Color Halftoning with Stochastic Screening and Adaptive Clustering

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Abstract

We introduce an algorithm for color halftoning using stochastic screening. This algorithm has three distinguished features: it uses clustering, it performs error diffusion and it employes an adaptive criteria to change the cluster size according to the variation of the image color values. Therefore, the method incorporates features from the traditional amplitude modulated (AM) digital halftoning methods, along with the advantages of the frequency modulated (FM) techniques, recently introduced into the raster image processors of high resolution phototypesetters.

Keywords. color printing, stochastic screen, adaptive clustering, space filling curve, electronic printing.

1 Introduction

The reproduction of color images is a problem of great importance in business, scientific and industrial applications. A comprehensive overview of this problem can be found in (Hunt, 1987). Different areas, and a great diversity of applications, lead to the necessity of using different midia in the color reproduction process: film, paper, monitor screens, video, etc. In this paper we are concerned with the reproduction of color images on paper.

There are different graphical devices that are capable of reproducing images on different types of paper. Dye sublimation printing technology produces continuous tone images on photographic quality paper. Wax transfer, inkjet and laser printers are able to reproduce color in a wide diversity of papers. In the printing industry, the offset printing process is capable of reproducing images of high quality in plain paper. The offset process surpasses the existing digital color reproduction techniques on what concerns the combination of great flexibility, cost, quality and printing volume.

Digital techniques have been introduced into the offset printing pipeline with the objective of reducing the costs and guarantee a better quality control. A complete account on the problems of using digital techniques on the offset printing pipeline can be found in (Stone, Cowan and Beatty, 1988).

In this paper we introduce a new halftoning technique for color reproduction. The algorithm adapts to a wide range of color reproduction processes that use halftoning in order to account for the elimination of quantization contours: inkjet printers, laser printers, wax transfer printers and the offset color printing process. We focus the applications and examples of the algorithm on low cost color inkjet printers, and on high resolution phototypesetters.

We should point out that in spite of the advances in the area of continuous tone digital printing technology (e.g. dye sublimation printers), halftoning techniques for color printing still have a long way to evolve. This technology is essential for the color printing industry, because of the adequacy of the offset printing process to rapidly reproducing colors with great flexibility, and low cost. Also, halftoning techniques will continue to be used on a wide range of color reproduction devices (inkjet printers, laser printers, wax transfer printers etc.).

The remaining of the paper is as follows: in section 2 we discuss the color printing pipeline; in section 3 we discuss the screening methods, for digital halftoning; in section 4 we describe the stochastic screening method using space filling curves; in section 5 we introduce an improvement to the method that allows an adaptive variation of the cluster size, into much better halftoned images; in section 6 we describe how to use the halftoning method with space filling curve for color printing; in section 7 we show results of experiments with images, using different printing devices; in section 8 we make some final comments and point to future research in this area.

Figure 1: Laser printer reproduction of a color image.

Figure 2: Cyan, Magenta, Yellow and Black channels of the image in Figure

2 Color Separation and Halftoning

Color printing is based on a reflective light process. The ink on the paper modulates the wavelength of the incident light, and as a result, a different color is reflected from the inked paper. This process is similar to the generation of color using a subtractive system: as we add different colors to the paper, light of different wavelength will be reflected, producing a great diversity of new colors.

Theoretically, by combining the three primary colors Cyan (C), Magenta (M), and Yellow (Y) to emulate a subtractive color system, we could be able to reproduce on paper a wide gamut of colors. Nevertheless, several considerations, of different nature, support the necessity of using Black, K, as an additional color in the printing process (see (Stone, Cowan and Beatty, 1988) or (Yule, 1967)).

The process of taking a color digital image and transform its color space to the $CMYK$ color space, is called *color separation*. Since, at least theoretically, we are able to generate the black component from the CMY primaries, we face the problem of trading off between CMY and K values in the color separation process. The literature about this topic is abundant. The interested reader should consult (Stone, Cowan and Beatty, 1988) for a good overview, or (Molla, 1988) for a more comprehensive discussion of the problem.

