Image Mapping to Control Frequency Modulated Screening

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Abstract

Throughout the history of hand-produced printing methods, such as ink drawing, stone lithography, or engraving, the artist has referred to the original image as a guide for creating the pattern of marks. Today, the scanned source-image can likewise algorithmically serve to guide the positioning of dots. The source image is the scanned and converted CMYK image, usually in an 8-bit per channel form.

A map of the source image provides a control for the production of 1-bit stochastic screens. The stochastic screen is composed of a pattern of dots that reflects the pattern of pixels of the source image. It is this pattern of dots that produces detail and image definition.

The ideal stochastic raster consists of dot positions that, without noise, accurately reproduce the source image. An ideal stochastic filter converts pixel depth to distances between dots accurately. When there is a change of pixel depth among a neighborhood of pixels, then there is a corresponding change of distances between dots. In image areas where there is little or no change of pixel depth, then the distances between stochastic dots are equal.

A software application version of a stochastic screening filter can refer to the source image for information in ways not readily available to RIP implementations. A process in which the stochastic filter is controlled by a preprocessing of the source image to limit noise in flat tonal areas is described. This is a procedure easily developed as software that can be extended to more complex source image mapping.

Introduction

The amount of noise stochastic filters produce is an important concern. The eye is sensitive to most unusual changes of spatial frequency, or noise, in any bandwidth.[1] This paper presents two dot mapping algorithms, along with an analysis of each, that illustrate a general strategy for using the source image to control the uniformity of dot positions.

Each algorithm converts the frequency of gray-level changes in the source image to the frequency of distance changes in the stochastic raster. For this paper, gray level changes are described as depth-frequencies. Depth-frequencies range from 0 where there is no change in gray scale, to a number representing the greatest variety of pixel depths for a group of pixels under consideration. In a 3×3 matrix of neighboring pixels, if all pixels are of the same gray level the frequency is 0. The maximum depth frequency therefore is 9. A change in distances between neighboring dots in the stochastic raster is referred to as spatial frequency. Spatial frequencies can vary from a flat frequency of 0 when all dots are of equal distance from each other, to a number that represents the greatest number of distances. In the 3×3 matrix of dots, if all dots vary their distances the maximum spatial frequency is 12; diagonal neighbors are not considered.

Preprocess mapping of the source image can influence the stochastic filter in three ways: to guide post-processing of the stochastic raster, change raster algorithms, and to modify the stochastic filter as it processes. The first algorithm demonstrates a post-processing process whereby a map of the image is used to guide the redistribution of dot positions only in low depth-frequency areas after the creation of the stochastic raster. The second algorithm illustrates a change of raster filters approach which divides the source image into two image maps; each image map then uses a different type of diffusion filter to convert the image to a 1-bit raster.

The Grain Formation Problem

The formation of grain is the result of two aspects of spatial frequencies in a first-order, or single-size dot, stochastic screen.

1. *Modulation Graininess*. Dots at too close a proximity for the gray value form grain. This is the result of the pseudo-random nature of the stochastic filter. The number of dots in a bit-plane is proportional to the gray level of the plane. The distances between the dots may vary. The noise factor introduced into the stochastic filter's error matrix is a primary factor in varying the distances between dots. In low depth-frequency areas, when two dots are nearer to each other than they are to other neighboring dots, the closeness of the dots looks grainy. In an image area containing detail or high depth-frequencies, spatial frequencies are controlled by the depth-frequency component of the image.

A metaphor that serves to demonstrate that noise is an inherent property of any stochastic raster-conversion process is the example of a crowd at a state fair. At the state fair, the individuals composing the crowd walk down the thoroughfare. They vary their distances apart and occasionally collide no manner how well they attempt to maintain their personal-distance zone. The perfect crowd is an army in lock-step. The perfect stochastic crowd is composed of individuals who maintain their personal space while varying their spatial relationship

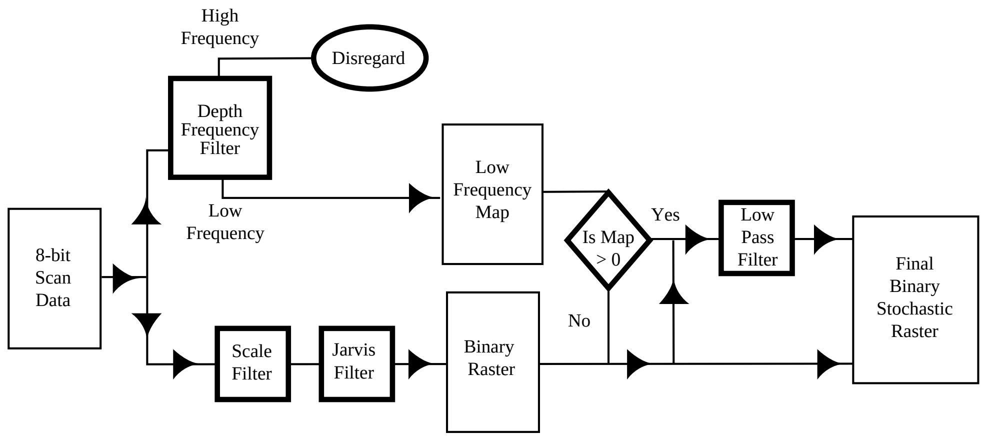

Figure 1.

to each other. The lock-step army is a metaphor for an organized, cluster-dot pattern or halftone.

