Multigeneration Color Copying

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Abstract

When color copies are made of color copies, color errors and noise grow from generation to generation. This paper presents two techniques for suppressing these problems. Both prevent color drift. One is optimum for flat color areas, and the other is optimum for sweeps or pictorial images. Methods for combining the two techniques are also discussed.

Introduction

A major enabler of the black and white copier business is the ability to make a copy of a copy. This is possible for black and white copy because the density levels are quantized. A white region always reproduces as white, even if it has a little background, and a black region always reproduces as black, even if it has a bit lower in density than usual. A white region can be reproduced as black, or a black region can be reproduced as white only on edges. These errors produce line growth or line thinning which gradually degrades the quality of the copy from generation to generation, but it generally takes many generations for the quality to become unacceptable.

Trying to accurately reproduce gray levels for copies of copies is much harder. If midtone grays tend to copy a little dark, in just a few generations they will go to black and if they tend to copy light, in just a few generations they will go to white. The situation is even worse for color copiers. Digital copiers have RMS errors of under 10 L*a*b* units, which is acceptable for many purposes. In three generations, however, the error can grow to 25-30 L*a*b* units, which is quite unacceptable. A possible solution for this problem is to quantize the colors into bins large enough so that a color centered in one bin has a negligible probability of crossing the boundary into another bin in one generation. This simple approach, however, produces contouring in sweeps and pictorials. It does not even work for many flat color images (pie charts, etc.) If a flat color in the image lies near a bin boundary, some of the pixels will fall in one bin, and some will fall in the other due to noise in the original print and the scanner. This produces color nonuniformities in areas that are supposed to be uniform, which is unacceptable.

Color Mapping

To solve this problem, a more sophisticated color quantization process can be used. We call this three step process color mapping. The three steps are:

1. Define Target Colors

An array of target colors is first defined. For each target color, the corresponding bin consists of all the points in color space closer to it than any other target color. For optimum results, all the target colors should be within the gamut of the printer, and the size and shape of each bin should be a function of the magnitude of the expected color error in its region of color space. Characterizing the accuracy of a color device in this much detail is a lot of work, and locating the target colors so that the corresponding bins come as close as possible to the correct size and shape is an interesting problem. For this preliminary investigation, a simple body centered cubic lattice in Xerox RGB space[1] was used for the target colors. This color space uses SMPTE phosphor primaries (red x = 0.630, y = 0.340; green x = 0.310, y = 0.595; blue x = 0.155, y= 0.70) and a D50 white point.

2. Find Features

The color histogram of each image is analyzed to find densely occupied regions of color space. Each of these regions is called a feature. The boundary of each feature is the surface passing through the minima in the histogram which surrounds the central maximum. All colors in the image belong to one feature or another.

3. Remap Colors

All the colors in a feature are mapped to the target color which is closest to the average color of the feature. All the pixels in regions of approximately constant color will therefore be assigned to the same target color.

This approach keeps image noise and color errors from accumulating from generation to generation. It does, however, introduce color quantization error in the first generation. The magnitude of this error is a strong function of the color accuracy of the basic copier system. If the bin is approximated as a sphere, and need be no bigger than twice the average error of the copier, the average quantization error is 1.5 times the average error of the copier, which should be good enough for many applications.

This color mapping technique does have some drawbacks, however. For example, it produces contours in sweeps and pictorials. It also produces defects at the edges of flat color regions. At these boundaries are pixels that also lie near the boundaries of different features in color space. Some pixels will be mapped to one target color, and some will be mapped to the other, producing ragged edges.

Warping

Both of these problems can be solved with another technique called warping. In this approach the color space is warped, as if it were made out of rubber, to move the average colors of the most highly populated features to the nearest target colors. The relationships between intermediate colors is not upset (colors that are close in the original will be close in the copy) so neither ragged edges nor contouring is produced by this technique. This method could therefore be used for multigeneration copying of pictorial images. The utility of this approach is limited, however, by the fact that it does not suppress multigenerational noise build up.

