Recent Progress in Digital Halftoning

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1. Introduction

Everything our eyes see in the natural world is continuous. All objects vary continuously in size, shape or color. Whenever we want to render those images and objects on a printer, however, we are forced to turn the continuous world into a discrete world. The subtle color variations of an autumn leave have to be represented by only a few discrete colors and its shape has to be represented at a finite number of discrete sampling points. The process of converting the images into something that a digital printer can print, is called Digital Halftoning.

This paper will show some of the approaches that are taken in digital halftoning in order to create prints that appear—to a human observer—as close to the original continuous object as possible. The approaches shown here are taken from several sources and authors, with the intention to show the breadth of the recent work in digital halftoning.

2. Historic Halftoning

The problem of representing color variations using only a small number of inks or colorants is as old as printing itself. It was first encountered in printing gray images using only black ink. The earliest patent known to the author, dates back to 1852 and is authored by Henry Fox Talbot.[1] In this patent specification "Improvements in the Art of Engraving", Talbot describes the use of a halftoning screen manufactured by using "two or three folds of black crape or gauze". In this way, all objects could be rendered in a way that "truly depicts the object".

One other historical example of halftoning should be mentioned here.[2] In this case, the black and white images where not formed on paper or some other material, but produced by weaving black and white threads. In 1827, this process allowed the weaving of silk images that resembled classical engravings, by using a loom that was operated by punch cards. In this way, binary images of 10.000.000 pixels were produced with a resolution of 125 threads to the inch. A striking feature of these silk images is their light resemblance to dispersed dot dithers, such as Beyer's.[3]

3. Computational Methods for Halftoning

Compared to the more than 100 year old tradition of halftoning, the mere 25 to 30 years of digital halftoning appears very short. At the same time, however, the use of computers has enabled a large variety of digital halftoning schemes that were not possible before. These methods can be roughly classified into two groups: non-adaptive methods that use a computationally designed halftone screen, and adaptive methods that produce the binary output image by a direct calculation based on the input image.

3.1 Non-adaptive Methods

One big advantage of non-adaptive methods is that the actual halftoning process can be implemented as a single comparison per input pixel. The task of improving the image quality of the binary output is thus converted to the task of calculating a threshold matrix, or dither array, that fulfills certain additional requirements.

3.1.1 Iterative Screen Design

In order to achieve a screen design that is optimal by some measure, iterative methods can be employed.[4] The final screen design is obtained by starting with an initial suboptimal screen and by applying boundary conditions either directly to the screen, or to the output of the screen for predetermined input sets.

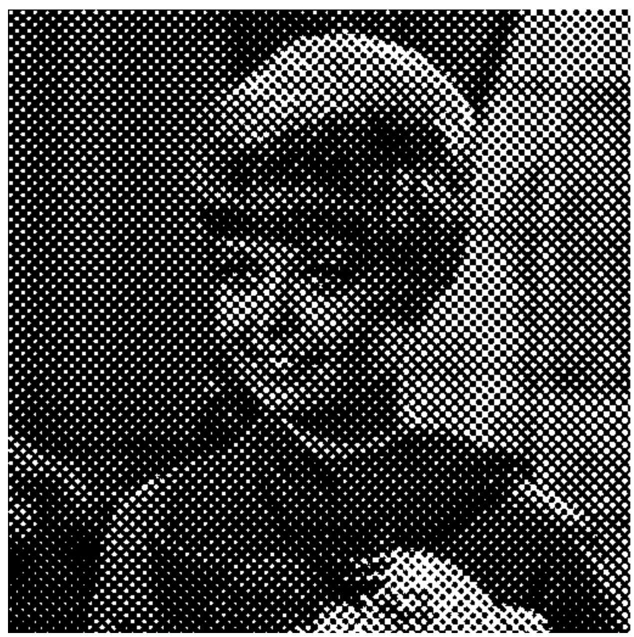
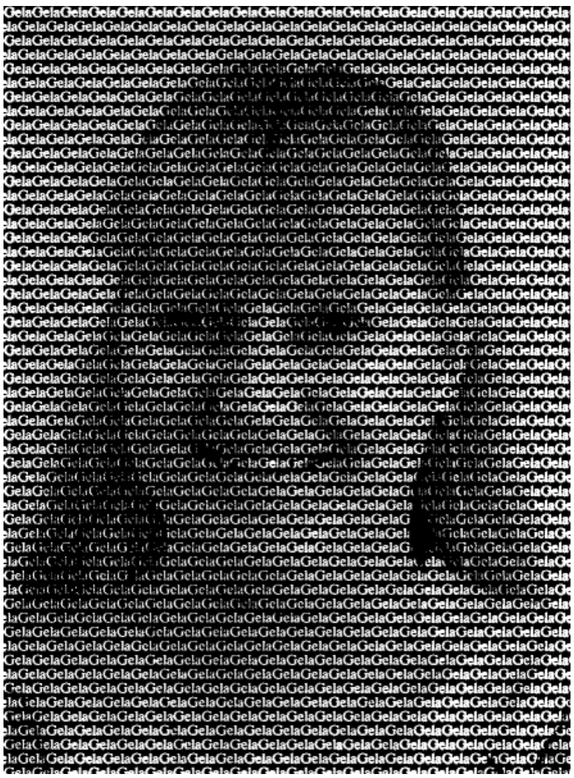


Image obtained using standard Holladay-dot halftoning. Courtesy of T. Holladay.