Figure 1 shows a printed color image, and Figure 2 shows the contents of each

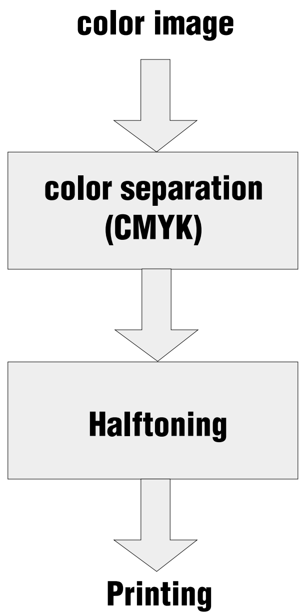


Figure 3: Color printing pipeline.

of its $CMYK$ channels. Figure 1 is essentially obtained by overprinting each of the $CMYK$ channels in Figure 2. We will return to this overprinting process later on. For the moment we should make an important remark: in order to print each of the channels $CMYK$, we must quantize it to a bitmap image. This remark points to us the necessity of using halftoning techniques (see (Ulichney, 1987)) in the quantization of each $CMYK$ channel, after the color separation process. Halftoning techniques avoid the perception of the severe contouring artifacts produced by the 1-bit quantization process.

A simplified diagram of the printing pipeline is shown in Figure 3. A more detailed diagram of this pipeline can be found in (Stone, Cowan and Beatty, 1988).

The necessity of using halftoning techniques for color reproduction on paper, resulted into a halftoning carpentry. Indeed, a lot of publications and patents have appeared about digital halftoning algorithms for color printing.

2.1 Halftoning Methods

The display of continuous-tone images in bilevel devices implies in the quantization of its intensities to one of two levels. Before the introduction of digital techniques halftoning was produced by an analog process. In this process, the grayscale image is photographed, using a high contrast film, through a very fine and uniform screen, originating an image formed by tiny black dots, whose size varies according to the gray level intensity of the original photography.

Digital halftoning techniques are called *dithering*. This is an extreme case of discretization in which continuous intensity values must be converted into a discrete set of values (in this case, only two). This operation may cause a loss of information which is estimated by the *quantization error*. At a particular image element, this error is the difference between the continuous and discrete values. For a region $R(i, j)$, $i = 1, \ldots, m$, $j = 1, \ldots, n$, of the image domain, we define the average intensity of the grayscale levels by

$$I_m = \frac{1}{|R(i,j)|} \sum_{i,j} f(i,j), \tag{1}$$

where $|R(i, j)|$ is the number of pixels in R. The quantization error on R is the difference between the average I_m, and the average of the quantized pixels within the region.

Dithering techniques use a trade-off between spatial and tonal resolution. As the quantization error is spread over larger areas of the image more tones can be represented. Gray levels are rendered in this way as patterns of black and white pixels. On the other hand, if dithering avoids contouring artifacts, it eliminates at the same time high frequency information contained in the image. The process transforms also true intensity boundaries into patterning features. In summary, intensity variation is displayed at the cost of poorer rendition of fine details. Good dithering techniques provide an optimal trade off between tonal values and the rendition of image details.

3 Screening Methods for Color Halftoning

Dithering techniques can be classified according to the nature of patterns they generate, and also the type of pixel configuration they produce. These two classification criteria capture the main features of the textures created to represent low frequency areas of the image, and also, to get a better rendition of the image high frequencies.

Textures can be rendered by *periodic* or *aperiodic* patterns. In general, periodic patterns are generated by deterministic process based on regular sampling grids, and aperiodic patterns are modeled as stochastic processes.

The type of pixel configuration produced by dithering algorithms is determined by the spatial configuration of the "on" and "off" state of the image elements. *Dispersed dot* methods simulate grayscale areas by distributing the pixels, while *clustered dot* methods concentrate the dots in small groups.

Dot clustering techniques try to mimic the traditional analog halftoning technique used by the printing industry. Dispersed dithering method perform the halftoning in a way similar to some traditional pen-and-ink illustration techniques.

