues of bit depth (for example, Cartolano et al. 1995) and palette shifts (for example, Tilton 1994). Little has been written about the fact that increasing the scanning resolution also results in better color reproduction. While the differences in color reproduction between high resolution scans and lower resolution scans are subtle, they can be quantified and illustrated graphically using the histogram feature of Adobe Photoshop, an image processing software package for the Macintosh. After a brief review of the principles of scanning, several images scanned at increasing resolutions, along with their histograms, will be presented in this paper to support the author's thesis.[1]

SCANNING RESOLUTION AND COLOR REPRODUCTION

The type of scanning discussed here produces output in raster format. That is, the information is displayed as an array of square cells, or pixels, each representing a corresponding piece of the original document (Pazner et al. 1992). When the original document is scanned, the scanner "sees" it as an ordered formation of pixels, each having a color or shade of gray, each of which reflect different amounts of light. The scanner then assigns a number to represent the reflectance of each pixel. This matrix of numbers becomes the digital image file.

This explanation of the process of scanning, while exceedingly brief, outlines the most important variable of concern to this paper, that is, the assignment of a single number to represent the reflectance value for the entire area of a square pixel, the size of which depends upon the preselected scanning resolution. Herein lies the basic problem. For example, a scanning resolution of one dpi would result in a digital image that has one pixel per square inch of the original document. All the colors present within the area represented by that pixel would be combined and a single number would be assigned that represents the average reflectance value for that pixel. In other words, all the discrete colors that are present within that area on the original would be blended to create a single color for the digitized image. If, however, the scanning resolution were increased, meaning that pixel size is decreased, then more colors could be portrayed within that same one square inch area because more pixels would be required to depict the same size area at the greater resolution; each pixel would be assigned its own separate color value that represented the reflectance of that smaller pixel area on the original document.

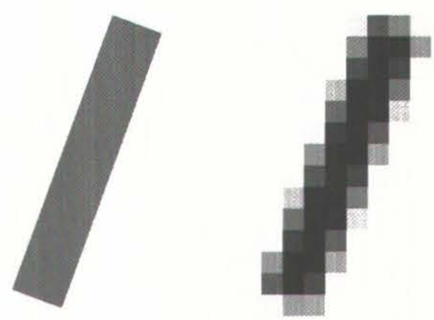
1. All the images used in this paper were scanned using the default settings for brightness, contrast and threshold. No extra image processing was done. In this way, the author hopes to ensure that comparison between the images will not be influenced by any data manipulation technique.

Figure 1. Demonstration of the effects of scanning resolution on color reproduction.

Figure 1a. Figure 1b. Figure 1c.

This principle is illustrated in Figure 1. The large empty boxes in Figure 1a represent the pre-selected scanning resolution, or the pixel size, and the black box represents a spot of color on the original image. In this example, when scanned, the spot of color would fall on the intersection of the four pixels. As a result, the scanner would combine the black color with the white background and produce a digital image that consists of four gray pixels, as in Figure 1b. In essence, the process of digitization has produced a completely new color that was not present in the original document. If, however, the scanning resolution were doubled, as in Figure 1c, then the black spot would no longer fall on the intersection of four large pixels, but completely fill four smaller pixels. In this instance, the black spot on the white background would be reproduced exactly, with no new colors added to the digital image.

Rarely do all the pixels in a digital image fall completely within the area dominated by one color or another. Usually there are a number of pixels that fall along the line separating areas of different colors. These are referred to in this paper as "edge-pixels." For example, Figure 2 depicts two heavy black lines on a white background. The line was originally drawn in ClarisDraw at 72 dpi and printed on a 360 dpi ink jet printer. The hard-copy was then scanned at 9 dpi. The digital image file was then imported into ClarisDraw where it was placed on the same page as the 72 dpi version for purposes of comparison. Because the lines are diagonal in relation to the pixel grid, there are many edge-pixels in the 9 dpi version which fall both within the body of the line and within the white background. Notice that these edge-pixels are various shades of gray, the darkness of which is dependent upon how much of the pixel fell within the body of the line. In other words, those edge-pixels that have the majority of their area covered by the line are darker than those which are mostly within the white background. In this instance, the scanner has produced a digital image that contains very few black pixels while producing many shades of gray that were not present in the original image.