A transformation technique based on Shepard's[2,3] method is used to do the color space warping this method requires. The difference between the average color of a feature, F(i), and the nearest target color, T(i), is considered to be an error vector, E(i) for feature i. The error at any point in color space, P, is calculated as the weighted average of the errors for the highly populated features, where the weight for each feature is proportional to 1/D to the fourth power, where D is the euclidian distance between P and F(i). The error vector at point P is subtracted from P to get the color value corrected by the warping transformation. For P very near F(i), D is small, and the i'th error vector, E(i) = F(i)-T(i), dominates in the weighted average. The corrected value of P is therefore approximately P - E(i), which is approximately F(i) - E(i), which is near T(i), as desired.

The fourth power was chosen because it is desired to have an error function where the error is dominated by the error vectors nearby, but also is as smooth as possible. The higher the power, the less smooth the function. The lower the power, the bigger the effect of distant errors. The fourth power is a good compromise. If, for example, the errors are distributed uniformly throughout color space, and all the error vectors outside a shell of radius R point one way, the total effect of these errors on a point at the center of the shell diverges as the number of error vectors goes to infinity when the power is chosen to be three. For this power, therefore, the effect of error vectors outside the shell can dominate the effect of error vectors inside the shell. When the power is chosen to be four, however, the calculation for effect of the error vectors outside the shell on a point at the center of the shell converges as the number of error vectors goes to infinity, so the effect of distant errors is much smaller.

Combined Method

To combine the best features of both methods, edge finding techniques are used to find the boundaries between differently colored patches. In a narrow band in the vicinity of these edges, the warping technique is used to suppress ragged edges. In the solid areas, where viewers are most sensitive to noise, the mapping technique is used, which suppresses multigenerational noise build up. The target colors for both warped and mapped regions are the same, and determined by analyzing the colors of the entire image.

Simulation

Most printers use halftone techniques to produce shades of color. In order to scan and reprint them using the techniques discussed above, the scanned image would have to be descreened. In this study, perfect descreening was assumed. The loss in quality associated with printing and scanning was therefore simulated by adding color errors and noise to the continuous tone electronic image that would have been sent to the printer in order to obtain the electronic image that would have been returned from a scanner with perfect descreening. The color error pattern for a MajestiK™ copier was measured to get an estimate of the combined scanner and printer error. Enough random noise was added to simulate the processes that produce graininess and mottle in the prints. It was found that a body centered cubic lattice that divided up each axis of Xerox RBG space into three segments gave bins big enough to prevent color error build up. The quantization errors were noticeable, but not objectionable. After three generations, simulated prints corrected using the techniques discussed above looked much better than simulated prints made without them. The uncorrected images had larger color errors, and were very noisy.

To detect the edges, a Gaussian filter with 5×5 support was followed by a Laplacian filter with 3×3 support. The resulting image was thresholded to find the edges. Defects in the edge region map were filled with a morphological filter, and the edge regions were thickened using a dilation filter. The build up of noise in this edge region, where warping is applied, was not noticeable.

Conclusion

Noise and color error buildup are problems in multigeneration color copying. In this presentation, we have proposed two techniques, mapping and warping, to cope with these problems. Initial simulations are quite promising.

References

1. "Color Encoding Standard" Xerox Corporation Systems Institute, Sunnyvale, CA, 1989, pp. 2-2.
2. Pekka Laihanen, "Colour Reproduction Theory Based on the Principles of Color Science", *Advances in Printing Science and Technology*, W. H. Banks, Ed., Pentech Press, London, 1988, pp. 1-36.
3. Pekka Laihanen, "Optimization of Digital Color Reproduction on the Basis of Visual Assessment of Reproduced Images", *Proceedings of the SID*, Vol **30**. No. 3, 1989, pp. 183-190.