Clustered-dot dithering techniques are in general based on the ordered dither method (Ulichney, 1987). They distribute the black and white dot patterns (*clusters*) periodically, using a regular screen. There are some algorithms on the literature that use clustering without distributing them over a regular screen. Examples of these

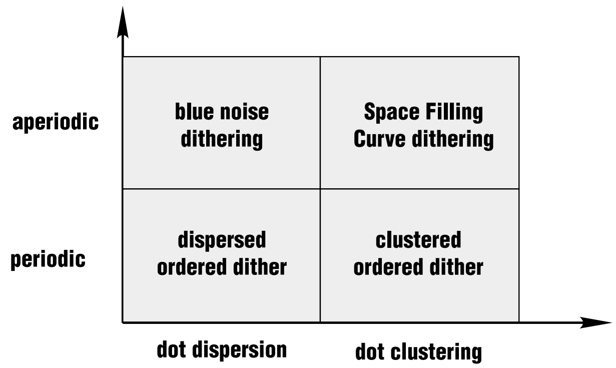


Figure 4: Dithering techniques.

algorithms are (Velho and Gomes, 1991) and (Allebach, 1976).

Most of the dispersed dot dithering techniques attain the dispersion of the image elements by diffusing the quantization error along neighbor regions. This process turns out to introduce a correlated noise in the spatial distribution of the black and white pixels. In general, the noise patterns are referred to as producing an *stochastic screen*. Good results are obtained using a correlated noise such that its spectrum lacks low-frequency power. This noise is referred to as *blue noise* on the literature (Ulichney, 1987). We should observe that some dispersed dot dithering techniques uses a regular, periodic, screen. The classical example is the dispersed ordered dithering algorithm introduced by Bayer (Bayer, 1973).

The wide range of dithering algorithms cover a different range of applications and are suited for color reproduction on a great diversity of display devices. Figure 4 summarizes the above review. The space filling curve dithering algorithm published in (Velho and Gomes, 1991) uses clusters, but it performs a diffusion of the quantization error between neighbor clusters along the space filling curve. This justifies its position on the diagram in Figure 4..

3.1 Regular Screening

Traditional screening methods, either analog or digital, obtain a dithered image by creating regular clusters of points, the black and white dot patterns inside the clusters has a variable size, according to the image tonal values. For this reason, these techniques are known by the name of *amplitude modulated* dithering technique, or simply *AM dithering*.

When this method is used, a halftoned image of each of the separated $CMYK$ channels is created. During the halftoning process the cluster grids are conveniently rotated in order to avoid full overprinting of the clusters from each of the $CMYK$

Figure 5: Detail of the printed $CMYK$ channels from Figure 1.

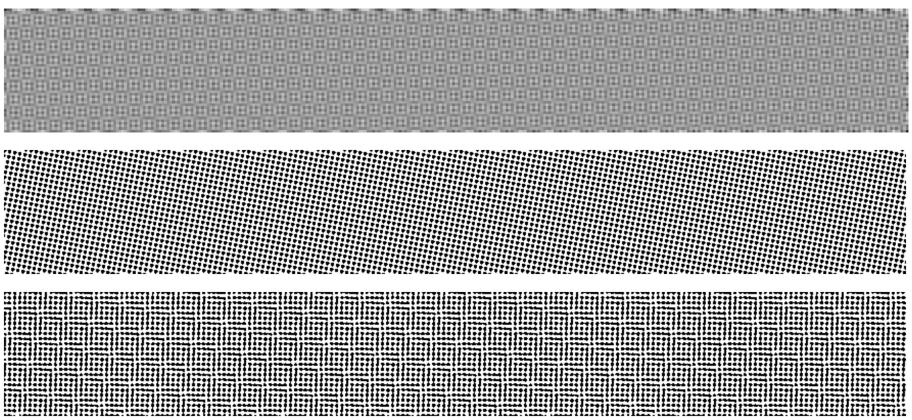


Figure 6: Moiree patterns.

channels. Thisis illustrated in Figure 5 where we show an amplification of a detail of the image printed in Figure 1.

The spatial distribution of the halftoning clusters on a regular screen is prone to producing moirée artifacts in the overprinting of the $CMYK$ channels. Moirée patterns are illustrated in Figure 6. On the top, we print a grayscale synthetic image that resambles the texture pattern of a cloth. In the middle, we print a 1-bit, halftoned, version of the image, using a regular screen with an angle of 6 degrees. At the bottom, we show another halftoned version using an screen of 5 degrees. Moirée patterns are quite noticeable, specially on the image at the bottom. Detailed discussion of moirée patterns can be found on (Amidror, 1991) and (Amidror, Hersch and Ostromoukhov, 1994).