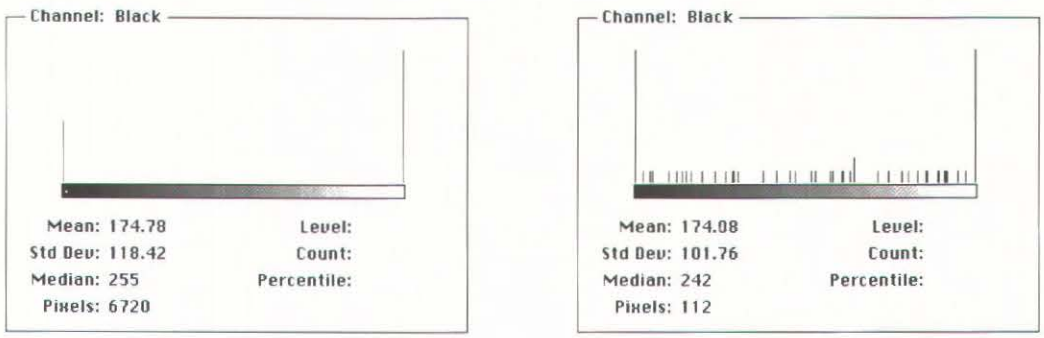


72 dpi 9 dpi

Figure 2. Comparison of images scanned at different resolutions.

This becomes very apparent when viewing the histograms for these two images (Figure 3, page 6). The x-axes of these histograms represent the color values from 0 (black) on the left to 255 (white) on the right. The y-axes represent the number of pixels in the image that have that particular value. The graph for the 72 dpi version clearly shows that there are only two colors present within that image, namely black and white. There is a tall, thin line at the extreme right end of the x axis of this histogram–it represents the number of white pixels. Conversely, the line at the extreme left end of the x-axis represents the number of black pixels in the image. Notice that there are no other values depicted on this graph, meaning that there are no other colors present within the image. However, on the histogram for the 9 dpi version, there are lines all along the graph, mean

Figure 3. Histograms for images in Figure 2.



72 dpi 9 dpi

ing that there are a substantial number of pixels that have intermediate values–essentially, they are various shades of gray.

This principle of edge-pixels can have some very interesting effects on color images. On very colorful originals, such as full color maps and color air photos, there could be a great number of edge-pixels present in the digital image. For example, Figure 4 (page 9) portrays four images of the same place from the National Topographic Series 1:50,000 Bath sheet (number 31C/2, edition 5, 1979) scanned at increasing resolutions. This image is a detail of a park (see the location map), the original size of which on the map was 3.74 mm by 6.78 mm (0.147 inches by 0.267 inches). Notice in the 75 dpi version, there is a line of brown and tan pixels along the right and bottom edges of the image while the rest of the image consists of green and taupe pixels. In the 150 dpi version, the brown line on the right side has become purple. This is very intriguing, for the NTS legend contains eight colors–red, orange, blue, brown, black, gray, green, and white. There are no features portrayed in purple on the original map sheet. This means that the colors present in the original which are contained within the purple pixel area were combined by the scanner to produce new colors that are not found on the original map. Also notice that the interior portion of the image has a greater variety of color compared to the 75 dpi version. Again, most of these shades are peculiar to the digital image and are not found on the original document.