2. Dot Perimeter Graininess. Individual dots that cluster inconsistently form grain. Clusters are the result of individual dots whose sides touch. Dots begin to touch and form clusters as the gray level of a gradient increases. These clusters grow as individual dots touch and group in larger numbers, until at the black gray-level the entire field is one continuous cluster. The non-deterministic touching of dots can be described as chaos clusters. Clusters alone do not result in graininess. When the clusters are irregularly surrounded by voids and individual dots, the result is visually grainy.

Chaos clusters, unlike halftone dot clusters, are usually anamorphic shapes, but seldom does the shape of clusters result in a grainy appearance. Many halftone dot shapes at coarse resolutions are irregular in shape. The linear growth of clusters in a gradient increasing in darkness is the primary method for controlling dot perimeter to area ink-gain.

The ideal stochastic filter linearly builds clusters composed of individual dots. In low spatial frequency situations, the clusters are positioned in uniform arrangements.

Dot Mapping Algorithms

The five filters used by the two algorithms are as follows:

The Bayer[2] *dither filter* generates a 1-bit dot pattern from the source image's 8-bit data. This algorithm is typical of organized dispersed-dithering filters containing primarily low spatial-frequency elements. It is the function of the Bayer filter to replace the high spatial-frequency element.

The Jarvis[3] *error-diffusion filter* is also used to convert the source image's 8-bit data to a 1-bit dot pattern arrangement. The Jarvis error-diffusion matrix contains the potential for all spatial-frequencies; however high spatial-frequency elements dominate. The Jarvis is superior to the Bayer at converting high depth-frequencies to high spatial-frequencies.

The low-pass filter performs a bit-shuffle to equalize the distance between the 1-bit dots. The filter's matrix grows dynamically as the clusters increase in size in order to retain the clusters.[4]

The depth-frequency filter is used to locate areas of the source image's pixel map where few changes in pixel depth occur. A typical filter would count the number of pixels of differing gray-levels in a matrix.

The scaling matrix filter is used to scale the source data to the output resolution. A more time consuming but more accurate bi-cubic mask may be used.

Algorithm 1. Depth frequency map controlling low-pass filter.

The first algorithm creates a map with the use of the depth-frequency filter. The filter identifies low depth-frequency neighborhoods and writes the locations of those pixels to a separate buffer. The depth frequency filter collapses the 8-bit data to 1-bit data describing the locations of pixels with neighbors of similar depth. The original source-image file is converted with a Jarvis filter to a 1-bit raster containing high-frequency artifacts. The low depth-frequency map guides a Boolean gate which turns off and on a low-pass filter as it traverses the 1-bit map to redistribute the dots only in the areas described by the map. The low-pass filter removes the remaining high spatial-frequency element.

Algorithm 2. Two 1-bit maps and two stochastic filters.

The second algorithm describes the creation of two different 8-bit image maps from the source image–pixels in low depth-frequency neighborhoods and pixels in high depth-frequency neighborhoods. The appropriate stochastic filter is then applied to each image map to convert the pixel 8-bit data to 1-bit data describing the number of dots, their positions and distances apart. The low depth-frequency neighborhood map is processed by the Bayer filter and the map with the high depth-frequency neighborhood is processed by the Jarvis filter. The resulting two 1-bit buffers are then combined to form a 1-bit stochastic raster.

Results

Criteria:

- Grain should be at a minimum. Grain is the product of modulation graininess (distances between dots), dot-perimeter gain graininess (size and shape of clusters) and multiplicative graininess (overlapping dot-

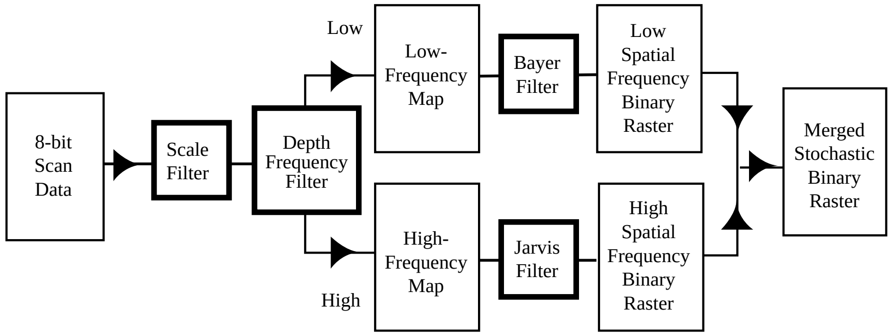

Figure 2.

patterns of various colors).[5]

- Dot count should increase in number linearly across the gradient. Each gray-level should be represented by the appropriate number of dots. *(Chart 1)*
- Chaos clusters should increase in size linearly across the gradient. *(Chart 2)*
- Dot perimeter gain should be linear across the gradient. *(Chart 3)*
- The pattern of voids and clusters should not change throughout the gradient.
- The resulting pattern of voids, dots and clusters should neither sharpen nor blur the image's edges.
- Position of the dots should be blue noise random, yet should limit multiplicative graininess.