3.1.2 Analytic Screen Design. One interesting approach to screen design comes from a number-theoretical background. Here, screen design can be formulated as finding a finite number sequence that has specific properties.[5] One interesting sequence in this context is the Fibonacci series. A two-dimensional form has been used[6] where the screen dimensions are two neighboring Fibonacci numbers.

3.1.3 Artistic Screen Design. Optimality of a screen design is always a function of the imposed boundary constraints. There are several constraints that can be imposed on the halftoning step that are not directly related to image quality. One of these constraints can be the artistic look of the halftone, with the requirement that the binary output will have information in addition to the obvious image information.[7] Examples are company and event logos, or text strings.



Digital halftone with artistic aspect. Courtesy of K. Knox.

3.2 Adaptive Methods

The advantage of adaptive methods over non-adaptive methods is the potentially higher image quality. A disadvantage is that the calculations of the binary output are in general more complex. Adaptive methods can be further distinguished as iterative and non-iterative methods, where the iterative methods take more than one path across the data for binarization.

3.2.1 Error Diffusion. Error diffusion[8] is the most common adaptive halftoning method. In error diffusion, the algorithm minimizes the average difference between the input continuous tone image and the output binary image. A large number of variations of the basic error diffusion algorithm exist. One of the is the modification of the error diffusion algorithm is the modulation of the binarization threshold.[9] This allows the introduction of edge enhancement into the output, as well as the control of the highlight and shadow dot positions.

Image of Lena, binarized using a Fibonacci based screen. Courtesy of P. Anderson.

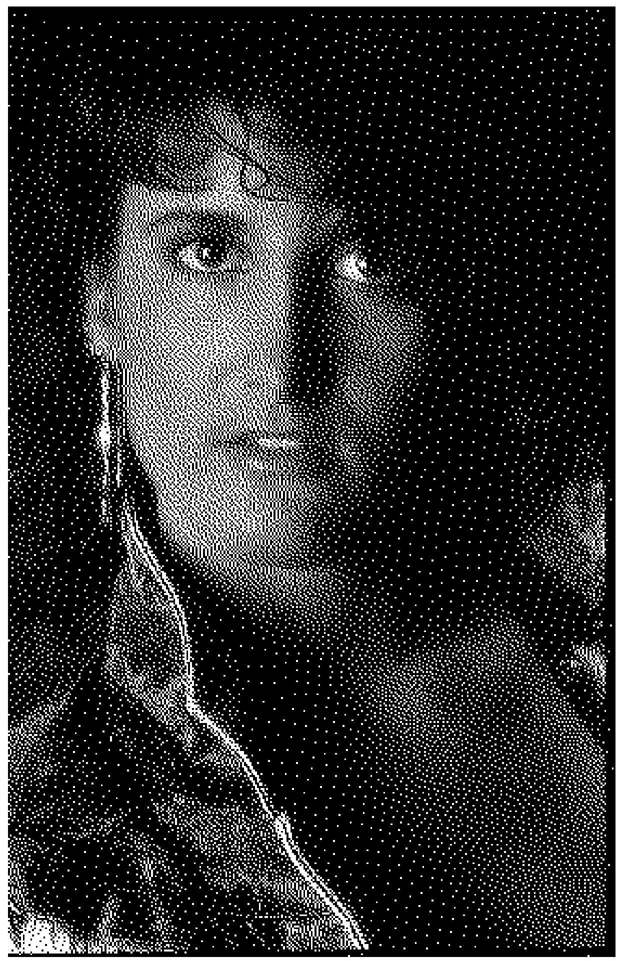


Image obtained by threshold modulated error diffusion.

3.3.2 Iterative Processing. In order to improve output image quality, it is possible that several passes are performed on the data to minimize some preset error criterion.[10,11] These iterations can either be performed in the spatial domain, or, more commonly, in a combination of spatial domain and transform domain, e.g., spectral domain.

4. Conclusion

The problem of representing continuous data on a fixed grid using a finite set of output colors seems, at first glance, an easily tractable and solvable problem. However, one easily recognizes that the "best" way to represent the input data is a strong function of additional constraints. These constraints can be imposed by the marking process, e.g., ink-jet vs. xerography; system considerations, e.g., language capabilities and speed; application requirements, e.g., artistic vs. realistic; and many other external factors. Consequently, a large number of halftoning techniques have been developed that attempt to meet those constraints. As applications get more and more diverse, it is to be expected that the number of different halftoning techniques will increase in the future.

Image obtained using a dot constraint error diffusion algorithm. Courtesy of G. Marcu.

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Image obtained by iterative halftoning (DBS). Courtesy of J. Allebach.

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