Like the 75 dpi and 150 dpi versions of this image, the 300 dpi and 400 dpi versions also contain many artifactual colors due to the edge-pixel phenomenon. Close scrutiny reveals that there is a small but significant number of pixels in the body of these images that are turquoise or aqua; neither of these colors are represented in the legend of the original document. Furthermore, the right and bottom edges are no longer brown, as in the 75 dpi version, or purple, as in the 150 dpi image, but a mottled collection of red, pink, gray, tan and brown pixels; some of these colors are in fact represented in the legend. Therefore, while these higher resolution images both contain artifactual colors, because more and more pixels are beginning to portray colors which are in the legend of the original, one can conclude that there is a positive relationship between scanning resolution and the quality of color reproduction. In other words, as pixel size decreases (or as scanning resolution increases), the effect of the edge-pixel phenomenon is mitigated and a closer reproduction of the colors of the original document is the inevitable result.

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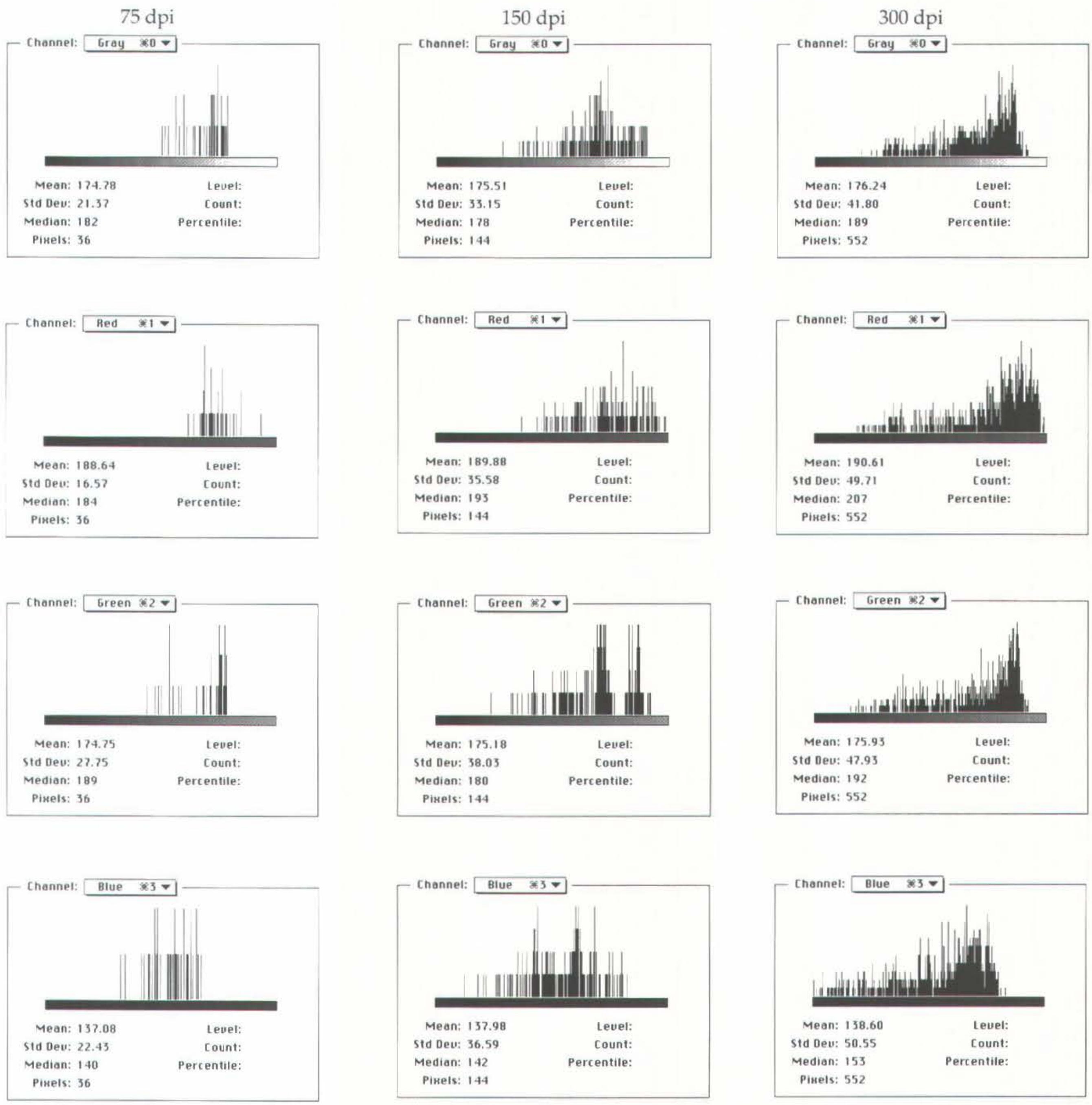
The histograms of these images highlight the differences in color reproduction between the increasing scanning resolutions. Photoshop 3.0 will generate a separate histogram for each color channel, plus a gray histogram that represents the overall brightness of the image (Figure 5). The histograms for the higher resolution images are denser because they portray more pixels, but the general trends between the histograms can be compared and analyzed. For example, all the histograms for the 75 dpi image depict a relatively narrow color range with a spike that dominates the graph. As the resolution increases, the color range widens and the spike becomes less dominant. This indicates that the digital images are portraying many more subtle variations of color. Furthermore, as indicated by the "mean" color value, the images are becoming brighter as the resolution increases. Therefore, as the only difference between the digital images is the scanning resolution, the differences in the histograms are products of the increased resolution.