3.2 Stochastic Screening

The first attempt to avoid the perception of quantization contours was done in (Roberts, 1962). In this paper it was introduced the use of white noise to decorrelate the quantization error. It is for this reason that dithering techniques that use regular patterns of clusters are known by the name of *ordered dithering.*

The idea of using noise to decorralate the quantization error, and to avoid the perception of the quantization contours is in the right direction. The problem with white noise is that it is completely uncorrelated, and therefore it destroys all of the image high frequencies.

Dispersed dithering algorithms use a fixed point size and modulate the spatial distribution of black and white points to render the tonal values of the image. In contrast to AM dithering techniques, these algorithms are called *frequency modulated* dithering, or simply *FM dithering.* FM dithering techniques have been introduced recently into the raster image processor of high resolution phototypesetters.

The use of correlated noise to distribute spatially the black and white dots over the image domain, is quite opposite to techniques that use a regular screen for the spatial distribution of the dott patterns. For this reason, noise correlated dithering algorithms are also known by the name of *stochastic screen halftoning.*

Since FM dithering algorithms do not use clustering, they do not perform well on printing devices which do not have a very good precision in the dot size and positioning. In this paper we will describe an algorithm that encompasses the characteristics from FM and AM dithering techniques:

- it uses clustering;
- it performs error diffusion;
- it uses stochastic screening.

Besides the above properties, the algorithm also is able to change the cluster size according to the rate of change of the image color intensities.

One of the main advantages of FM dithering techniques resides in the fact the it does not use regular screens. This avoids the classical problem of moirée patterns in the color printing process with halftoning techniques.

4 Stochastic Screening with SFC

In this section we briefly review the dithering with space filling curves (SFC) published by (Velho and Gomes, 1991). The method takes advantage of the characteristics of space filling curves to perform neighborhood operations essential to the spatial dithering process. The path of a space filling curve approximation is used to scan the image, generating a parametrization of the image elements satisfying two properties:

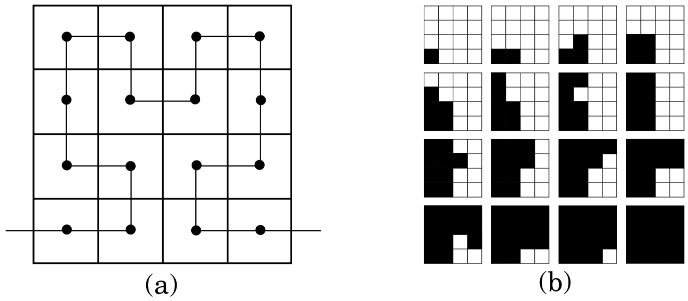


Figure 7: Cell generation and dot patterns (from (velho and gomes, 1991)).

- *continuity*: two consecutive pixels along the path of the space filling curve are in the same 4-connected neighborhood;

- *non-directionality*: in general, three consecutive pixels along the space filling curve path are not aligned.

We observe that the traditional scanline trasversal of the image elements has an exagerated horizontal directionality and does note have continuity. The dithering method with space filling curves consists of four steps:

- subdivide the image domain into cells;

- compute the average image intensity inside each cell;

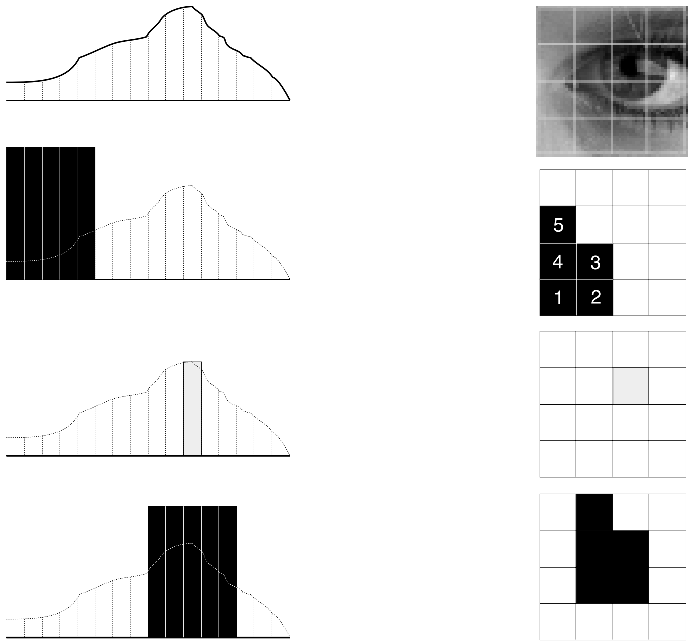
- generate a black and white dot pattern with the cell average intensity;