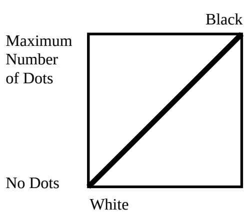

Chart 1.

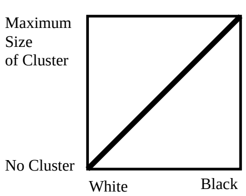

Chart 2.

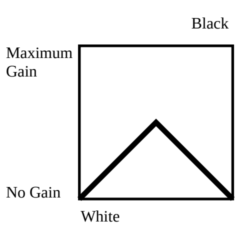

Chart 3.

Algorithm 1. Depth frequency map controlling low-pass filter.

If properly controlled, dot count and cluster size are not affected by the low-pass filter. There is some blurring caused by the shuffle of dots, but low spatial-frequency neighborhoods contain no sharp delineations that would be adversely affected. Dot positions are non-deterministic; however there is the potential that as positions regularize, the dots may overlap dots of other colors causing multiplicative grain to increase.

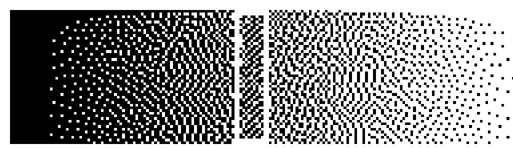

Illustration 1.

The low-pass redistribution filter has the highest performance criteria. It needs to be non-deterministic to avoid moiré, yet orderly to avoid modulation graininess. The low-pass filter should evenly position clusters without breaking clusters into smaller clusters or a non-linear increase in dot-gain will result. A lowpass filter that shuffles bits to uniform distances with a dynamic matrix to preserve clusters will preserve patterns and perimeter gain. *(Illustration 1).*

Algorithm 2. Two 1-bit-maps and two stochastic filters.

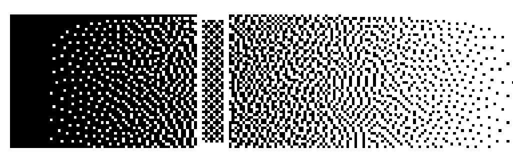

Illustration 2.

Dot count and dot gain are consistent within each filter's output, but cluster growth is non-parallel to each filter. Both filters can be controlled so that they do not affect the sharpness of the image (i.e. the filters are neutral). Each filter produces entirely different clusters. With the introduction of noise, both filters can position dots so as to avoid multiplicative graininess. The Bayer filter delays the formation of clusters until late in the mid-tone range. The Jarvis diffusion filter forms clusters late in the highlight range. *(Illustration 3)* Each filter produces distinctly different dot patterns and dot perimeter gain curves. The Bayer filter produces a larger amount of dot gain. A 1-bit raster comprised of the output of two different filters will result in appropriately uniform dot positions; however printer reproduction problems caused by change in pattern and dot gain are of greater importance than the grain problem solved by the use of the two filters. *(Illustration 2).*

Illustration 3.

The example of equalizing dot distances resulting in even greater reproduction problems is not unusual. Dithering considerations are the balancing of properties.

- As modulation grain decreases, perimeter gain increases.
- As modulation grain decreases, moiré increases.
- As low spatial frequencies regularize, blurring occurs.

Even the most random positions of dots and chaos clusters can result in both grain and moiré simultaneously. Silk-screen printing has demonstrated that moiré results when the stochastic dot resolution matches the thread resolution.

Chart 4a shows a typical Jarvis filter dot perimeter-gain curve. A curve that is the result of the Bayer filter replacing the Jarvis dot pattern at one bit-plane is shown in *Chart 4b.*

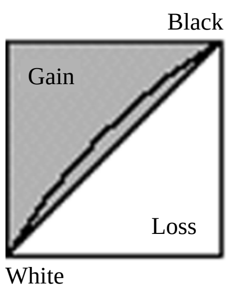

Chart 4a.

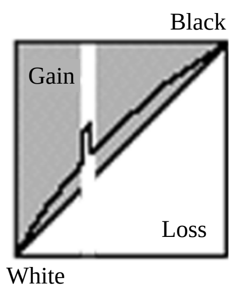

Chart 4b.

Conclusion

An intelligent consideration and mapping of the source image to guide the size and pattern of dots can result in many benefits.

Examples of maps that may prove to be useful are:

- Edges can be mapped and used to guide dots for better edge definition.
- RGB out-of-gamut mapping can guide the filter to enlarge the CMYK gamut by overlapping the dots or changing the shape of dots.
- The “direction” of the dots can be determined by a mapping of the image’s perspective.
- The size and shape of the stochastic dot can be determined by a map of color density.

Future explorations for source image mapping considerations can lead to ornamental effects or the electronic equivalent of fine art print-making. The source image can guide the direction of marks as in engravings, the density of marks as in stone lithography, and the texture of marks as in intaglio printing.

References

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