

Be sure to turn in all your Matlab or Python code for the problems below.

1. Design an 8x8 clustered dot threshold matrix for which the corresponding dot profile function starts in the highlight areas as a single dot that grows to produce the character for the first letter of your first (given) name in single dot stroke width. Then at higher absorptance values, the stroke width gradually widens. As you move into the shadows, the halftone texture forms a white space that again has the shape of this character. To do this, you may need to invert the white space character either horizontally or vertically, or both, or you may need to make it overlap the black dot character.

For your solution, turn in the following:

- a. The threshold matrix.
 - b. The dot profile function for all 65 levels.
2. Write a program in Matlab or Python to implement monochrome screening.
 - a. Turn in your code.
 - b. Design simple 2x2, 4x4, and 8x8 clustered dot screens.
 - i. Turn in your threshold matrices.
 - ii. Turn in print-outs of the *ramp* image and the *woman_bw* image halftoned with each of these screens. These images can be downloaded from the *Data Files* section of the course website.
 - iii. Discuss the effect of the screen period in terms of tone reproduction and detail rendition.
 - c. Halftone the *woman_bw* image using the threshold matrix that you designed for your solution to Problem 1, and turn in a print-out of the result. Compare the image quality with your clustered-dot 8x8 result.
 - d. An 8x8 Bayer threshold matrix can be defined as follows:

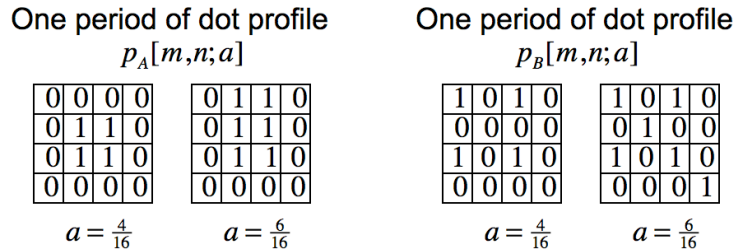
$$t[m,n] = \frac{1}{128} \begin{bmatrix} 1 & 65 & 17 & 81 & 5 & 69 & 21 & 85 \\ 97 & 33 & 113 & 49 & 101 & 37 & 117 & 53 \\ 25 & 89 & 9 & 73 & 29 & 93 & 13 & 77 \\ 121 & 57 & 105 & 41 & 125 & 61 & 109 & 45 \\ 7 & 71 & 23 & 87 & 3 & 67 & 19 & 83 \\ 103 & 39 & 119 & 55 & 99 & 35 & 115 & 51 \\ 31 & 95 & 15 & 79 & 27 & 91 & 11 & 75 \\ 127 & 63 & 111 & 47 & 123 & 59 & 107 & 43 \end{bmatrix}$$

Here, the continuous-tone image is assumed to be scaled between 0 and 1. Halftone the *woman_bw* image using the 8x8 Bayer threshold matrix, and turn in a print-out of the result. Compare the image quality with your clustered-dot 8x8 result and with the image halftone with the 8x8 matrix that you designed for your solution to Problem 1.

- This problem deals with the spatial frequency analysis of halftone textures as a means of understanding the appearance of these textures as seen by a human observer. Throughout this problem, we will consider a printer with addressable pixel spacing R , and periodic halftone textures with a halftone cell size $X = MR$ that can be implemented using a screening process. We will further assume that $M = 4$; so our halftoning process will yield 17 levels of gray, including full white (0) and full black (1) in units of absorptance. Typically, $R = \frac{1}{600}$ inch; but we will just use the symbol R to keep things simpler. We will assume an ideal printer dot profile given by

$$d(x,y) = \begin{cases} 1, & |x|, |y| < R/2 \\ 0, & \text{else} \end{cases}$$

The figure below shows just one period of the doubly spatially periodic dot profile function $p_i[m,n;a]$ where $i = A, B$ for just two levels of absorptance $a = \frac{4}{16}$ and $a = \frac{6}{16}$. These dot profile functions correspond to two different screens A and B, which produce clustered-dot textures and dispersed dot textures, respectively. Here, we assume that $p_i[m,n;a] = p_i[m + kM, n + lN; a]$, \forall integer k, l .



Let's denote the continuous-parameter version of the dot profile function as $p_i[x,y;a]$, where $i = A, B$. We can then write

$$p_i[x,y;a] = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} p_i[m,n;a] d(x - mR, y - nR)$$

where $d(x,y) = \text{rect}(x/R, y/R)$.

- Consider absorptance level $a = \frac{4}{16}$. Using the replication operator and the function $\text{rect}(x,y)$, develop the simplest possible expressions for $p_A[x,y;\frac{4}{16}]$ and $p_B[x,y;\frac{4}{16}]$. **Hint:** For Dot Profile A, you should use just one *rect* function to represent each dot cluster.