- position the dot pattern inside the cell to generate the *cluster*.

The subdivision of the image domain into cells is performed by following the path of the space filling curve until the number of elements visited is equal to the cell size. Figure 7(a) shows part of the path of a Hilbert space filling curve, and a cell with 4×4 pixels. Figure 7(b) shows 4×4 clusters with intensities varying from 15/16, on the upper left corner, to 0, on the lower right corner. This figure was reproduced from (Velho and Gomes, 1991).

The last step of the algorithm positions the black and white dot pattern within the cell to generate the cluster. The choice we take consists in positioning the central pixel of the black pattern at the pixel inside the cell which has the highest black intensity level. This is illustrated in Figure 8(a) for the 1-dimensional case, and in Figure 8(b), for the 2-dimensional case. Each of these figures shows (from top to bottom):

- an image cell with 16 elements;



(a) (b)

Figure 8: Position of the dot pattern to create the cluster.

- a dot pattern with 5 elements that represents the average intensity within the cell;
- the cell element with the highest black intensity level (in gray);
- the translation of the dot pattern center to the position of the highest black intensity level element of the cell.

This positioning method results in a cluster that provides a much better rendition of the image details, without sacrificing the low frequency textures.

We should observe that besides the non-directionality implied by the space filling curve trasversal, the method used above to construct the cluster introduces a randomness to the distribution of the clusters over the image domain. Also, it is important to mention that the quantization error in a cell is propagated by the algorithm to the neighbor cell, along the path of the space filling curve. This characterizes the algorithm as a clustered-dot dithering with stochastic screening.

In brief, the dithering algorithm with space filling curves uses clustering similar to the traditional amplitude modulated (AM) algorithms, but at the same time it performs error diffusion, and disperses the clusters along the path of the space filling curve. Therefore, it incorporates characteristics of FM dithering techniques.

5 Stochastic Screening with Adaptive Clustering

The usual expedient to minimize the loss of image detail on the halftoning process, consists in performing an image enhancement, either as a preprocessing step, or incorporated in the dithering algorithm prior to quantization. Although this alleviates the problem, it is an ad-hoc solution and the results are far from being optimal.

Much better results can be obtained by a careful application of dithering where it is needed. In image areas where the intensity changes slowly there is only shading information. In image areas with abrupt changes of intensity there is also shape information that is often manifested in the form of edges. Therefore, when dithering is applied to image areas of low contrast it generates patterns of dots conveying the impression of gray tones with no loss of information. But, when it is applied to image areas of high contrast the dither eliminates edges destroying spatial information.

In order to preserve spatial detail it is necessary to constrain the contours created by transitions between black and white areas to align as much as possible with the real edges of the original image. This must be done without changing the overall image contrast.

In the case of dispersed-dot dither these goals can be achieved by various methods that try to use some type of correlated noise. In the case of clustered-dot dither the best method to obtain a faithful reproduction of image details it to use an adaptive method to change the cluster size according to the variaton of the image intensity values. In fact, with a fixed cluster size it will not be possible to capture features smaller than the size of the halftone screen dots. The best strategy is to make the size of clusters vary according to rate of change in intensity over regions of the image.

In this section we will show how to extend the dithering algorithm from (Velho and Gomes, 1991) in order to obtain an adaptive control over the cluster size. This control will enable us to incorporate a variable cluster size, that along with the above mentioned properties creates a dithering texture similar with the granularity found in photography.