When viewing the images, the user may be hard pressed to find any substantial color variations between higher resolution and lower resolution scans; as demonstrated with the histograms of the color images, the

Figure 5. Histograms for images in Figure 4.



differences are very subtle. Indeed, how the image is viewed will have an impact on the theoretical "gain" in color reproduction; the gain is most noticeable when the image is greatly magnified. That is, if the image is to be viewed on a 1 to 1 magnification ratio as a paper print out, then the increased quality of the color will be virtually unseen. However, if the image is magnified on a high resolution computer screen, then the differences are most conspicuous.

CONCLUSIONS

When digitizing a color image, the digital preservationist must ask him/herself the following question: are the images to be used for research purposes, or for browsing and/or indexing? The answer to this question will have an impact upon the resolution and standards which will be used in the digitization process. Different researchers have different uses for digital images. If the image is to be used in an application where the quality is not critical, for example as an index image, then considerations other than color reproduction, such as file size, compression ratio, and minimum legibility requirements, must take priority. However, another researcher may be concerned with the paper stock on which the original work was produced. He/she may be interested in identifying the watermark, or seeing the chain lines and laid lines in an attempt to identify the paper manufacturer. Likewise, another researcher may be interested in the inks and dyes used in the printing process. In these instances, digital images are typically used by researchers either in lieu of handling the fragile originals or because the originals are not easily accessible due to their location, and under these circumstances, better color reproduction will be invaluable to the researcher. If the digital image contains a large number of artifactual colors from the digitization process the usefulness of the image is reduced dramatically.

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Under most circumstances, images intended for research purposes need much more accurate color reproduction than those intended for browsing or indexing. It is recommended that research images be digitized using the highest possible quality standards for color reproduction. As one of the tenets of digital preservation is to produce a faithful replica of the original, it is ironic that most research into digital imaging is concerned with finding that quality which is simply "good enough." That is, in the search for the "perfect" compromise between file size and image quality, all too often the priority is to minimize the disk space required to store an image rather than find the optimal image quality. It is impossible for a digital preservationist today to know what will be required of digital images in the future. Therefore, if the image is to be used for archival/research purposes, it is imperative that the image be captured at the highest possible quality. Given that the technology for capturing, storing, retrieving and viewing images is constantly improving, images that are "good enough" today likely will be wholly inadequate in the near future.

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Figure 4. The effects of scanning resolution on color reproduction.