- b. Use your answer to part (a) and standard Fourier transform pairs to find the 2-D continuous-space Fourier transforms $P_A[u, v; \frac{4}{16}]$ and $P_B[u, v; \frac{4}{16}]$ for the two dot profile functions $p_A[x, y; \frac{4}{16}]$ and $p_B[x, y; \frac{4}{16}]$, respectively. Remove all operators from your answer; and simplify your answer as much as possible.
- c. Based on your answer to part (b), sketch and fully dimension the spectra $P_A[u, v; \frac{4}{16}]$ and $P_B[u, v; \frac{4}{16}]$. Pay particular attention to the location and amplitude of each spectral impulse.
- d. Consider absorptance level $a = \frac{6}{16}$. Using the replication operator and the function $\text{rect}(x, y)$, develop the simplest possible expressions for $p_A[x, y; \frac{6}{16}]$ and $p_B[x, y; \frac{6}{16}]$. **Hint:** For $p_A[x, y; \frac{6}{16}]$, your answer should have a form that is very similar to that obtained in your answer to part (a) for $p_A[x, y; \frac{4}{16}]$. On the other hand, you should express $p_B[x, y; \frac{6}{16}]$ as the sum of $p_B[x, y; \frac{4}{16}]$ and an additional term that accounts for the two new printer dots within each period of the dot profile function.
- e. Use your answer to part (d) and standard Fourier transform pairs to find the 2-D continuous-space Fourier transforms $P_A[u, v; \frac{6}{16}]$ and $P_B[u, v; \frac{6}{16}]$ for the two dot profile functions $p_A[x, y; \frac{6}{16}]$ and $p_B[x, y; \frac{6}{16}]$, respectively. Remove all operators from your answer; and simplify your answer as much as possible.
- f. Based on your answer to part (b), sketch and fully dimension the spectra $P_A[u, v; \frac{6}{16}]$ and $P_B[u, v; \frac{6}{16}]$. Pay particular attention to the location and amplitude of each spectral impulse.
- g. Based on your answers to parts (c) and (f), discuss the differences and similarities of the spectra among the four halftone textures corresponding to the dot profiles $p_A[m, n; \frac{4}{16}]$, $p_B[m, n; \frac{4}{16}]$, $p_A[m, n; \frac{6}{16}]$, and $p_B[m, n; \frac{6}{16}]$. For Dot Profile A, what happens to the spectrum as the absorptance increases from $a = \frac{4}{16}$ to $a = \frac{6}{16}$? For Dot Profile B, what happens to the spectrum as the absorptance increases from $a = \frac{4}{16}$ to $a = \frac{6}{16}$?
- h. Based on your answer to part (g), and assuming that these halftone textures are viewed at a distance such that the spatial frequency $1/(2R)$ (300 dpi) is just beyond the cut-off of the spatial frequency contrast sensitivity function for the human viewer, discuss the visual appearance of the four halftone textures corresponding to the dot profiles $p_A[m, n; \frac{4}{16}]$, $p_B[m, n; \frac{4}{16}]$, $p_A[m, n; \frac{6}{16}]$, and $p_B[m, n; \frac{6}{16}]$.
4. This problem deals with dispersed-dot stochastic halftoning via a screen.
- a. Download and read Robert Ulichney's paper on void and cluster halftoning from the References:Halftoning section of the ECE 638 course website.

- b. Write a program in Matlab or Python to generate a 128x128 threshold matrix using void-and-cluster. You should write the void and cluster algorithm yourself, not use a program that can find on the Web or elsewhere. Turn in your program.
 - c. Use your mask to generate a halftone version of the *woman_bw* image
 - d. Also generate a halftone version of the *woman_bw* image by thresholding with a random white noise sequence uniformly distributed between 0 and 255. Compare the quality of your image to that which you obtained in part (c) above.
5. This problem deals with the spectral properties of digital halftone images.
- a. Write a simple Matlab or Python routine to compute the magnitude of the 2D-DFT of an image. Be sure to shift the origin to the center of the spectral magnitude image. To prevent the strong DC component from swamping out all the spectral information, you should logarithmically compress your spectral magnitude samples according to

$$H_{OUT}^{mag}[k,l] = 255 \frac{\log\left(\kappa H_{IN}^{mag}[k,l] / \max_{k,l}\{H_{IN}^{mag}[k,l]\} + 1\right)}{\max_{k,l}\left\{\log\left(\kappa H_{IN}^{mag}[k,l] / \max_{k,l}\{H_{IN}^{mag}[k,l]\} + 1\right)\right\}}$$

Note that the output of this transformation always lies between 0 and 255, and that the amount of compression that it provides increases as the non-negative real-valued parameter κ increases beyond 1. You should experiment with several values of κ to determine what works best, and report the value that you are using. It may vary depending on your halftoning scheme. Be sure to choose a sufficiently large value of κ to suppress the DC component in the spectrum of the halftone image, and show the details in the weaker parts of the spectrum.

- b. Compute the compressed magnitude of the 2D-DFT of the following images that you generated earlier:
 - i. the *woman_bw* image used for Problems 2 and 4.
 - ii. the clustered-dot periodic halftone version of the *woman_bw* image generated in Problem 2 using your 8x8 threshold array.
 - iii. the dispersed-dot, periodic halftone version of the *woman_bw* image generated in Problem 2 using the 8x8 Bayer threshold array.
 - iii. the halftone image generated in Problem 4(d) by thresholding the *woman_bw* image with white noise.
 - iv. the halftone version of the *woman_bw* image generated in Problem 4(c) using your 128x128 void-and-cluster screen.
- c. Compare the five halftone spectra computed in part (b) above. For the void-and-cluster halftone, estimate the average principal frequency for the entire halftone image expressed in units of cycles/pixel.