The space filling curve algorithm subdivides the image domain into cells, and at each cell it approximates the image function $f(x, y)$ by some bi-level image function $\overline{f}(x, y)$. The approximation criteria is a perceptual one, based on pixel intensities. The adaptive clustering dithering consists of changing the size of each cell, and therefore of its associated cluster, based on some adaptive criteria, in order to get a better binary approximation $\overline{f}$ of the image function f.

The adaptive criteria to compute the cluster size depends on the desired effect to be obtained by the halftoning method. In our case, the goal is to achieve the best rendition of image detail without compromising tonal reproduction. Therefore, we should use an adaptive critera that varies the cluster size according to the rate of change of the image intensity. In order to accomplish for this, we need to measure the variation of image intensities as we scan the image.

Since we are using the $CMYK$ color space, the image function is a map $f\colon U \subset$

$\mathbf{R}^2 \to \mathbf{R}^4$, therefore, the rate of change of the image color values along the space filling curve can be measured by the derivative $f' \colon \mathbf{R}^2 \to \mathbf{R}^4$. If we denote the coordinates of the image function by $f = (f_C, f_M, f_Y, f_K)$, the derivative f' is represented by the jacobian matrix

$$f' = \begin{pmatrix} \frac{\partial f_C}{\partial x} & \frac{\partial f_C}{\partial y} \\ \frac{\partial f_M}{\partial x} & \frac{\partial f_M}{\partial y} \\ \frac{\partial f_Y}{\partial x} & \frac{\partial f_Y}{\partial y} \\ \frac{\partial f_K}{\partial x} & \frac{\partial f_K}{\partial y} \end{pmatrix}. \tag{2}$$

Since we are scanning the image along the path of the space filling curve, the norm of the directional derivative along the curve furnishes a good measure for the rate of change of the image intensities along the scanning direction. The directional derivative is computed by applying the jacobian matrix from equation (2), to the unit vector $u = (u_1, u_2)$ along the scanning direction defined by the space filling curve. That is,

$$\frac{\partial f}{\partial u} = f' \cdot u = \begin{pmatrix} \frac{\partial f_C}{\partial x} & \frac{\partial f_C}{\partial y} \\ \frac{\partial f_M}{\partial x} & \frac{\partial f_M}{\partial y} \\ \frac{\partial f_Y}{\partial x} & \frac{\partial f_Y}{\partial y} \\ \frac{\partial f_K}{\partial x} & \frac{\partial f_K}{\partial y} \end{pmatrix} \cdot \begin{pmatrix} u_1 \\ u_2 \end{pmatrix}. \tag{3}$$

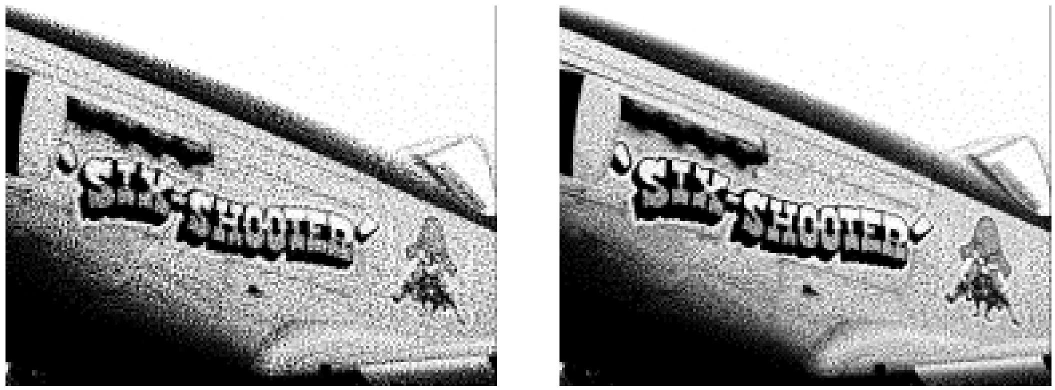
We should point out that for a grayscale image, that is $f \colon U \subset \mathbf{R}^2 \to \mathbf{R}$, equation (3) reduces to the well know inner product formula between the gradient of the image function f, and the unit vector u

$$\frac{\partial f}{\partial u} = f' \cdot u = \langle \mathrm{grad} f, u \rangle. \tag{4}$$

After deciding that the directional derivative will take care of the adaptiveness criteria, it remains to obtain the correct relationship between the cluster size and the directional derivative vector. As the norm of the derivative vector gets bigger, image intensities change faster and, therefore, the cluster size should get smaller.

We first observe that the intensities distribution in a dithered image must follow a perceptual criteria. Also, the eye response to intensity changes obeys a logarithmic law (see (Rosenfeld and Kak, 1976)). Based on these two remarks, we conclude that we should vary the cluster size exponentially with the gradient magnitude. This rule maintains a linear relationship between the perceptual intensity inside each cluster and the directional variation of the image intensity.

Figure 9 shows an example of a dithering with space filling curve of the same image, using a fixed cluster size of 11 pixels (a), and using the derivative adaptiveness criteria to change the cluster size (b), allowing a maximum value of 11 pixels for the cluster size. From these images, it is noticeable how the adaptive clustering algorithm provides a better rendition of image details, without compromising the tonal values on the low frequency regions of the image.



(a) (b)

Figure 9: (a): image with a constant cluster size of 11 pixels. (b) adaptive variation of cluster size with maximum size of 11 pixels.

We should remark that there are different variations when using the above method to obtain an adaptive change of the cluster size for color image halftoning. We will return to this topic later on in Section 6.2

6 Color Halftoning with SFC

In this section we will describe the different possibilites of the use of stochastic screening with space filling curve, for color printing. According to the techniques we discussed in the previous sections we have two methods of choice:

- color printing with fixed cluster size;
- color printing with an adaptive cluster size.

In the first case the cluster size is fixed for each of the image channels C, M, Y, and K. In the second method we use an adaptive procedure to change the cluster size for each of the four channels.

By combining the two methods above we are able to devise different algorithms for color printing using space filling curves. These algorithms take into account the two possibilities above, with the fact that it is possible to vary the dot pattern position to generate the cluster for each of the channels C, M, Y, and K. We will describe these methods below.

6.1 Color Halftoning with Fixed Cluster Size

By fixing the cluster size we have two possibilities for the cluster position:

- independent cluster position;

- correlated cluster position.

In the first method, there is no relationship between the position of the cluster for each of the $CMYK$ channels. In the second method the position of the cluster for each of the CMY channels are influenced by each other.

Independent Cluster Position

This method subdivides into two different options. The first option consists in positioning the cluster randomly inside each cell, for each of the $CMYK$ channels. We have discarded experiments with this method because it gives no control over color cluster overlapping in the printing process. This would certainly give poor final results.

The other possibility arising from independent cluster positioning, consists in centering the cluster size in each of the channels $CMYK$ on the pixel of highest intensity of the channel within the cell.

Correlated Cluster Position

The strategy of this method consists in devising a correlation of the cluster position in order to minimize color overlapping in the printing process. From section 4 we know that the clusters of the black channel should be centered at the pixel of highest black intensity within the cell in order to obtain a better rendition of image details.

Therefore, a good strategy consists in positioning the black cluster to obtain a better definition of image details, and position the C, M, and Y clusters in such a way to minimize color overprinting between between these channels. More precisely, the positioning strategy is done in the following way (see figure 10):

- center the cluster of the black channel at the pixel of highest black intensity within the cell;

- subdivide the cell into three subcells, and position the center of the cluster of each of the C, M, and Y channels at the center of each of the three subcells.

We illustrate the above cluster positioning method for the two-dimensional case in Figure 11: figure 11(a) shows the cell subdivision into three subcells, and in Figure 11(b) shows the position of the C, M, and Y clusters center within each subcell. Notice that the order of the cyan, magenta and yellow clusters along the path of the space filling curve is $C < Y < M$. This order turns out to give better results. Changing it, will result in a subtle color shift on the printed image.

As we remarked before, the positioning of the CMY clusters is done in such a way to minimize color overlapping in the printing process. In Figure 11 there will be an overlapping of CMY clusters only if the cluster size is greater than 5 pixels.

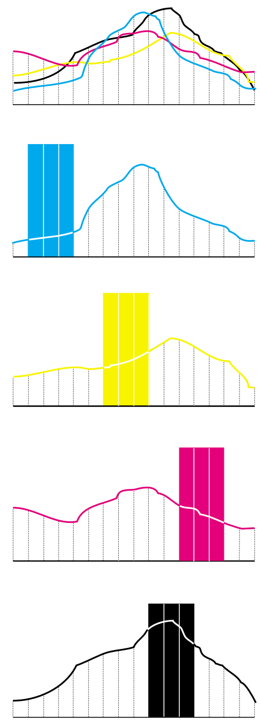


Figure 10: Correlated positioning of the $CMYK$ channels.

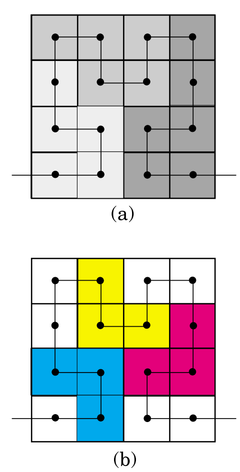


Figure 11: Two dimensional correlated cluster positioning.

6.2 Color Halftoning with Adaptive Cluster Size

In Section 5 we described how to use the directional derivative of the image function to obtain an adaptive variation of the cluster size. Using this method, we can devise three different procedures for color halftoning with the adaptive space filling curve algorithm:

- independent cluster;
- constrained cluster;
- correlated cluster.

Independent Cluster

In this method the adaptiveness of the cluster size is performed independently for each of the four channels $CMYK$. The cluster is positioned in the pixel of highest intensity inside the cell.

Constrained Cluster

In this method we compute the adaptive size of the cluster for the black channel, replicate this size to each of the CMY channels, and position the clusters in the pixels of maximum intensity within the cell.

Correlated Cluster

In this method we use a constrained cluster size as described in the previous section, and we position the $CMYK$ clusters acoording to the correlation method explained in section 6.1, and illustrated by Figures 10 and 11.

7 Experiments and Results

In this section we show some results of applying the halftoning method with space filling curve, using different printing devices. All of the images were halftoned using the adaptive correlated cluster size method.

We should remark that we did not dedicate too much time for dealing with the adequate color correction for each device. Our main interest in these experiments were related with the choice of the best cluster size variation for each device.

Figure 12 shows the original test images. These images were printed on a Kodak XLT 7720 digital continuous tone printer, from RGB 24 bits image files. Dye sublimation technology produces grayscale images, and we printed them for comparison with the printed images on different devices, using our halftoning technique.

Figure 13 shows the result of printing the two test images on an Hewlett-Packard deskjet 560C color printer. This printer uses the inkjet technology, and can print either on plain paper, or on a special paper. The images here were printed using the special HP glossy paper. The printing resolution if 300 dpi, and the maximum cluster size if 3. The decision of using this size was influenced by the good quality of the printer using dispersed error dithering techniques.

The color separation process was done by the authors based on some information about the color behavior of the printer, provided by Hewlett-Packard.

The images on Figure 14 are color proofs of the two test images. These color proofs were made from a film printed on a linotronic 300 phototypesetter, using a resolution of 600 dpi. For these images we used a value of 7 pixels for the maximum cluster size. The color separation for the production of these images was done using Photoshop^{TM} from Adobe. The color proof was done on a color printing service bureau.

8 Conclusions and Future Research

In this paper we introduced a halftoning method for color reproduction that incorporates characteristics from both AM and FM halftoning techniques. Therefore, the algorithm uses dot-clustering, stochastic screening, performs error diffusion and is able to change the cluster size according to image color variation.

These features result in a very flexible color halftoning technique, which is able to adapt to a wide range of printing devices. This is shown by some of the experiments with the algorithm we included in the paper.

Since the algorithm uses stochastic screening, it avoids the occurrence of moirée patterns, when we overprint each of the halftoned color channels. Therefore, it is a natural halftoning technique for printing with any number of process colors. We intend to make some experiments with the algorithm for hifi color printing.

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Figure 12: Test images printed on the Kodak XLT 7720 continuous tone printer.

Figure 13: Test images printed at 300 dpi on the HP 560C inkjet printer.

Figure 14: Color proof of the test images from a film printed on a linotronic 300 using an output resolution of 600 dpi